National Nanotechnology Coordinated Infrastructure

NNCI Coordinating Office Annual Report (Year 10)
April 1, 2025 – March 31, 2026
NSF Award 2100059

Submitted: February 8, 2026

NNCI Coordinating Office Annual Report 2026

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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.

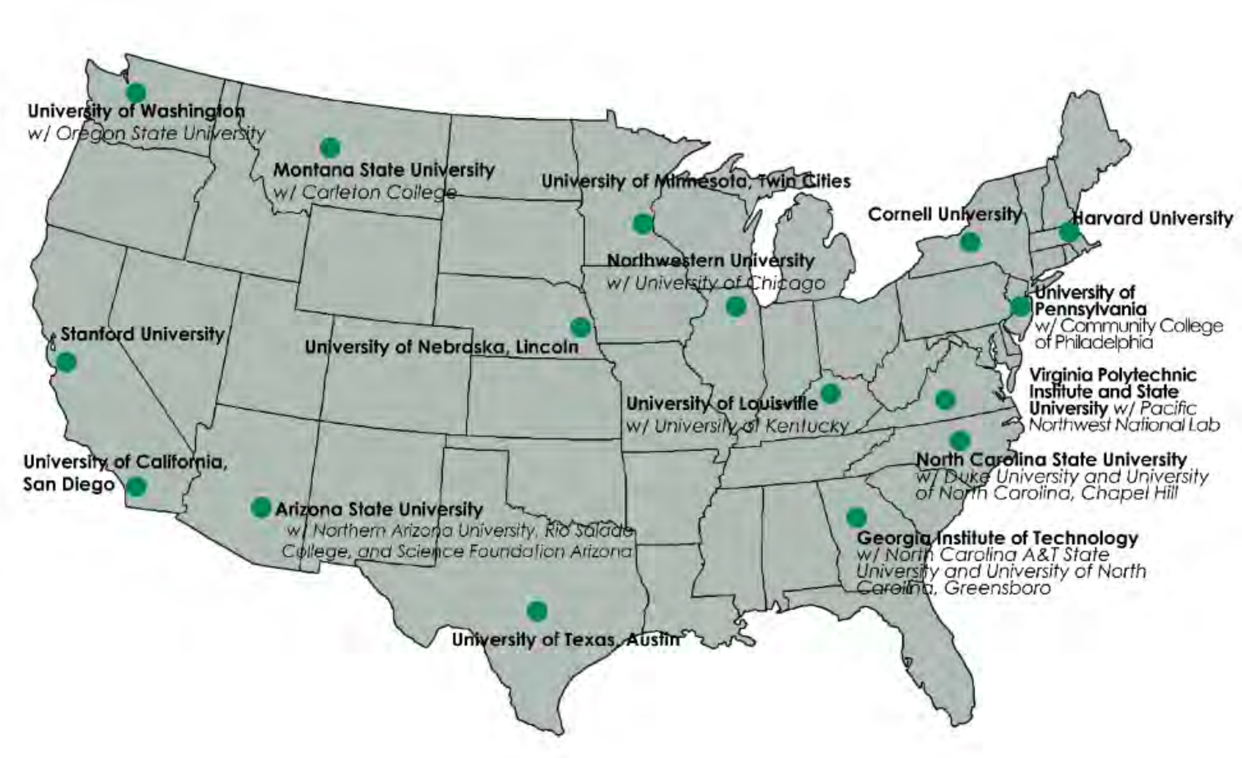


Figure 1: US Map with Locations of the 16 NNCI Sites (Years 6-10)

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 10 by more than 15,000 users including 3,900 external users, representing more than 230 US academic institutions, almost 1000 small and large companies, 50 government and non-profit institutions, as well as more than 40 foreign entities. Overall, these users have amassed more than 1.2 million tool hours. During Year 10, the network trained more than 5,100 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.

This report summarizes the activities and progress for Year 10 of the Georgia Tech Coordinating Office of the NNCI, from April 1, 2025 - March 31, 2026. NNCI sites are funded via separate cooperative agreements between NSF and each site, with reporting of site-specific data and activities corresponding to Year 10 (October 1, 2024 – September 30, 2025). Since the official end of NNCI in August 2025, most NNCI sites (13) have continued to operate under no-cost extensions, as has the Coordinating Office.

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.

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 10 (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 Rio Salado College Science Foundation Arizona	ASU NanoFab Eyring Materials Center Advanced Electronics and Photonics Core Facility Nano in Society User Facility Center for the Life Cycle of Nanomaterials ¡MIRA! Center at NAU

Nebraska Nanoscale Facility (NNF) University of Nebraska-Lincoln	Nebraska Center for Materials and Nanoscience Nano-Engineering Research Core Facility
Northwest Nanotechnology Infrastructure (NNI) University of Washington Oregon State University	Washington Nanofabrication Facility Molecular Analysis Facility Advanced Technology and Manufacturing Institute Materials Synthesis & Characterization Facility Ambient Pressure Surface Characterization Lab Oregon Process Innovation Center
Research Triangle Nanotechnology Network (RTNN) North Carolina State University Duke University University of North Carolina at Chapel Hill	Analytical Instrumentation Facility NCSU Nanofabrication Facility Shared Materials Instrumentation Facility Chapel Hill Analytical and Nanofabrication Laboratory Zeis Textiles Extension for Economic Development Nuclear Reactor Program Public Communication of Science & Technology Project Duke Magnetic Resonance Spectroscopy Center Chemical Analysis and Spectroscopy Laboratory
San Diego Nanotechnology Infrastructure (SDNI) University of California-San Diego	Nano3 Cleanroom Microfluidic Medical Device Facility Chip-Scaled Photonics Testing Facility CMRR Materials Characterization Facility
Southeastern Nanotechnology Infrastructure Corridor (SENIC) Georgia Institute of Technology Joint School of Nanoscience and Nanoengineering (NC A&T State University, University of North Carolina-Greensboro)	Institute for Electronics and Nanotechnology-Micro/Nano Fabrication Facility Materials Characterization Facility JSNN Cleanroom and Labs
Soft and Hybrid Nanotechnology Experimental (SHyNE)Resource Northwestern University University of Chicago	Northwestern University Atomic and Nanoscale Characterization Experimental Center Integrated Molecular Structure Education and Research Center Northwestern University Center for Atom Probe Tomography J.B. Cohen X-ray Diffraction Facility Northwestern University Micro/Nano Fabrication Facility Simpson Querrey Institute Pritzker Nanofabrication Facility Pulsed Laser Deposition Core
NNCI Site @ Stanford (nano@stanford) Stanford University	Stanford Nano Shared Facilities Stanford Nanofabrication Facility Stanford Microchemical Analysis Facility

	Stanford ICPMS/TIMS Facility
Texas Nanofabrication Facility (TNF) University of Texas-Austin	Microelectronics Research Center Nanomanufacturing Systems for Mobile Computing and Mobile Energy Technologies The Center for Nano and Molecular Sciences Texas Material Institute

Through a 2020 update of the NNCI Staff Directory (following the renewal proposals), sites have identified approximately 250 staff that support the NNCI program (Table 2), although some individuals fulfill multiple roles within a site's operations. Many additional technical staff 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

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.

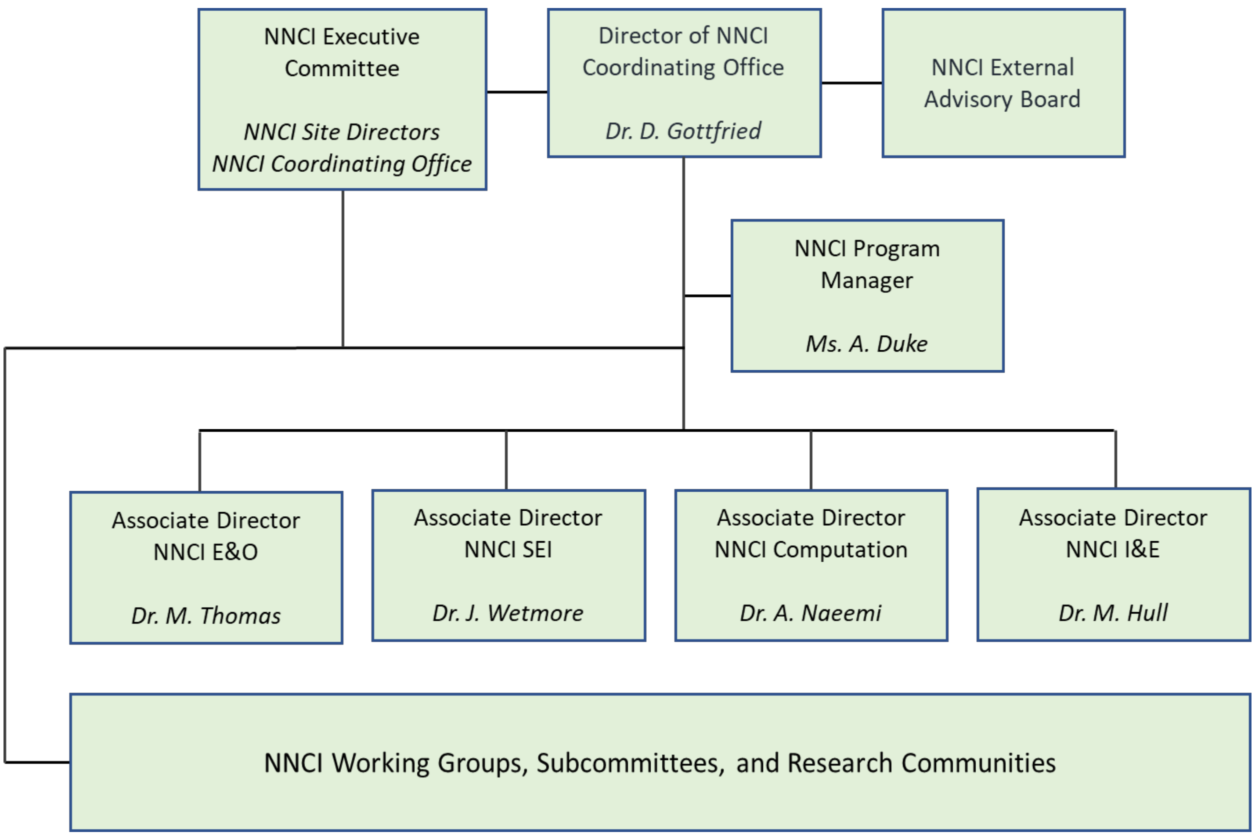


Figure 2: NNCI Coordinating Office Organizational Chart (Years 6-10). Revised May 2023.

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 last NNCI Conference (October 2024) was provided in the 2025 Annual Report. No Annual Conference was held during 2025.

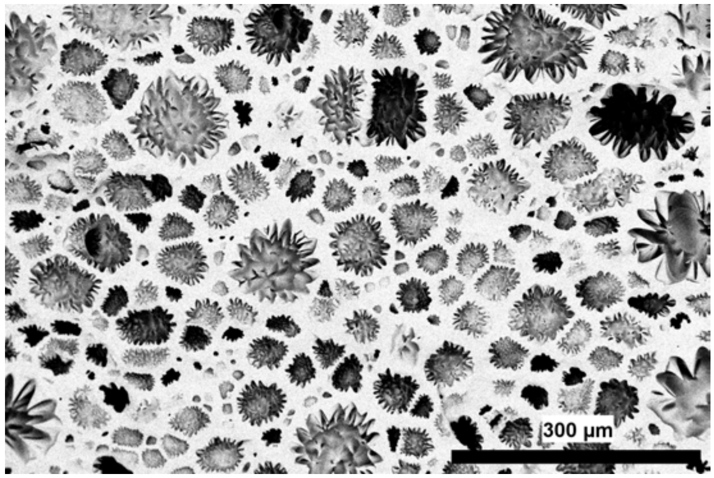
4. Associate Director Reports

4.1. Education and Outreach

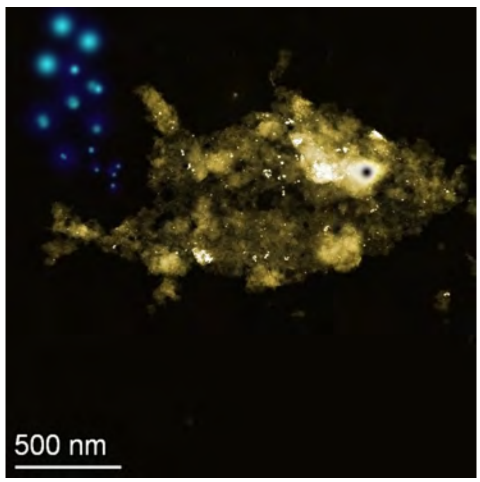
The mission of the NNCI Education and Outreach (E&O) efforts is to offer education and training to address the growing need for a skilled workforce and informed public, provide resources, programs, and materials to enhance knowledge of nanotechnology and its application to real-world issues, and support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

The 16 sites of the NNCI each have separate E&O programs in order to address these goals. Throughout the NNCI Year 10, E&O coordinators reached more than 73,000 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 slight increase from the previous year (70,000 people). All sites have returned to their pre-pandemic formats, while still using virtual programs developed during the pandemic. Of the people reached this past year, 43% are K-12 students, 8% post-secondary students (undergraduate and graduate students), 5% educators (K-12 teachers and community/technical college faculty), 34% general public, and 11% professionals (short course and workshop participants, seminar attendees, etc.). Outreach to K-12 students continues to improve compared to the previous year, and overall reach has surpassed pre-pandemic levels. Programs for educators increased participation to over 3,400 teachers and community or technical college faculty, an increase of 5% over last year. The number of post-secondary students and professionals reached also increased to more than 13,600 (increased from 11,600 in Year 9) as more sites offered webinars, virtual symposia, and other online options. The 73,000 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 additional programs in total reached over 130,000 individuals.

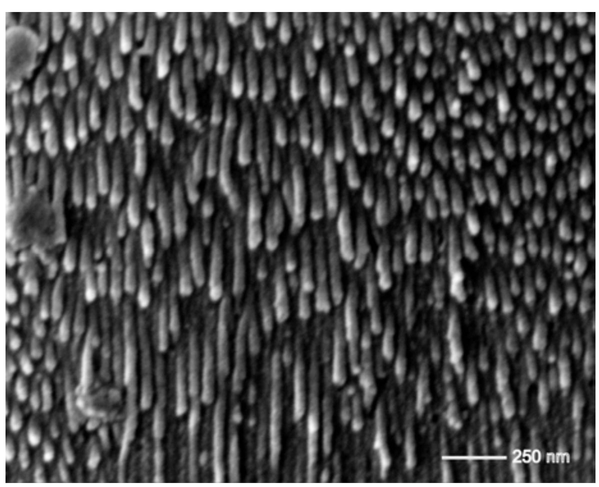
In celebration of National Nanotechnology Day, the NNCI again hosted its image contest, *Plenty of Beauty at the Bottom*. Ten sites submitted 25 images created at one of their facilities during the past two years. Images were submitted in three categories: Most Stunning, Most Unique Capability, and Most Whimsical. Public voting took place Sept. 23-Oct. 7, 2025, with sites promoting the contest through their various communication channels. More than 2,100 votes were cast to determine the winner in each category. The winners were announced on National Nanotechnology Day, October 9, 2025. In addition to the winning entries shown below, honorable mentions were awarded to entries from NanoEarth (Most Stunning), KY Multiscale (Most Whimsical), and MONT (Most Unique Capability).



2025 Most Stunning (NNI)



2025 Most Whimsical (MiNIC)



2024 Most Unique Capability (MiNIC)

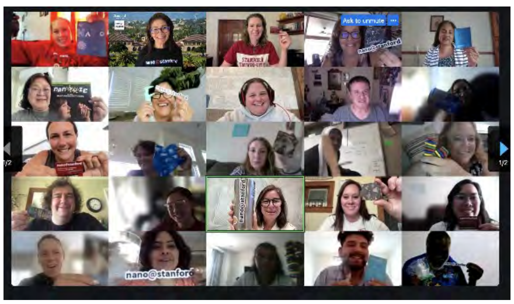
To facilitate the sharing of information across the network, coordinators participate in monthly calls and post to the education and outreach listserv. The purpose of the call is to share information about upcoming events, partnerships, conferences of interest, and for working group leads to update the 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 Sumer 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.

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). 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. NNF continued to host its high school internship program. The 2024 intern program was so successful that many labs wanted their intern to return for 2025 or even return to work during the school year. The application process was robust as they had 87 applications for 15 spots in 2025. The funding for the program was provided by Woolam Ellipsometry and the EPSCoR EQUATE (Emergent QUAntum materials and Technologies) program. 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. SHyNE partnered with Hitachi to participate in Oakton College Futures Unlimited Day. They brought a tabletop Hitachi SEM to this middle school event in order to present the field of microscopy as a career path. MiNIC hosted 60 middle school students from Bloomington Public schools on campus as part of their Nano Day activities. The students were able to explore stations about cleanrooms, photolithography, computing, and circuits. MANTH also visited students during Nano Day. They managed to present to 1,127 K-12 students in Philadelphia, the suburbs, and rural areas during the event. Hands-on materials were provided by MANTH, so students could interact with nanotechnology in their classrooms.

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, and NNF, was funded in August 2024. The first cohort under this renewal was held in the summer of 2025. Each site hosted 4 teachers. Eight teachers were from high schools, and four teachers were from community colleges. The instructors spent six weeks on campus and were partnered with a faculty member and graduate student mentor. The cohort will present their research and the lesson plan they developed at an event held at Georgia Tech in February of 2026.

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. SENIC trained 23 teachers in their in-person NanoSIMST workshop in July 2025. Nano@Stanford offered NanoSIMST in 2025 as a virtual workshop to further expand the reach of the program and enrolled 49 teachers sponsored by 10 NNCI sites including Stanford (SHyNE, MONT, CNS, RTNN, MiNIC, SDNI, NCI-SW, KY-Multiscale, and NanoEarth). Since 2017, nano@Stanford has trained 246 teachers in their NanoSIMST programs. As a network, NNCI trained over 100 teachers in the NanoSIMST program in 2025. Another resource used during NanoSIMST and available to the community are video recordings of talks on nanotechnology careers posted on the NNCI's YouTube channel: "X/Nano: The enabling Potential of a Career in Nanotechnology" (Matt Hull, NanoEarth) has nearly 1000 views and "Careers in Nanotechnology: Opportunities for STEM Students" (Jim Marti, MiNIC) has more than 3,000 views. The nano@Stanford education coordinator maintains a listserv for educators that have participated in an NNCI program, and it is also open to teachers who have not yet participated in an NNCI program. Twice a month the teachers receive an email highlighting 1 or 2 NSE education resources with information on how they connect to the Next Generation Science Standards and tips on implementation.



NanoSIMST Virtual Session led by nano@stanford.

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. NNI increased the number of short course offerings during the reporting period, and they also increased the number of hands-on activities in these courses due to user feedback. Their Nanofab Short Course is an extensive weeklong class covering process flows, lithography, metrology, subtractive technologies, additive technologies, surface modification, CAD design tutorial for photomasks, back-end-of-line, packaging, and advanced/emerging technologies. The course was updated during this reporting period to be an official provider of IEEE certificates. Short course participants can obtain 4 continuing education units (CEU) or 40 professional development hours (PDH). SHyNE hosted the 5th annual *Women in Microscopy Conference* with nearly 500 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. NCI-SW is working with other local colleges and industry to develop workforce training programs tailored specifically for semiconductor manufacturing. This program is designed to address rising demand for skilled professionals by offering specialized education and training in semiconductor manufacturing. NCI-SW provided expertise in nanoelectronics and advanced manufacturing processes. This program was highlighted on "PBS NewsHour" and that video can be found at https://www.youtube.com/watch?v=uR6xaHmqsDM.

Eight NNCI sites were able to have their Research Experience for Undergraduates (REU) programs this past summer. The NNCI REU Convocation was hosted by The University of California – San Diego (SDNI) on August 3-5, 2025. The convocation was a 3-day event and featured over 50 student short talks and posters on their summer research. They also heard keynote talks from academia and industry, discussion of entrepreneurship, and a career panel.

REU Convocation 2025 Attendees at the Univ. of California – San Diego.

In further support of undergraduates, nano@stanford's internship program in nanotechnology and microelectronics trained students from local community colleges. 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 (e.g., communication, teamwork, leadership) through leading intern meetings, training new lab users, speaking about their experiences at TechConnect, and posting to their shared Instagram page. The network continues to maintain a strong connection to this group by providing virtual and in-person resources. Five NNCI sites (SDNI, NCI-SW, SENIC, CNF, RTNN) participated in the Microelectronics and Nanomanufacturing Certificate Program. This NSF-funded 12-week program is designed to prepare veterans for working in the microelectronics and semiconductor workforce. Students are recruited from partner community/technical colleges, receive virtual lectures from researchers at Penn State University, and then receive hands-on training in the NNCI facilities.

Georgia Tech Science and Engineering Day

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). Girl Scout STEM Day is one of RTNN's largest and continually growing events. In 2025, the event served 400 total participants. Three different museums in the state of Nebraska hosted NNF's traveling nanoscience exhibit. The

Kearney Children's Museum, the Strategic Air Command and Aerospace Museum, and the Hastings Museum of Natural and Cultural History hosted the exhibit over the past year, and more than 80,000 people were able to interact with this exhibit during that time. SENIC organized Celebrate STEAM as the kickoff event of the annual Atlanta Science Festival. More than 6,000 campus visitors interacted with more than 50 interactive demos of work that is being done on Georgia Tech's campus.

Education and outreach coordinators have embraced the move to virtual outreach as an opportunity to reach a larger and more diverse audience. While sites have moved 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.

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 Implications (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. Through small events, meetings, and publications designed to integrate SEI across the NNCI and beyond; 2. Through the coordination of The Winter School on Emerging Technologies; and 3. Through supporting two versions of the Science Outside the Lab program in Washington, DC.

<u>Events and Publications:</u>

Dr. Wetmore has been extending the reach of SEI throughout the NNCI and beyond through forums, panels, and online workshops. For instance, in February 2025 he gave a seminar to the Future Science Policy Leaders at the University of North Carolina Greensboro entitled "What is US Science Policy?" In June 2025 he participated in the NCI-SW REU Speaker Series, open to REU students from across the NNCI, presenting "How Did Federal Research Work?" In both March and November 2025, he worked with Associate Director Matt Hull's Inventor's Academy to help participants understand some of the social implications of their work by using the technologies they were developing as examples. And in February 2025 Wetmore met with a delegation of students from Hiroshima University to discuss the social and personal implications of the future of nanotechnology through an interactive exercise entitled "The Future of Life Extension is Here."

The CO's Societal and Ethical Implications initiative sponsored an NNCI-wide webinar in May 2025. Debbie Stine, director of the Science and Technology Policy Academy, presented "Behind the Curtain: What is happening in US Science & Technology Policy Today?" to help participants better understand how the science policy landscape has been changing.

Over the past year Co-PI Wetmore has also completed two publications to share the work done within the NNCI on SEI more broadly. In 2026 Palgrave Press will publish Technology Humanities: Essays in Honor of Ronald R. Kline. Included in the collection will be an article written by Wetmore entitled “Science Outside the Lab: Ethics Training through Science Policy Immersion” that explains the history and impact of the NNCI’s SOtL program. Also, in 2026 Lever Press will publish the NSF CREATE/STS funded STS Teachbook: Recipes from Science and Technology Studies Communities for Critical Pedagogies. Included in it will be an article by Wetmore entitled “The Future of Life Extension is Here,” which details a teaching module that walks participants through a nano and society case study to help them reflect on everything from the role of democracies in technological decision making to how to evaluate personal risk.

Jameson M. Wetmore, “Science Outside the Lab: Ethics Training through Science Policy Immersion,” in Jennifer Lieberman and Anto Mohsin (eds.), ***Technology Humanities: Essays in Honor of Ronald R. Kline***, Palgrave, 2026.

Jameson M. Wetmore, “The Future of Life Extension is Here,” in Emily York et al. (eds.), ***An STS Teachbook: Recipes from Science and Technology Studies Communities for Critical Pedagogies***, Ann Arbor, MI: Lever Press, 2026.

Winter School on Emerging Technologies:

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 eight, which made the 2025 school the 12th 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.

The 2025 Winter School was led by a team including Dr. Vasiliki Rahimzadeh (Baylor College of Medicine), Dr. Dalton George (ASU/Rice University), Toby Shulruff (ASU), ASU Staff Deron Ash and Bethany Lang, and Dr. Jameson Wetmore. From over 80 applicants, we invited 12 participants including students from 3 NNCI universities: University of Washington, Georgia Institute of Technology, and Virginia Tech (Figure 3). Two students from Arizona State University were also able to join for a one-day visit during the week. In addition, this year we hosted a parallel gathering for a group of nine Winter School alumni who also served as speakers for the main program.

Figure 3: The 2025 NNCI Winter School Cohort

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. The program included a series of 15 talks with 22 speakers (including then NNCO deputy director Quinn Spadola and NNCI Associate Director for Entrepreneurship Matt Hull). Each session addressed a different kind of scholarly impact including community engagement, measuring impact, collaboration, policy, partnerships, creativity, and the media. We encouraged each speaker to share a variety of strategies and pedagogical tools that enhanced participants' ability to think about the impact of their own personal career including partnership strategies, expert roles, clarifying vision and goals, storytelling and pitching ideas, and self-assessment exercises to leverage the critical capacities of the participants with the support of speakers and facilitators.

Over the years the Winter School has had a large and important impact on the trajectory of the careers of many young scholars. We asked all of our 2025 participants to offer their reflections on the program.

One engineering student observed:

> "Before attending this program, I saw social impact as simply the development of advanced technology to improve human life. However, after reflecting on the session, I now think more specifically about how people's perceptions of technology are influenced by their life values. I am also considering how to make technology not only more valuable but also more practical and accessible for individuals, ensuring it meets the needs of society in meaningful ways."

One social science participant reflected:

> "I truly appreciate the preparation for this great program. Overall, it was extremely valuable in helping me understand the concept of social impact. It has also enhanced my critical

> thinking skills regarding how technology can improve human life in a more thoughtful and impactful way."

While NNCI CO funding for the Winter School ended with the 10th year of the grant (2025), the Alfred P. Sloan Foundation agreed to step in and provide funding for a 13th program in January 2026. While Sloan has provided only one year of funding, it helps to ensure the continuity of the program and gives us time to find future sources of funding to continue what has become an important institution for scholars engaging in emerging technologies around the world.

<u>Science Outside the Lab</u>

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 2025 we offered two SOtL programs.

As we have every year since 2016 (except for 2020), we ran a graduate student Science Outside the Lab program in June 2025. Demand for the 2025 graduate student SOtL was again very high with 65 applications from which we were able to select 15 participants (Figure 4). The 15 participating graduate students represented 10 NNCI universities: Northwestern (4), Stanford (3), Harvard (1), UNC Greensboro (1), Minnesota (1), NC State (1), Washington (1), Georgia Tech (1), Texas (1), and ASU (1).

Figure 4: 2025 SOtL Graduate Students at the Organization of American States.

During the first week of June the participants met with 35 science policy professionals including NSF program managers, EPA regulators, NAS program managers, GAO scientists, and the science staff at the Organization of American States. Once again, the participants got to see the strength of the SOtL alumni network firsthand. Eleven of our speakers previously participated in SOtL including Jamie Kern, Policy Officer for Energy in the Delegation of the European Union to the United States; Sindhu Nathan, staff in the office of Senator Tina Smith; and one of our recent graduates Levi Helm who is a Peacekeeping Advisor at the US Department of State.

Once again, the feedback from participants was incredibly positive. One PhD student pursuing a degree in Nanoscience argued:

> "SOtL provided so much context that I did not fully grasp about how science policy works and changes. Experiencing the daily lives of science policy folks added a layer of understanding that I could not conceptualize from just theoretical understanding of science policy. There are so many ways to participate in science policy on many levels."

Another Chemistry PhD student reflected:

> "SOtL was an amazing and rich experience that let me learn firsthand that science policy is the career I want to pursue, and I gained the knowledge to help fellow graduate students understand the political landscape that shapes their daily scientific lives when I went home. My SOtL leaders, TA, and fellow cohort mates helped me find community among like-minded scientists who care deeply about the intersection of science and federal policy. I highly recommend SOtL, for it was one of the most rewarding learning experiences of my graduate career that cannot be replicated through traditional education!"

From the very beginning the SOtL program has sought to train scientists and engineering students in the social and political dimensions of their work not just for their own knowledge, but so that they could spread that understanding throughout their communities and to their colleagues. Thus in the 2025 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 through the fall. Many students worked with the education coordinators at their NNCI site, and across cohorts with other SOtL alumni, to more fully integrate them, and SEI work, into their local programs. This year students engaged in a wide range of activities including presenting what they learned directly to other students through seminars, organizing science communication seminars taught by SOtL 2025 speakers, holding cross-generational discussions, developing a card game, and the creation of new science policy clubs. One student is anxious to share a very similar experience with their colleagues and is organizing a return trip to DC with ten other graduate students to meet with policymakers in the spring of 2026.

After the successful launch of a faculty version of Science Outside the Lab in 2023, we once again invited faculty and postdocs from across the NNCI to join us in Washington, DC for an executive version of the SOtL program. In May 2025 eight faculty and postdocs participated in the program. Six NNCI Universities were represented: Stanford (2), ASU (1), UNC Greensboro (1), Harvard (1), NC A&T (1), and Northwestern (1). In addition, a professor from Howard University joined us for the program (Figure 5).

Figure 5: Participants in the 2025 Faculty SOtL Program.

The focus of the faculty version of SOtL is slightly different from the graduate student program. We start with the assumption that, unlike graduate students, faculty participants have a pretty good idea of how the traditional university/government funding process works and is likely to have served as reviewer of NSF proposals and other similar funding streams. We therefore shift the focus to help participants better understand how to increase the chances that the work done in their labs can better inform the policy process and have a positive impact on the world. Even in the shorter time frame we were able to meet with over 30 policymakers. This year's speakers included the Counsellor for Science & Innovation at the EU's Delegation to the United States and his team; members of the GAO's Science, Technology Assessment, and Analytics Team; and Victor McCrary, Acting Director of the National Science Board.

After the conclusion of the program one of the faculty participants shared with the entire group that:

> "It was a great experience, and I will recommend it to everyone who may be interested (and I hope there's a program for faculty/postdocs again next year) … A crash course in science policy should be mandatory for every STEM graduate student in the country."

In June and July, Wendy Barnard of NCI-SW conducted a post program survey with participants from both the graduate student and faculty Science Outside the Lab programs. Once again it is clear that the participants think very highly of the program. All of the faculty participants who completed the survey said they were "extremely satisfied" with the program and "extremely likely" (5/6) or "likely" (1/6) to recommend the program to a colleague. In the graduate student program 10/11 respondents said they were "extremely satisfied" with the program and 1/11 said they were "satisfied." 10/11 respondents said they were "extremely likely" to recommend the program to a friend and 1/11 said they were "likely" to recommend.

Barnard also asked a number of more specific questions and found that student participants underwent a significant shift in how they thought about their own research as a result of the program. Prior to the program 36% argued that "my research clearly demonstrates the need for certain policy decisions." After the program that number rose to 82%.

The Science Outside the Lab program does not work without the assistance of many science policy professionals in the DC area who share their time and expertise with our participants. Barnard surveyed them as well and found much enthusiasm for the program. All the presenters who responded said that they would "definitely" (11/13) or "probably" (2/13) be interested in presenting in the program again in the future. They also were happy to encourage their peers to participate in the program. All of the presenter respondents said they would either "definitely" (11/13) or "probably" (2/13) recommend to colleagues that they present in future SOtL programs.

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 compiled. 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 NNCI sites. Most of these hardware resources serve internal users with the exception of the UT-Austin computing cluster which can be accessed by external users with a nominal fee and the CNF Nanolab Computing Cluster that is available to all users. The users of the CNF Computing Cluster have access to a wide range of modeling software packages tailored for nanoscale systems. Several classes of nodes, all linked via Gigabit Ethernet, are available on the cluster. The cluster runs Scientific Linux 7 with OpenHPC and a batch job queuing system. The staff will 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.

During 2024 and 2025 Prof. Dragica Vasileska (ASU) worked on the development and deployment of a seminar series entitled "Semiconductor Device Modeling and Simulation" on the nanoHUB science gateway platform: https://nanohub.org/resources/37981. The goal of this lecture series is to introduce researchers to basic concepts of solid-state electronics and semiconductor transport as they relate to semiconductor device physics and device modeling. Afterwards, a TCAD tool Silvaco is introduced and used to address phenomena occurring in state-of-the-art semiconductor devices. As of January 10, 2026, there were 6,980 viewers of these lectures.

Prof. Vasileska and Prof. Stephen M. Goodnick at ASU organized a workshop in collaboration with Silvaco entitled, "Device TCAD Hybrid Workshop: From Fundamentals to Applications," which was held on January 16, 2026. The participants spent the morning grounding themselves in semiconductor physics then transitioned in the afternoon to instructor-led, hands-on Silvaco TCAD labs (e.g., MOS Capacitors, MOSFETs, SOI Devices, FinFETs). Attendees learned to use Silvaco TCAD effectively and know how to select the appropriate physical models and material parameters for their devices. Attendees left with a practical grasp of semiconductor physics and the skills to use Silvaco TCAD effectively and efficiently. The workshop had close to 120 attendees.

In the fall of 2024 and Spring of 2025, Prof. Vasileska also served as a mentor to a high-school student Daniel Jeon (as part of "The Science and Engineering Experience" (SCENE) at ASU). The student developed a GUI, using Jupyter Notebook, for a recursive Green's function code developed in the group of Prof. David K. Ferry (ASU Professor Emeritus) to study magnetotransport in quantum nanowires, quantum point contacts and quantum dots. Another high-school student from SCENE program (Adit Shah) is currently porting the tool on nanoHUB for network-wide access.

In the Summer of 2025, Prof. Vasileska taught EEE436 Fundamentals of Solid-State Devices. While teaching this course, Prof. Vasileska developed 7 computational labs, the purpose of which is for students to get a better understanding of the electronic structure (using the piece-wise-constant potential-barrier tool – PCPBT, and the bandstructure lab), the operation of diodes, BJT, MOS capacitors, MOSFETs, SOI devices, MESFETs and solar cells, using several tools on nanoHUB. These labs were published on nanoHUB as part of the NNCI activities. Solutions to these labs are also provided for instructors. The labs can be accessed via https://nanohub.org/resources/40061. Since September 2024, 2,507 users (data from January 10, 2026) from various teaching institutions around the world have downloaded these labs.

Prof. Dragica also led the efforts for the development of the virtual source model for silicon-on-insulators (SOI) devices operated at cryogenic temperatures (with Prof. Ivan Sanchez from ASU).

Prof. Azad Naeemi's team at Georgia Tech have developed an open-source process design kit (PDK) for the 3nm Gate-All-Round nanosheet 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. In 2025, the documentation for guiding users was completed and Prof. Naeemi's team worked closely with several research groups across the country helping them setting up the computational environments and also helping them with technical challenges and difficulties. Additionally, these interactions allowed the team to see various applications of the PDK and helped them identify and address the gaps and shortcomings. In less than 9 months, the PDK has been downloaded (cloned) more than 100 times, and several journal and conference papers have already been published based on the work of researchers using the PDK.

4.4. Innovation and Entrepreneurship

The Innovation & Entrepreneurship (I&E) initiative continues to implement and refine programs focused on fostering a robust and inclusive NNCI-wide innovation ecosystem. 14 of 16 sites have been represented on the I&E working group, which meets quarterly to establish and execute the NNCI I&E agenda. As the current NNCI concludes, the group held its final meeting on August 19, 2025.

To date, 160 students from 100 student/post-doc-led teams representing 11 NNCI sites have participated in the NNCI Nanotechnology Entrepreneurship Challenge (NTEC), a seven-week pre-I-Corps™ Virtual Accelerator program for training nano-savvy innovators and entrepreneurs. The NTEC Alumni Community has been established on LinkedIn to help connect members of current and previous NTEC cohorts.

In 2025, we added new elements to the NTEC program. First, we included a weekly seminar series with speakers from across the NNCI and organizations like NSF, Activate, and VentureWell. Second, we launched a "Future Innovators" session at the TechConnect meeting in Austin, TX, June 9-11, 2025. The session included a panel discussion with local innovators, entrepreneurs, and investors based in Austin and Houston, TX, and featured live pitches from the top four NTEC teams selected from our virtual NTEC Showcase. First, second, and third place teams were selected by the "Future Innovators" panel and awarded additional funding for participant support costs at NNCI sites. An additional $1,000 award was provided by industry sponsor, Jones-Dilworth, Inc. of Austin, TX. While the panel deliberated awardees, Dr. Branden Brough of Lawrence Berkeley

National Laboratory presented a keynote entitled "Entrepreneurs at DOE National Labs: A Powerful Pairing."

Supplemental support from NSF and the NNCI CO allowed the I&E WG to run a second NTEC cohort in Fall 2025, which kicked off on National Nanotechnology Day (10/9). A collaboration with the Advanced Technology Technician Training (AT3) program led by Jared Ashcroft expanded the reach of NTEC to include a national network of students from community colleges, technical training programs, and high schools. The top four teams from the Fall program were selected December 4, 2025 during the virtual NTEC Showcase. Those teams will compete in a second "Future Innovators" session to be hosted at the TechConnect meeting in Raleigh, NC, March 10-12, 2026, in collaboration with Jacob Jones and representatives from RTNN.

The NNCI Research and Entrepreneurship Experience for Undergraduates (REEUs), which offers a gentle entrepreneurship introduction to NSF REU students, entered its fifth year having reached 120 students across eight NNCI sites. In 2025, we added approximately 200 additional students across four REEU sessions, bringing our total reach to over 320 students. This year the REEU program reached beyond NNCI sites to include students associated with the AT3 program and the Integrated REU program led by Andrew Greenberg at the University of Wisconsin-Madison.

The "Pain to Pitch 180™" program, which was launched in collaboration with the ASU Winter School, entered its fourth year (2023 to 2026) and has reached a total of 50 students. The goals of the program are to 1) provide a general idea of what an "entrepreneur" is/does and how entrepreneurship connects to students, their research, and the discoveries they make, and 2) help students learn to operate like an entrepreneur by using a hypothesis-driven process to connect solutions to customer challenges, derive a value proposition, and make a pitch for an idea they think solves a "pain-point" impacting their classmates. The program achieves these goals within a single three-hour program (i.e., 180 minutes).

To date, 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." Seminar scheduling was paused for 2025 but could be resumed with additional funding support and interest.

Background

The 2021 NNI Strategic Plan calls for *"innovative mechanisms to realize the transformational societal benefits that flow from faster commercialization of nanotechnologies"*. 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. Dedicated funding, personnel, and reporting mechanisms for I&E were not originally included in the NNCI but were prioritized during program renewal in 2020 for implementation during years 6-10. 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 2025, the NNCI I&E Working Group (current roster shown in Figure 6) met quarterly on the following dates: January 28th (Q1), June 3rd (Q2), and August 19th (Q3). The August 19th meeting was the final formal meeting of the NNCI I&E WG based on conclusion of the original NNCI funding timeline. While formal meetings have ended, subsets of I&E team members continued to meet on an ad hoc basis to continue supporting programs such as NTEC, Innovator's Academy, REEU, and the Translational Panel at the REU convocation hosted by Yves Theriault at UC San Diego (SDNI). 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 6: The 2025 NNCI I&E Working Group included representatives from 13 NNCI sites.

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

- **NNCI I&E Speaker Series –** recommendations for NNCI-wide speakers who can speak on topics pertinent to I&E and industry engagement
- **NNCI-wide Entrepreneurs-in-Residence (EiRs) –** faculty/staff entrepreneurs based at individual sites (including external users from small companies) who may be interested in serving as EiRs in an assortment of capacities
- **NNCI-wide Student-led Nanotechnology Entrepreneurship Challenge (NTEC) –** strategies to develop/sustain student-focused entrepreneurship at the site-level and NNCI-wide
- **Research and Entrepreneurship Experience for Undergraduates "REEU" program –** collaborative effort with the NNCI education & outreach 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

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

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 summarized below:

In January 2025, the "Pain to Pitch 180™" experience was delivered for the fourth consecutive year. The program is offered in collaboration with the ASU Winter School and the NNCI Assoc. Director for SEI, Jamey Wetmore, to immerse attendees in the process of translating solutions to customer "pain points" and broader societal challenges. Participants spend 180 minutes uncovering pain points and pitching a potential solution to those pain points.

Matthew Hull (CO/NanoEarth) along with an NNCI delegation organized by David Gottfried, attended the 4th European Nanofabrication Research Infrastructure Symposium (ENRIS) that took place May 13-15, 2025 in Bologna, Italy. Hull presented a talk entitled *"Networked Support for Innovation and Entrepreneurship: A Case Study on the US National Nanotechnology Coordinated Infrastructure (NNCI)"*. Symposium details are available online at https://enris2025.org/.

Yves Theriault and SDNI hosted the 2025 REU Convocation. Yves moderated and participated in an I&E panel discussion with Dr. Stephen Oldenberg, a serial entrepreneur based in San Diego, CA, and Matthew Hull, NNCI/NanoEarth AD I&E (Figure 7). The objective of the panel was to discuss successes, challenges, and resources related to research translation with REU students attending the meeting.

Figure 7: Yves Theriault (SDNI) hosted a panel on technology translation at the 2025 REU Convocation at UC San Diego.

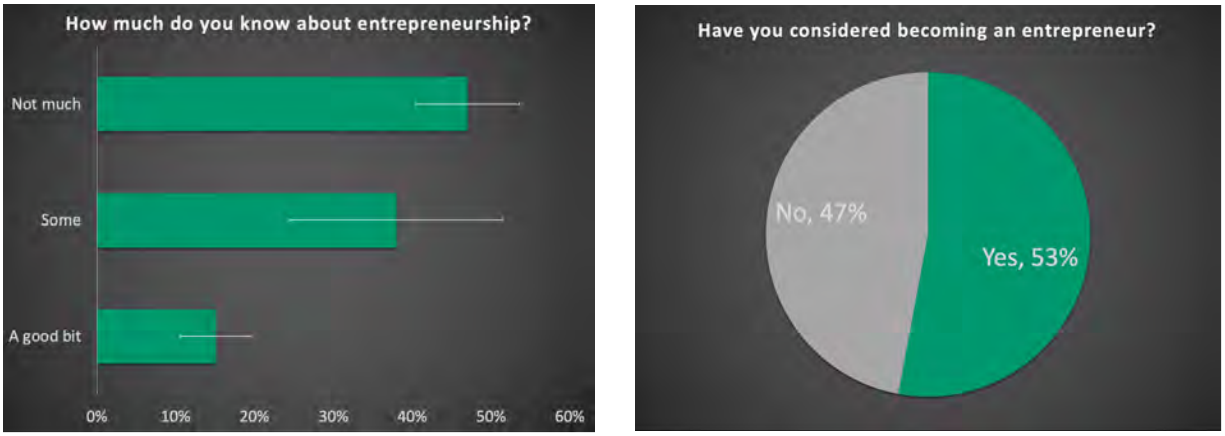
Research and ENTREPRENEURSHIP Experience for Undergraduates (REEU)

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

In 2025, NNCI Assoc. Director for I&E (Matthew Hull) gave four REEU seminars by Zoom. The number of NNCI sites participating in the REEU program remained at eight but included sessions with two programs outside of NNCI – the AT3 program led by Jared Ashcroft and the University of Wisconsin-Madison Integrated REU program led by Andrew Greenberg (Figure 8). REEU modules are offered in collaboration with the NNCI Assoc. Director for E&O (Mikkel Thomas) and local REU coordinators. Participating NNCI sites now include: NNF (Jenna Huttenmaier and Steve Wignall), SDNI (Yves Theriault), KY MultiScale (Ana S. Galiano), MANTH (Kristin Field), NanoEarth (Matthew Hull), NCI-SW (Jessica Hauer), SENIC (Leslie O'Neill), and MONT (Heather Rauser). In 2021-2025, 320 REU students participated in the program.

Figure 8: 2021-2025 REEU Participation: 8 NNCI sites, 2 external programs and 320 REU students engaged in translating research.

Throughout years 6-10, interest in industry research careers and entrepreneurship has remained 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. From 2021 to 2025, nearly half of REEU participants claimed that they did not know much about entrepreneurship (Figure 9a). Students claiming to know "a good bit" about entrepreneurship remains at about 15%. In 2024 and 2025, more than half of REEU participants indicated that they had considered becoming entrepreneurs (Figure 9b).



a. **b.**

Figure 9: Feedback to date (2021-2025, n = 5) from REU students participating in the NNCI REEU module when asked a) how much they know about entrepreneurship, and b) whether they have considered becoming an entrepreneur (2024 and 2025 only, n = 2).

Overall, the students continue to express a favorable opinion of entrepreneurship, using terms like "creativity", "innovation", and "freedom" as entrepreneurship descriptors, but they also recognize the challenges through terms like "risk", "grind", and "hard work". Figure 10 shows a word cloud generated by students participating in the AT3 program. Ongoing assessments of REU student perceptions of entrepreneurship can help the I&E and E&O working groups continue to better understand student interest in entrepreneurship and tailor program content for maximum efficacy.

Figure 10: Word cloud based on responses of AT3 community college students participating in a 2025 REEU session when asked "What comes to mind when you think of entrepreneurship?"

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

There were no NNCI I&E Seminars hosted in 2025 as the NNCI concludes and personnel focus on new priorities. In years 6-10, seven I&E seminars (two in 2024, two in 2023, one in 2022, and two in 2021) have been hosted as part of the broader NNCI seminar series and shared virtually across the NNCI to help foster awareness of industry-specific challenges and engagement of industrial problem solvers. Industry seminars foster awareness of key I&E topics or issues and enable the deeper relationships required to effectively engage and recruit non-traditional NNCI users, particularly small business users pursuing opportunities such as SBIR/STTR. Compared to site-level seminars, however, NNCI-wide I&E seminars: a) have relevance across multiple or all NNCI sites by elevating the message of an impactful I&E story (e.g., a success story), collaboration, trend, or opportunity, b) are promoted by the NNCI coordinating office, and c) are often co-hosted along with an NNCI site (e.g., the home site of the I&E WG member who proposed the seminar).

Seven NNCI industry seminars have been hosted to date and are summarized below. 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.

- **Seminar 7.** Panelists: Yossi Feinberg, Adams Distinguished Professor of Management and Professor of Economics, Stanford University; Jennifer Dionne, Professor of Materials Science and, by coursey, of Radiology, Stanford University, Chan Zuckerberg Investigator, Co-Founder of Pumpkinseed; Keegan Cooke, Director, Stanford Ecopreneurship, Stanford University, "From Lab to Launch: Stanford's Entrepreneurial Ecosystem" (9/17/2024) [Moderated by Matthew Hull, AD Innovation & Entrepreneurship, NNCI/NanoEarth] – ***YouTube views as of this report date: 249***
- **Seminar 6.** Panelists: Jacques Chirazi, Director of Student Entrepreneurship, The Basement Blackstone Launchpad Campus Director, UC San Diego; Christine Liou, Assistant Director, The Basement, UC San Diego; Yves Theriault, Program Manager, Education & Outreach, Qualcomm Institute, UC San Diego, Executive Director of Education & Outreach, SDNI, "How to Engage with Diverse Student Populations in Entrepreneurship" (3/11/2024) [Moderated by Matthew Hull, AD Innovation & Entrepreneurship, NNCI/NanoEarth] – ***YouTube views as of this report date: 36***
- **Seminar 5.** Panelists: Nathan Hancock, Senior Principal, Flagship Pioneering; Cristina Jauset, Associate, Flagship Pioneering, "Venture Creation for Sustainability" (12/19/2023) [Moderated by Matthew Hull, AD Innovation & Entrepreneurship, NNCI/NanoEarth] – ***YouTube views as of this report date: N/A (Removed for sensitive content at presenter's request)***
- **Seminar 4.** Panelists: Hannah Murnen, Managing Director, Activate Anywhere; Jill Fuss, Managing Director, Activate Berkeley; Karin Lion, Chief Growth Officer, Activate; Austin Hickman, CEO, Soctera, Activate Fellow, "Activate Fellowships – Empowering Scientists and Engineers to Bring Their Research to Market" (5/3/2023) [Moderated by Matthew Hull, AD Innovation & Entrepreneurship, NNCI/NanoEarth] – ***YouTube views as of this report date: 191***
- **Seminar 3.** Miguel Urteaga, Director of Foundry Products and Services, Teledyne Scientific Co, "Lab-to-Fab: Transitioning from University Cleanrooms to Industrial Prototyping and Low-Volume Production" (10/12/2022) [Hosted by Andrew Lingley, Manager, Montana Microfabrication Facility] – ***YouTube views as of this report date: 193***

- **Seminar 2.** Kurt Petersen, PhD, Member of the Silicon Valley Band of Angels, "What Investors are Looking for in Early-Stage Start-up Companies" (10/28/2021) [Hosted by Karl F. Böhringer, Director, Northwest Nanotechnology Infrastructure] **– *YouTube views as of this report date: 140***
- **Seminar 1.** Terrance Barkan, Executive Director, The Graphene Council, "2D Advanced Materials and US National Priorities" (5/27/2021) **– *YouTube views as of this report date: 176***

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.

2025 marked the fourth year of the NNCI-wide NTEC program (and the program's 12^{th} year, overall). Instead of running a single NTEC cohort in the Spring, as in previous years, in 2025 we ran two cohorts – one in Spring and one in Fall. In the Spring cohort, 22 student-led teams comprised of 27 students from six different NNCI sites participated. Another 19 teams participated in the Fall cohort with teams consisting of 40 students from nine different NNCI sites. Three teams were led by community college students from the Advanced Technology Technician Training (AT3) Program directed by Jared Ashcroft. The AT3 teams were partnered with an NNCI site that offered tools and expertise that best aligned with each team's needs and interests. Teams from both cohorts participated in the seven-week NNCI Virtual Accelerator program. The Spring cohort kicked off March 6, 2025, and concluded June 10, 2025, with a live pitch event at TechConnect in Austin, TX. The Fall cohort kicked off October 9, 2025 (National Nanotechnology Day) and will conclude March 11, 2026, with a live pitch event at TechConnect in Raleigh, NC. Figure 11 shows a zoom capture from the 2025 NTEC Spring and Fall Cohorts.

Figure 11: Zoom captures from the NTEC Spring and Fall 2025 NNCI NTEC Cohorts.

Table 4 summarizes NTEC projects for the Spring 2025 cohort, with 6 NNCI sites, 27 students, and 22 teams. the largest number of teams ever competing in NTEC.

Table 4: 2025 NNCI NTEC Spring Cohort

Team #	Team Lead	NNCI Site	Mentor(s)	NTEC Title
60	Suraj Pavagada (withdrew)	nano@stanford	Dr. Gözde Durmuş	DART-Met: Dynamic AI-Driven Raman Techniques for early detection and monitoring of metabolic liver disorders
61	Milo Eirew	nano@stanford	Polly Fordyce	A Dynamically Reconfigurable MEMS-based Microfluidics Mold for Rapid, Extremely Inexpensive Fabrication of Microfluidic Devices

62	Kevin Lee	NNI	Lilo Pozzo	High-Power-Density Battery Electrodes for Aviation Electrification
63	Anmol L Purohit	NNI	Dr. Igor Novosselov	Synthesis of Metal Organic Framework (MOF) particles for removal of short and ultra-short chain PFAS from water
64	Liubov Palchak	RTNN	Marina Dobrovolskaia, Alexander Kabanov	Nanolipids with reverse architecture
65	Hallie Hutsell	RTNN	Dr. Alexander V. Kabanov & Dr. Marina A. Dobrovolskaia	ROS-Responsive Poly(2-Oxazoline) Micelles for Multi-Drug Delivery
66	Einollah Sarikhani	SDNI	Zeinab Jahed, Yves Theriault	Targeted intranuclear delivery of genes using nanotechnology
67	Patrick Opdensteinen	SDNI	Yves Theriault, Nicole Steinmetz	Plant-made nanomedicines for accessible and affordable life-saving medication worldwide
68	Riam Badr	SDNI	Yves Theriault, Drew Hall, Eliah Aranoff Spencer	Electrochemical Biosensor for Detection and Quantification of Infectious Diseases
69	Gregory Roberts	SENIC	Dr. Shyam Aravamudhan	Light-Energized Smart Bandages for Enhanced Wound Healing
70	Nona Hashemi (withdrew)	SENIC	Dr. Sammuel Oliveira	PathoDetect & Microbiome profiling
71	Oreoluwa Alonge	SENIC	Dr. Sammuel Oliveira	CardioNanoTech: Combining cardiovascular focus with nanotechnology expertise
72	Vamsi Satti	SENIC	Dr.Shyam Aravamudhan	Next-Generation Modular Microplasma Reactor for Clean Energy and Recycling
73	Maurelio Cabo Jr	SENIC	Dennis Lajeunesse	Solubilizing bacterial nanocellulose in reinforced eutectic solvent as a biosemiconductor
74	Farbod Ebrahimi	SENIC	Prof. Kristen Dellinger	SILVERED (Surface-Induced Layered Vapor Energy Refined Enhanced Deposition) for Biosensing
75	Kameron Burton	SENIC	Kristen Dellinger	Smart Multifunctional Designer Particles: AI-Driven, Stimuli-Responsive Nanocomplexes for Therapeutics, Agriculture, and Beyond
76	Alden Contreras	SENIC	Prof. Jeffrey Alston	Shattering Nanomaterial Synthesis Barriers with Subsurface Laser-Engraved Glass Microreactors
77	Anjali Kumari	SENIC	Dr. Kristen Dellinger	EMBED (Evaluating and Modeling Barriers for EV Delivery)
78	Moonwon Jeon	NanoEarth	Sharad Jaswandkar	Development of Bioactive Glass Nanoparticles for Synergistic Photothermal and Chemotherapy in Cancer Treatment
79	Narges Yousefpour	NanoEarth	Mr. Jarret Wright	FIB Fabrication Techniques of Polymer Fiber based Devices for Implantable, Multifunctional Neural Applications
80	Yanan Pan	NanoEarth	Hongyu Wang	Sustainable and Cost-Effective Nanotechnology for Critical Mineral Extraction
81	Vera Bordah	NanoEarth	Dr. Bahareh Behkam	Living Biosensor for Food Security Applications

Table 5 summarizes NTEC projects for the Fall 2025 cohort, with 9 NNCI sites, 40 students, and 19 teams. This cohort also included community college students from the Advanced Technology Technician Training (AT3) Program led by Jared Ashcroft.

Table 5:2025 NNCI NTEC Fall Cohort

Team #	Team Lead	NNCI Site	Mentor(s)	NTEC Title
82	Daria Didenko	MANTH	Dr. Gerald G. Lopez	Miniaturized Optical Microscopy Probe for Deep Tissue Imaging
83	Holly Dahlstrom	NanoEarth (via AT3)	Dr. Dominic Salerno; Matthew Hull, PhD; Jared Ashcroft, PhD	VitaFilm
84	Samantha van Rijs	nano@stanford	Prof. Tom Soh	Nano-Engineered BioFET Neural Probes Enabling Closed-Loop Neurochemical Sensing and Modulation
85	Chi-Hsin Huang	nano@stanford	H.-S. Philip Wong	Machine Learning-Based Prediction of Oxide Semiconductor Device Performance Using Nanotechnology Characterization
86	Alejandro Lopez	NCI-SW	Anton	Project Accessibility
87	Kevin Lee	NNI	Lilo Pozzo	Anodeless Battery Electrode Design for Next-generation Transportation
88	Anh Tran	RTNN	Abraham Vazquez-Guardado	Active Photonics for Brain Imaging of Neural Activity
89	Max McKee	RTNN	Chris Mumford	SpartanPods
90	Bhavya Jain	RTNN	Dr. Amay J. Bandodkar	EnviraCell
91	Patrick Smith and Sean McDowell	SDNI	Yves Theriault and Ivonne Gonzalez Gamboa	Smart Agrochemical Delivery for Resilient Crops in Climate-Stressed Soils
92	Richard Sedeafor	SENIC	Dr. Kerui Wu	Formulation of magnesium ion nano-nourisher wound healing and skincare products
93	Maurelio Cabo Jr	SENIC	Dennis LaJeunesse	Bio-Flex: A Semiconductive, Antimicrobial Material from Green Solvents
94	Samuel Adegoke	SENIC	Dr. Dennis LaJeunesse	Harnessing nanoparticle to combat bacterial multidrug Resistance
95	Rutujaa Pradyumna Kulkarni	SENIC	Dr. Jeffrey R. Alston	Upcycling Urban Biomass: A Nanotech Approach to Cellulose Production
96	Farbod Ebrahimi	SENIC	Prof. Kristen Dellinger	SILVERED: A Dual-Function Platform for Detection and Surface Protection
97	Anjali Kumari	SENIC	Dr. Kristen Dellinger	ExoVerse Solutions (EMPLOY- Engineer Micropillar Platform for Ligand-based Optimized Yield)
98	Vaishnavi Kandula	SENIC	Dr.Michael Curry	Sustainable Flexible Photodetectors for Next-Generation Electronics

99	Malexa Patel	TNF	Ravi Brahmbhatt	StepLight – Nano-Enabled Emergency Lighting Floor Tile
100	Naimat Kalim Bari	NanoEarth	Professor Bahareh Behkam	Extracellular matrix targeting living therapeutics

A new addition in 2025, for both cohorts, was the NNCI Innovator's Academy, which included weekly webinars on key topics related to technology translation and use of NNCI facilities. The optional webinars allowed teams to explore entrepreneurship topics and opportunities more deeply and were delivered by experts from across multiple NNCI sites and other entities like NSF, Activate, and VentureWell. Table 6 summarizes the weekly NNCI Innovator's Academy sessions for both the Spring and Fall NTEC cohorts and includes links to recordings of each on YouTube (unlisted).

Table 6: Summary of Spring and Fall 2025 NNCI Innovator's Academy Speakers. Hyperlinks provide recordings of each session posted to YouTube (unlisted).

Week	SPRING 2025 Innovator's Academy Virtual Seminar	FALL 2025 Innovator's Academy Virtual Seminar
1	**Kickoff: NNCI & Your Start-Up** **Matthew Hull**/NNCI CO **Tonya Pruitt**/NanoEarth March 6, 2-3PM ET, by Zoom | LINK	**Kickoff: NNCI & Your Start-Up** **Matthew Hull**/NNCI CO **Tonya Pruitt**/NanoEarth Oct. 9, 2-3PM ET, by Zoom | LINK
2	**Value Proposition & Customer Validation** **Yves Theriault**/SDNI March 13, 2-3PM ET, by Zoom | LINK	**Value Proposition & Customer Validation** **Yves Theriault**/SDNI Oct. 16, 2-3PM ET, by Zoom | LINK
3	**Responsible Development** **Jamey Wetmore**/NCI-SW March 19, 2-3PM ET, by Zoom | LINK	**Activate Fellowships** Panel: **R. Kempinski**/Activate, **A. Cruz**/Edulis Labs Oct. 23, 2-3PM ET, by Zoom | LINK
4	**Operations & Scaling Your Startup** **Ron Olson**/Cornell March 27, 2-3PM ET, by Zoom | LINK	**Operations & Scaling Your Startup** **Ron Olson**/Cornell Oct. 30, 2-3PM ET, by Zoom | LINK
5	**Customer Relationships & Growing Your Venture** **Gerald Lopez**/MANTH April 3, 2-3PM ET, by Zoom | LINK	**Customer Relationships & Growing Your Venture** **Gerald Lopez**/MANTH Nov. 6, 2-3PM ET, by Zoom | LINK
6	**NSF Translational Programs** **Barry Johnson**/NSF	**VentureWell Programs**

	April 10, 2-3PM ET, by Zoom | LINK	Panel: **S. Wharmby**/VentureWell, **M. Fernandez**/Ecoplasticity Nov. 13, 2-3PM ET, by Zoom | LINK
7	**Activate Fellowships** Panel: **K. Turner**/Activate, **R. Kempinski**/Activate, **P. Imany**/Icarus Quantum, **J. Slack**/Rhoic April 17, 2-3PM ET, by Zoom | LINK	**Responsible Development** **Jamey Wetmore**/NCI-SW Nov. 20, 2-3PM ET, by Zoom | LINK
Final	**Spring 2025 NTEC Showcase with Special Guest** **Daniel Surinach/Objective Biotechnology** April 29, 2-3PM ET, by Zoom | LINK	**Fall 2025 NTEC Showcase with Special Guest** **Ivonne González-Gamboa/UC San Diego** December 4, 2-3PM ET, by Zoom | LINK

In previous years, the NNCI NTEC program concluded 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. In 2025, however, rather than concluding the NTEC program, the Showcase was instead used to select the top NTEC teams to advance to an in-person NNCI NTEC pitch competition. For the Spring 2025 cohort, the top 4 teams selected from the NTEC Showcase advanced to an in-person pitch challenge at the TechConnect World Innovation Conference & Expo in Austin, TX, June 9-11. A $6,000 supplement from NSF helped support student travel to the live pitch event. Anmol L Purohit, Ji Feng, and Almond Lau from the Northwest Nanotechnology Infrastructure (NNI) at the University of Washington achieved first place for "Synthesis of Metal Organic Framework (MOF) particles for removal of short and ultra-short chain PFAS from water". Igor Novosselov served as the team mentor. As the top team, they received $4,500 in support from the NNCI and a $1,000 award from Jones-Dilworth, Inc. (Figure 12). Additional details on the Spring 2025 NTEC competition can be found here, in an online article compiled by NanoEarth's Tonya Pruitt: Winners Announced for the Spring 2025 Nanotechnology Entrepreneurship Challenge. Details on the Fall 2025 NTEC competition will be available after the in-person pitch event in March 2026.

Figure 12: Douglas Freeman of Jones-Dilworth, Inc. (2nd from right) and Matthew Hull of NNCI (far right) present a check to the top overall NTEC Team from the Spring 2025 Cohort: Anmol Purohit (2nd from left), Ji Feng (far left), Almond Lau (not pictured), and team mentor, Igor Novosselov (not pictured) of NNI.

Entrepreneurs-in-Residence (EiR)

Currently, there remain four identified NNCI EiRs as shown in Table 7, although many members of the NNCI I&E WG effectively function in a similar but informal capacity. The I&E Assoc. Director serves as the NNCI EiR in situations where a site-specific EiR has not been identified. 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 7: NNCI Site Entrepreneurs-in-Residence

Site	EiR
MONT	Trevor Huffmaster
SDNI	Yves Theriault (students and postdocs)
NNI	Mike Robinson
NanoEarth	Matthew Hull
NNCI (when local site EiR is not 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 7). Positions on these committees were offered to each member of the Executive Committee (site PIs), along with any site co-PIs who wished to participate. Most Site Directors serve on two of these subcommittees with a subcommittee chair selected by the Coordinating Office. Additional input may be sought from members of the External Advisory Board and other experts as needed. Members of the Coordinating Office serve on some of the subcommittees as ex-officio members. As a starting point, the Coordinating Office created a number of guiding questions for each subcommittee. One of the subcommittees is selected to report to the full group of site directors and coordinating office (Executive Committee) every other session during the regular monthly meetings. Subcommittee topics, chairs, and members were reviewed and updated during 2021. The Entrepreneurship and Commercialization subcommittee was 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. The remaining subcommittees have completed their work, and no further reports are provided.

Table 7: NNCI Executive Committee Subcommittees (2025)

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	
Nanotechnology Infrastructure of the Future	Debbie Senesky (nano@stanford)
Building the User Base – sunset 2023	

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 8) in (1) important "network" responsibilities, such as environmental health & safety, vendor relations, or equipment maintenance, (2) particular process technologies, such as lithography or characterization (although these are only examples of possible topic areas), and (3) education and outreach activity. Most of these working groups began in Year 1, while new ones were added in Years 2 and 3. In addition, some topical areas (EBL, Etch, and ALD) have begun working groups through grass-roots efforts of NNCI staff, with support from the Coordinating Office. The outcomes of these working groups can have many forms, including process recipes, recommendations to vendors for future equipment development, maintenance and training videos/webinars, recommendations on how to evaluate the safety of new processes, or direct recommendations for new users. Each working group has one or more dedicated coordinators selected from one of the NNCI sites, and staff participation in the working groups can be one measure for site performance. Participation in these working groups can also be considered as a mechanism for staff growth and career development or as support for an NNCI Outstanding Staff Award. During 2021, leadership 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 8: NNCI Working Groups (2025)

Working Group Topic	Working Group Lead(s)
Network Support Working Groups	
Equipment Maintenance	Jeremy Clark (Cornell)
Vendor Relations	Vacant
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), Durga Gajula (Georgia Tech), Vince Genova (Cornell), Lavendra Mandyam (Stanford)
Photolithography	Vacant

Atomic Layer Deposition	Mac Hathaway (Harvard)
Imaging and Analysis	David Bell (Harvard)
Education and Outreach	
K-12 and Community	Vacant
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 10, 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 $5000 travel funding) to encourage staff participation. Recent events included:

- NNCI Etch Symposium, June 30-July 2, 2025 (MIT)

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. Regional Networks

We held our regional network working group meeting on Tuesday October 14, 2025. The following NNCI members representing their associated regional network included: Gary Spinner and Walter Henderson from the Southeastern Nano Facility Networks (SENFN), Darick Baker and Andrew Lingley from the Northwest Nanotechnology Laboratory Alliance (NWNLA), Ana Sanchez Galiano from Ohio Valley Nano+AM Regional Network, and Ron Olson from the NY State Nanotechnology Network (NNN).

We discussed the following two topics:

1. This year's events and objectives
2. Regional networks and the Next Network

NY State Nanotechnology Network (NNN)

Ron Olson discussed the NNN 2025 activities and goals. The last NNN event took place at Rochester Institute of Technology on September 27, 2024. We were trying to have an event this year but because of end of year scheduling conflicts with the steering committee and host site we scheduled the event for March 2026. The focus remains on workforce development and regional collaboration, particularly within the New York State region. The 2026 NNN Symposium "New York State Talent & Technology Shaping the Future – Rising Stars" will be hosted by Syracuse University. The event will feature speakers from companies like GlobalFoundries and Micron and the program will include a panel discussion with industry experts on semiconductor career paths, as well as a booklet highlighting New York State's facilities and capabilities.

Southeastern Nano Facility Network (SENFN)

Walter Henderson and Gary Spinner discussed their regional network. The team held regular monthly meetings August through December 2024. In August and September, they had lab directors Felio Perez and Wang Guiren present on operations at their facilities at the University of Memphis and the University of South Carolina, respectively. These were the last of a series of presentations and discussions about their facilities throughout 2024 that included a discussion regarding novel equipment access. The group made preliminary plans to meet in person in February 2025, but due to group leader Henderson having an unusually busy period in early 2025, the plans fell through and the group did not meet until October 2025. In that meeting, the group had a quick round-robin check-in and update on measures taken to deal with policy changes and budget uncertainties in 2025. They made plans to meet again in November and December and have already had one request for intra-group visit (from Memphis to Georgia Tech) for staff enrichment.

The team plans to meet monthly (possibly bi-monthly) through video chat in 2026 and in-person at UGIM in July 2026 at Stanford.

Ohio Valley Nano+AM Regional Network

Ana Galiano from the University of Louisville discussed how KY Multiscale engaged in a number of activities and events in 2024-2025 focused on growing their regional partnerships and increasing the regional participation in their NNCI node. These events and activities included the following:

1. The annual Nano+Additive Manufacturing Summit and the 2024 NNCI Annual Conference.
2. Workshops including the Kurt Lesker Vacuum Technology Workshop in May 2025 and the state-wide Kentucky IDeA Networks of Biomedical Research Excellence (KY INBRE) BioImaging Workshop with participants from regional colleges in August 2025.
3. The Interdisciplinary Micro/Nano/Additive Manufacturing Program Addressing Challenges Today (IMPACT) REU Program, recruiting 50% of their undergraduate participants from Kentucky regional colleges.
4. Partnered with the University of Cincinnati to develop a Rapid Semiconductor Certification Program.
5. KY Multiscale collaborated with fellow NNCI sites, including the RTNN, in a new initiative called the National Network for Microelectronics Education (NNME) Regional Node, which includes the University of Florida and other southeast region schools.
6. Participated with Ohio State University in the Midwest Microelectronics Consortium.
7. Hosted, the Regional Midwest Association of Core Directors (MWACD) Conference in 2024 in Louisville and continued participating in MWACD annual meetings, including this year at the University of Wisconsin, Madison.
8. Joined the 20th Anniversary Celebration of the Birck Nanotechnology Center at Purdue University, reflecting on their active involvement in the broader nanotechnology community.

Northwest Nanotechnology Laboratory Alliance (NWNLA)

Andrew Lingley and Darick Baker provided an update on the Northwest Nanolab Alliance's recent activities. The 2025 Northwest Nanotechnology Laboratory Alliance (NWNLA) meeting brought together over 30 participants from institutions across the Pacific Northwest and beyond, including Montana State University, University of Washington, Western Washington University, Boise State University, University of Oregon, University of British Columbia, Cal Poly, University of Colorado, University of Nevada, and Pacific Northwest National Laboratory. Various equipment vendors also participated. Held at Fluke Hall on the UW campus, the two-day event featured facility tours, panel discussions, and breakout sessions focused on core facility management, onboarding strategies, and training effectiveness. Attendees also enjoyed networking during a group dinner.

Regional Networks and the Next Network

The group discussed the future of regional networks in the context of workforce development and potential funding challenges. Gary emphasized the importance of training in vacuum technology and troubleshooting, and Ana stressed the value of regional networking for identifying potential partners. The participants agreed that maintaining regional networks is crucial, whether or not there is a future NNCI proposal, and discussed potential funding sources, including state-level support and industry partnerships.

Darick and Andrew are exploring external support to sustain future gatherings. One promising direction is to partner with Micron and Boise State University to host the next meeting in Boise, Idaho. This would expand regional engagement, strengthen industry-academic collaboration, and ensure continued knowledge-sharing among nanofabrication professionals. They are also hoping to work more in regional workforce development, with the NWNLA network supporting schools building new cleanrooms and providing cleanroom access to schools without cleanrooms.

Ana emphasized that maintaining engagement in regional networks is important for several reasons. It provides support when equipment is down or specialized personnel are needed, and it allows sharing of unique resources with regional partners who may not have access to them. Being actively connected regionally also helps identify potential collaborators for proposals, expand the user base in our core facilities, and create workforce development opportunities. Additionally, staying engaged in these networks helps track ongoing research activities, identify trends, and foster collaborations, ensuring that institutions, and researchers, remain aware of who is doing what kind of research in the region.

The team discussed the benefits of regional networks, with everyone expressing concerns about funding distribution. Everyone agreed that regional collaboration helps with partnerships and building relationships between facilities, and that maintaining these networks is important despite potential funding challenges. 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	Brian Olmstead
Southeastern Nano Facility Network	SENIC	Gary Spinner, Walter Henderson
Mid-Atlantic Nanofab Managers Meeting	MANTH	Eric Johnston
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

6.3. Etch Processing

The leadership team of the Etch Working Group comprises Durga Gajula (Georgia Tech), Lavendra Mandyam (Stanford University), Vince Genova (independent consultant), and Ling Xie (Harvard University). The mission of this working group is to provide a forum for etch personnel from all NNCI sites and affiliates to share information on a wide range of topics, including etch capabilities; established and emerging etch processes; equipment maintenance and preventive care; baselining initiatives; equipment modifications; and the acquisition of new etch tools and technologies. We host both virtual and in-person meetings within and beyond the NNCI network and collaborate with national and international etch experts to address the growing challenges of plasma etching at the nanoscale.

Major activities undertaken by the team in 2025 included: (i) organizing the NNCI Etch Symposium, (ii) collaborating with the Australian National Fabrication Facility (ANFF) to launch an international webinar series on plasma etching, and (iii) initiating the Global Nanolab Etch Working Group.

(i) The 2025 NNCI Etch Symposium was co-hosted by Harvard CNS and MIT.nano and held on the MIT campus June 30-July 2. Dr. Jorg Scholvin and Kelly Gavin from MIT.nano served on the organizing committee. Major topics covered at the symposium included:

1. Device driven plasma etch challenges
2. Advances in Atomic Scale Processing
3. Advances in Cryogenic Etching
4. Plasma characterization, diagnostics, and manipulation
5. Modeling/Artificial intelligence/Machine Learning for Plasma Etching
6. Sustainability in plasma etching

In several respects, this symposium reached new heights compared with previous events. First, the oral presentation program encompassed a broader range of topics, with greater emphasis on the frontiers of dry etching technologies. These included advancements in atomic layer etching, cryogenic plasma etching, ultra–high aspect ratio feature etching through combined ALD and ALE, and pulsed plasma processing, all developed in recent years to address the challenges of nano- and atomic-scale fabrication and vertical 3D silicon transistors.

Second, the symposium featured a more diverse group of speakers, including leading professors, graduate students, and senior managers and engineers from major industry players, such as Applied Materials and Lam Research. Modeling and simulation also emerged as key highlights of the event.

Third, the two panel discussion sessions were particularly noteworthy. It was an honor to host top scholars and experts in the field as panelists, who provided in-depth, comparative discussions on fundamental questions in plasma etching.

There were approximately 170 attendees on site, and about 60 additional participants joined online.

Vladimir Bulović, Director of MIT.nano, delivered a keynote address and officially kicked off the symposium.

Top scholars in the plasma etch field served as panelists. From left to right: Prof. Christophe Vallée from the University at Albany, Prof. Mark Kushner from the University of Michigan, and David Coumou, Managing Director of Core R&D at Applied

Eighteen companies participated in the exhibit and provided financial support for the event.

NNCI staff members and students joined the poster session.

(ii) The NNCI etch leadership team held virtual meetings with the ANFF team to discuss webinar topics and recommend speakers. Below are the finalized program and schedule. The first lecture took place on November 5, 2025, with approximately 60 attendees.

Dry Etch Webinar Series

	Melb, Syd	Adelaide	Perth	Berlin	NY	LA	Topic / Title	Facilitator / Speaker
W1	AEDT 11:00 06.11.25	ACDT 10:30 06.11.25	AWST 08:00 06.11.25	CET 1:00 06.11.25	EST 19:00 05.11.25	PST 16:00 05.11.25	50 Years of Reactive Ion Etching in Microelectronics	Christophe Vallee (University at Albany)
W2*	AEDT 16:00 27.11.25	ACDT 15:30 27.11.25	AWST 13:00 27.11.25	CET 6:00 27.11.25	EST 0:00 27.11.25	PST 21:00 26.11.25	The Physics and Chemistry of Plasma Etching (Part I)	Henri Jansen* (DTU)
W3*	AEDT 16:00 11.12.25	ACDT 15:30 11.12.25	AWST 13:00 11.12.25	CET 6:00 11.12.25	EST 0:00 11.12.25	PST 21:00 10.12.25	The Physics and Chemistry of Plasma Etching (Part II)	Henri Jansen* (DTU)
W4	AEDT 12:00 29.01.26	ACDT 11:30 29.01.26	AWST 09:00 29.01.26	CET 2:00 29.01.26	EST 20:00 28.01.26	PST 17:00 28.01.26	Atomic Mechanisms During Plasma Etching	David Graves (Princeton University)
W5	AEDT tbd .03.26	ACDT tbd .03.26	AWST tbd .03.26	CET tbd .03.26	EST tbd .03.26	PST tbd .03.26	Using the right tool for the job: Comparing ALE, RIE and IBE	Nick Chittock (Oxford Instruments Plasma Technology)
W6	AEST 11:00 08.04.26	ACST 10:30 08.04.26	AWST 9:00 08.04.26	CEST 3:00 08.04.26	EDT 21:00 07.04.26	PDT 18:00 07.04.26	Helicon Double Layer Thruster: A radiofrequency plasma source with many applications	Christine Charles (ANU)

(iii) In early November 2025, the Etch Working Group leadership team received an email from the Global Nanolab initiative committee about an opportunity to connect with etch staff from ANFF and EuroNanoLab. The team responded promptly, first holding an internal virtual meeting, followed by a joint meeting with the EuroNanoLab etch group leaders on December 5. The ANFF representative was unable to attend because she is currently on leave.

At this meeting, the NNCI Etch Working Group presented its major activities from the past 20 years, and the EuroNanoLab group did the same. We then agreed to meet monthly to further explore potential collaboration opportunities.

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, D. Prescott)

Montana State, (J. Heinemann)
Virginia Tech (D. Leber, M. Hollingsworth)
University of Chicago (P. Duda, S. Kaehler)

6.4. Evaluation and Assessment

The Evaluation & Assessment working group collaborated during Year 10 to gather historical surveys and evaluations of educational outreach, economic impact, and program evaluation tools. While the original thought was to archive these documents on the NNCI website, it was noted that the website would likely not be hosted past the expiration of the NNCI funding. Therefore, these tools will be archived in a Dropbox folder for future networks to review as needed.

Members: Jessica Hauer (NCI-SW, Chair), Tonya Pruitt (NanoEarth, Co-Chair), Dan Ratner (NNI), Ana Sanchez Galiano (KY Multiscale), Carolyn Plumb (MONT), Wendy Barnard (NCI-SW & ASU CREST), and Karen Gordon (NCI-SW & ASU CREST)

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 9 along with the lead and participating sites. In 2022, a new community focused on Microelectronics and Semiconductors was added, as a partial response to increasing national interest in this area. The Research Communities provided an overview of their past and planned activities at the 2023 NNCI Annual Conference, and these can be viewed along with other resources on the Research Community page of the NNCI website.

Table 9: NNCI Research Communities

Research Community	Leader(s)
Nanotechnology Convergence	Jacob Jones (RTNN)
Nanoscience in the Earth and Environmental Sciences	Trevor Thornton (NCI-SW), Mitsu Murayama (NanoEarth),
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.

During 2025, due to wind down of NNCI expenses and the changes in the national research funding landscape, NNCI Research Communities were mostly inactive and so no reports are provided here.

The **Research Community for Nanotechnology Convergence** did have some activity during NNCI Year 10. The RTNN leads this effort, in collaboration with KY Multiscale, SDNI, and NCI-SW. Nanotechnology facilities play central roles in enabling national-priority topics requiring convergence approaches, e.g., quantum information science (from synthesis of quantum structures through computer science and application in diverse fields like finance) and rules of life (involving the integration of nanoelectronics with biological components). On June 10, 2025, the RTNN and the Research Community for Nanotechnology Convergence hosted the Soft Matter Infrastructure Symposium (SMIS), which brought together over 60 participants with needs and expertise in soft matter characterization to facilitate building a national network of open-access shared instrumentation facilities for characterization and fabrication of soft materials and recorded collective thoughts and insights on topics including University-Industry Engagement, Unmet Needs in User Research Services, Best Practices and Management, and Emerging/Needed Capabilities.

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 and international conferences.* In the past, the Coordinating Office hosted an exhibit booth at conferences such as TechConnect or MRS. This activity was suspended in 2020 and 2021 due to pandemic-related travel restrictions and was discontinued due to lack of impact. However, during the past year, NNCI was represented at TechConnect 2025 through sessions organized by Matt Hull for the NTEC program. NNCI also had a significant presence with 13 attendees and 9 presentations at the 2025 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

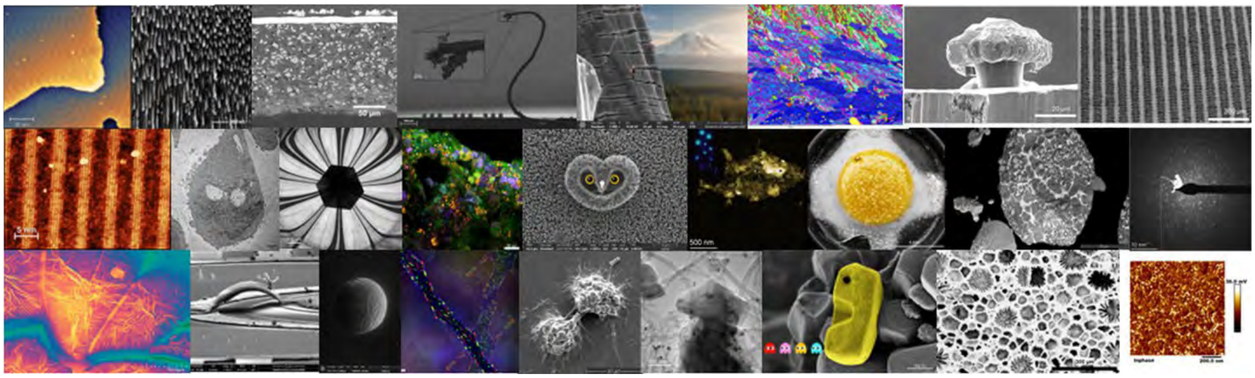
During the first year of the NNCI Coordinating Office, one of the main activities was the creation of a web portal (www.nnci.net) to provide a comprehensive list of tools and experts available within the network for both user recruitment and support. The design of a new, comprehensive website was predicated 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, 2025, the video had been viewed nearly 2,800 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
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. 23-Oct. 7, 2025, 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 2025 there were approximately 47,000 visitors to the website, a 5.6% increase over the prior year but a 22% decrease from the peak in 2021 (likely related to pandemic era online activity). As in previous years, a large spike in visitors was observed in October, primarily to participate in the image contest voting. For the year, 98% were new visitors with 52% from the United States, consistent with previous years. There were more than 98,000 pageviews, which is a 13% increase from the prior year. The average session duration was only 34 seconds, less than previous years. During this time period, the top ten pages visited are shown in Table 10 below. These ten pages account for 41% of all pageviews, much less than previous years, indicating a broader distribution of interests by site visitors. In general, the top pages include the education-related pages ("careers", "what is nano", and "how small is nano" pages), consistent with previous observations.

Table 10: NNCI Website Page Visits (2025)

Page	# Pageviews in 2025	%Change from 2024	% Pageviews in 2025
/	11,008	-7.3%	11.2%
/careers-nanotechnology	5,938	-16.9%	6.0%
/research-experience-undergraduates	4,382	-8.7%	4.4%
/what-nano	3,731	-16.7%	3.8%
/plenty-beauty-bottom	3,134	-6.0%	3.2%
/how-small-nano	3,024	-36.2%	3.1%
/sites/view-all	2,809	-4.5%	2.7%
/search/tools	2,544	-4.8%	2.6%
/about-nnci	2,317	+9.8%	2.4%
/nnci-image-contest-2025-stunning	1,838		1.9%

Since the NNCI website's debut in late 2016, the growth in annual visitors and pageviews is shown in Figure 12 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 few years.

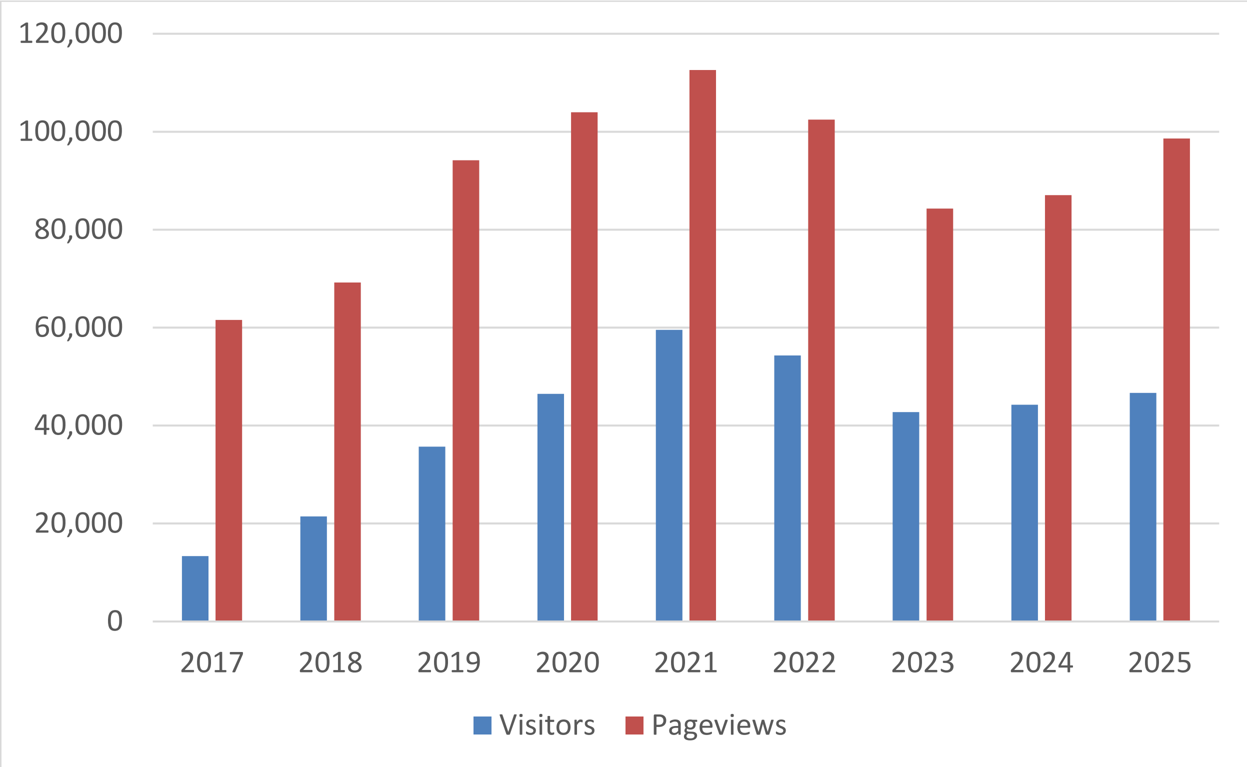


Figure 12: Annual NNCI Website Usage

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 13). The organic search rate of 45% is sharply down from 2024 (60%) and decreased from a peak of 67% in 2020. On the other hand, direct acquisition increased to 47%. The referral route increased slightly while the social route decreased slightly from 2024, but these continue to remain relatively minor acquisition routes for website visitors.

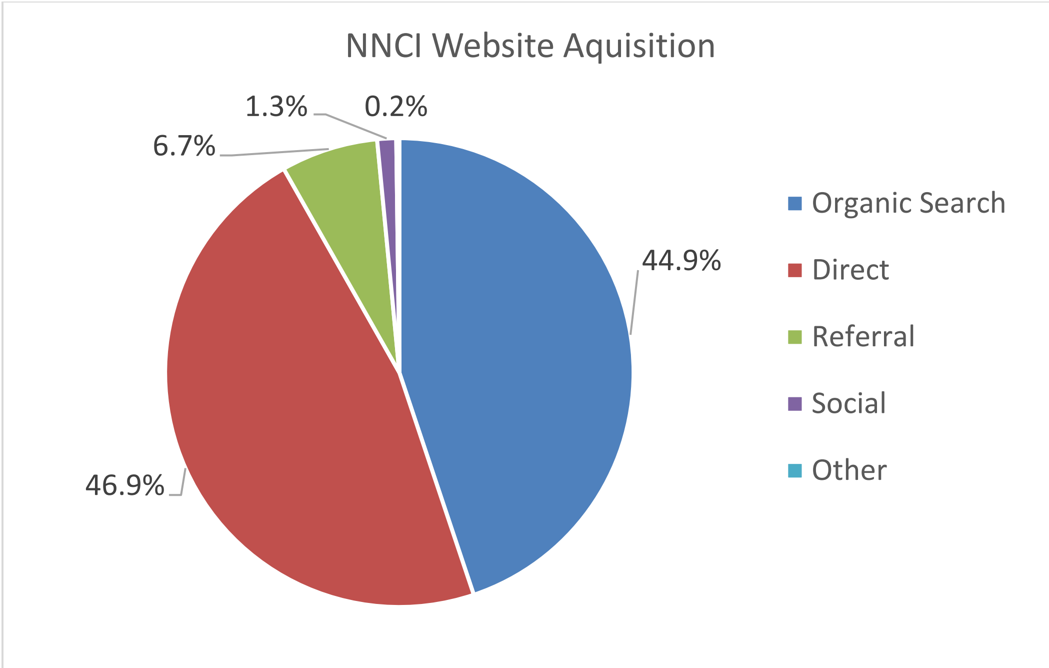


Figure 13: Site Acquisition (how visitors get to the website) for www.nnci.net (2025)

The geographic distribution of visitors to the website is illustrated by the map in Figure 14 below indicating the nearly complete global reach. The top ten locations of visitors are shown in Table 11 and these account for 87% of all visitors to the website. This past year saw a surge in visitors from China (136% increase) and Singapore (1,166% increase).

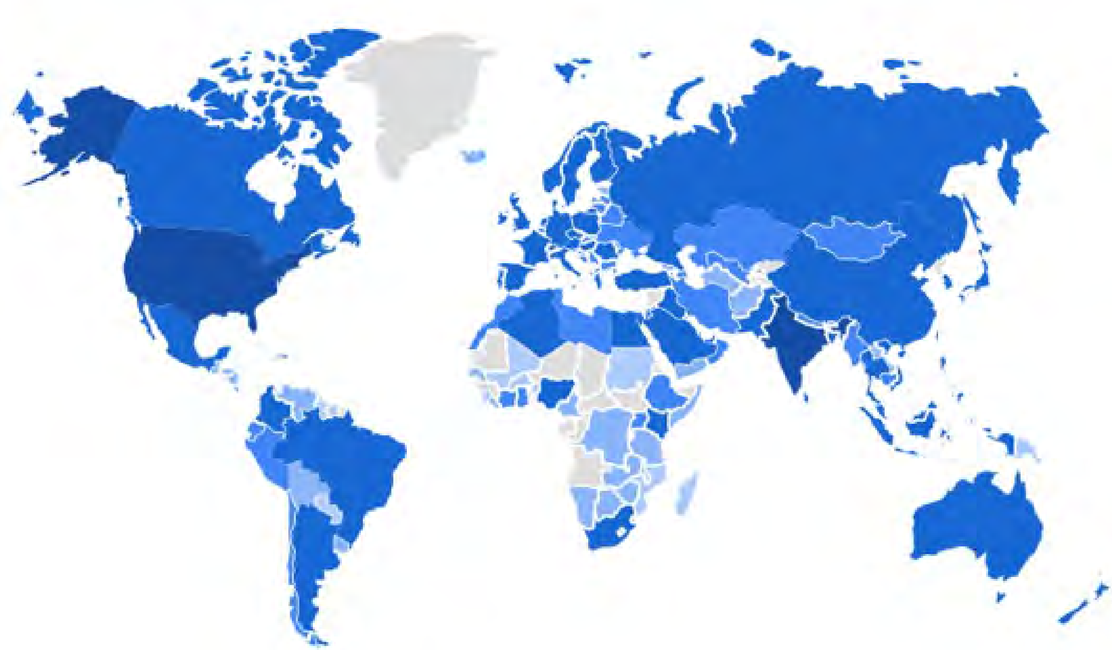


Figure 14: Geographic Distribution of Visitors to www.nnci.net (2025)

Table 11: NNCI Website Visitors by Location (2025)

Country	# Visitors	% Visitors
United States	24,081	51.6%
China	6,186	13.3%
India	3,736	8.0%
Singapore	2,608	5.6%
Germany	778	1.7%
Canada	758	1.6%
Philippines	673	1.4%
United Kingdom	650	1.4%
South Korea	515	1.1%
Thailand	515	1.1%

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 Washington are the top 5) 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. Based on input from the NNCI executive committee, the User Survey was not conducted in 2025.

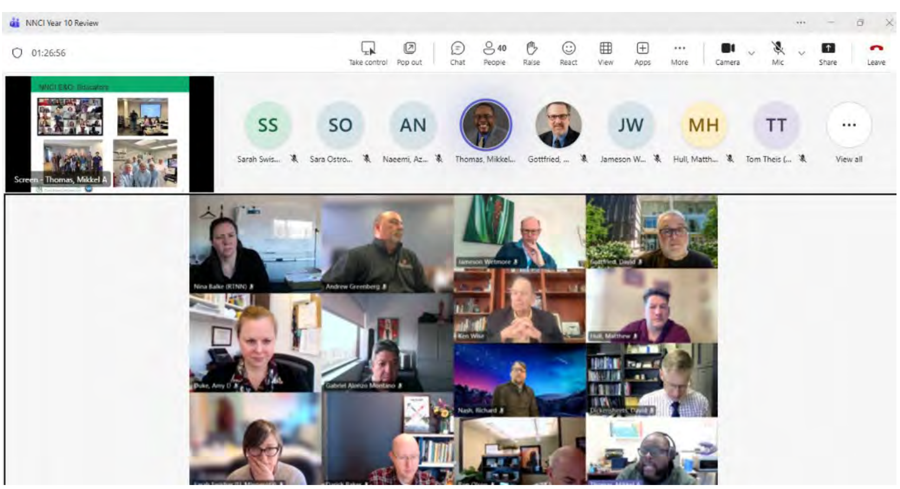
9. NNCI Annual Conference

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."

During 2025, the NNCI did not host an annual conference.

All Coordinating Office presentations, site reports, research community summaries, and other information from previous NNCI Annual Conferences (2017-2024) are provided, along with the full meeting agendas, on the NNCI website https://nnci.net/nnci-annual-conference.

In lieu of an annual conference, on January 28, 2026, the Coordinating Office hosted a virtual NNCI Year 10 Review. The 90-minute meeting included presentations by the Director and Associate Directors regarding Year 10 programs, activities, and facility usage as well as plans for the upcoming year (no-cost extension). Attendees of the meeting (45) included NNCI site leadership and staff from all 16 sites, members of the External Advisory Board, and NSF officials.



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. Ten NNCI sites submitted 25 entries for the "Plenty of Beauty at the Bottom" image contest in 2025.
6. Hosting summer REU students and participating in NNCI REU Convocation (Hosted in Aug. 2025 by SDNI)
7. 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
8. Participating in the NNCI Nanotechnology Entrepreneurship Challenge (NTEC) competition, Innovator's Academy, and Showcase event
9. Providing content for the NNCI website
10. Participation in the NNCI Outstanding Staff Awards program
11. Discussions between site staff on equipment repair and maintenance issues
12. Dissemination and promotion of NNCI, network events, and opportunities (webinars, workshops, job postings, etc.) through electronic communications and other marketing
13. User referrals to other sites, via NNCI email list or responses to NNCI website contact form
14. Leadership of and participation in the NNCI Research Communities
15. Future of the NNCI Task Force: With the future of NSF funding for a nanotechnology facility network in jeopardy, NNCI created an ad-hoc group to develop plans to maintain a version of the NNCI network with alternate funding sources. Over the course of several months in 2025, more than 30 members from 14 NNCI sites met to discuss options. The discussions were tabled when NSF funding appeared more optimistic.

16. Global Nanolab: NNCI sent a delegation of 13 people (9 NNCI sites) to attend and present at the 4th European Nanofabrication Research Infrastructure Symposium (ENRIS) in Bologna, Italy (May 2025). One aspect of this conference was for NNCI leadership and staff to convene with other national networks: EUROnanoLAB, Australian National Fabrication Facility (ANFF), Canada's CMC Microsystems, and Japan's ARIM networks. One outcome of this event was the creation of Global Nanolab.

<u>Multi-Site Activities</u>

1. Hosting and participation in workshops and technical events supported or sponsored by the NNCI Coordinating Office or individual NNCI sites, not including local seminars and webinars:
    a. CNS, in collaboration with the Lab14 Group, organized the "Direct Writing and Integration Symposium," hosted at Harvard University June 4–6, 2025.
    b. RTNN organized the "2025 Soft Matter Infrastructure Symposium" (virtual) on June 10, 2025
    c. NNCI 5th Etch Symposium, June 30-July 2, 2025, hosted by Harvard CNS and MIT.nano. The program was organized by Etch Working Group and supported by MIT's Dr. Jorg Scholvin and Kelly Gavin. The event had 170 attendees on site and approximately 60 additional participants joined online.
    d. NCI-SW (ASU) organized a workshop in collaboration with Silvaco entitled, "Device TCAD Hybrid Workshop: From Fundamentals to Applications," which was held on January 16, 2026. Nearly 120 people attended the event.
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. They also refer students to online resources (e.g., Stanford's online course, which complements the RTNN course, as it goes into further detail and offers more intensive training videos on specific tools).
    b. nano@stanford partnered with Prof. Dohyung Kim (Univ. Pennsylvania) to support a research project not currently feasible using equipment at MANTH. N. Mehta mentored a team of nano@stanford interns in developing processes to grow abnormally thick oxides and polysilicon.
    c. NNI's WNF has been involved in remote projects with Montana State University.

   d. SDNI continues interactions with other NNCI sites to enable nanofabrication capabilities, discuss best practices, and service the nanotechnology community.

3. Staff technical interactions:
   a. CNF has user project support, workforce, development and technical interactions; mostly with nano@stanford, University of Washington (NNI), MANTH, and CNS.
   b. MONT and NNI are continuing to collaborate on managing the NorthWest Nano Lab Alliance.
   c. MONT has been using the headsets for virtual reality training content from Cornell's CNF nanofabrication facility. The content is comprised of several interactive modules that take the viewer through the entire microfabrication process.
   d. nano@stanford and NNI collaborated on technician training through the Microelectronics Commons, NW-AI-Hub's working group. This included adopting an IEEE microcredentialing program, with NNI staff training nano@stanford staff on how to run the program.
4. Research Experience for Teachers (RET) program. Georgia Tech, (lead institution), with Univ. Minnesota and Univ. Nebraska were funded by NSF to hold program activity during the summers of 2025-2027. During the summer of 2025, the first cohort consisted of 4 educators hosted at each site (8 high school teachers and 4 community college instructors).
5. Partnership in the NSF AccelNet project "Global Quantum Leap" (GQL) (MiNIC is lead, with CNF, SENIC, SHyNE). GQL establishes an international network-of-networks linking the NNCI to quantum networks in Asia and Europe. The GQL supports a webpage (www.globalquantumleap.org), Twitter, and LinkedIn pages. GQL's main goal is to train nano- and quantum scientists to work in diverse, international environments. The 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. This past year GQL organized student / faculty exchanges coordinated and funded through the GQL; bootcamps, short courses for K-12, undergrads, teachers and professionals; planning is underway for our third workshop on Quantum Engineering Infrastructure (WQEI3), held as a one-day in-person meeting the Sunday before the American Physical Society 2026 meeting in Denver, Colorado, with participants from industry, the national laboratories, funding agencies and academia.
6. North Carolina Collaborations: Due to close geographic proximity, RTNN collaborates with JSNN (a partner of the SENIC Site in the NNCI) in several ways, including organization and participation in the Carolina Science Symposium and collaboration outreach events, when possible. 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).” All of the RTNN universities are members of the Southeastern Nano Facility Network (SENFN) organized by SENIC/Georgia Tech.

7. 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. Univ. Washington and Montana State University jointly hosted the third meeting of the Northwest Nanotechnology Laboratory Alliance (NWNLA) at the University of Washington Seattle campus August 7-8, 2025.
    b. Nano Summer Institute for Middle School Teachers (NanoSIMST): This weeklong workshop, originally developed by Stanford, was implemented in 2025 at most 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 develop a nationwide virtual NanoSIMST program, which extends the reach to more low resource communities where there is an increased diversity in the student population. Ten NNCI sites (Stanford, SHyNE, MONT, CNS, RTNN, MiNIC, SDNI, NCI-SW, KY Multiscale, and NanoEarth) sponsored 49 teachers from their local areas.
    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).
8. Participation in SEI Programs: Jamey Wetmore coordinates the efforts of the four primary SEI sites at NC State, Georgia Tech, UT-Austin, and ASU, to maximize the benefits of their work across the network. Each has agreed to develop a program that other NNCI sites, who may have less access to SEI expertise, can plug into.
9. NCI-SW, RTNN, NNF, SDNI, nano@stanford, and SENIC participate in the Nanotechnology Applications and Career Knowledge (NACK) Network’s Remote Access Instrumentation in Nanotechnology (RAIN) coordinated by Penn State University.
10. Several sites (ASU, Georgia Tech, Cornell, and UC San Diego) collaborate with Penn State 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 offers a 12-week program, where each site provides laboratory access to students from a local community/technical college.

11. Several sites participate in education programs and meetings organized by MNT-EC (Micro Nano Technology Education Center), NACK (Nanotechnology Applications and Career Knowledge) network, and MNTeSIG (Micro Nano Tech Education Special Interest Group).
12. 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.

Site Activity on Behalf of the NNCI

1. CNF publishes "Nanooze", and, in addition to direct distribution to classrooms, distributes it to all NNCI sites for use in their outreach activities.
2. Georgia Tech (SENIC) maintains the current NNCI website. RTNN receives requests from the Spanish language "Contact Us" form and responds to all inquiries made via this method.
3. CNF manages International Research Experiences in Japan: the IRES program that proivdes a second-year research experience abroad from among the highest rated REU interns from the previous summer and the International Research Training Experience (IRTE) as part of the Global Quantum Leap AccelNet program.
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 on the "Pulse of the Planet" long form podcast. 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. "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 SDNI (August 2025). The 3-day event for more than 50 REU students included oral presentations, poster sessions, keynote speakers and panel discussions, and social events.
7. Until recently, KY Multiscale hosted the UGIM website (now hosted by UC Berkeley) and NNCI staff are members of the UGIM Steering Committee (Aebersold/KY Multiscale and Tang/Stanford). nano@stanford will be the host for the 2026 UGIM Conference.
8. nano@stanford provides organizational support for the NNCO-Nanoeducators Forum and coordinates the "NNCI Educators" email distribution list and curated monthly bulletins that

contain nano-related resources for teachers and students. Yves Theriault (SDNI) made a presentation to the group in Jan. 2025.

9. Mikkel Thomas (SENIC, CO) has met monthly with Jared Ashcroft, Director of the NSF-supported Micro Nanotechnology Education Center, to discuss mutual interests.
10. David Gottfried (SENIC, CO) had a monthly meeting with the Director and Associate Director of the National Nanotechnology Coordination Office, until that office was re-organized in mid-2025.
11. David Gottfried (SENIC, CO), Mary Tang (nano@stanford), and Gerald Lopez (MANTH) serve on the steering committee and ongoing discussions around the creation of Global Nanolab.

10.2. Regional Facility Networks

Initiated by efforts at MiNIC and MANTH, a number of sites within the NNCI have established informal networks of regional fabrication and characterization facilities to provide mutual assistance, develop best practices, and provide staff networking opportunities. The map below (Figure 15) shows the updated geographic distribution and regional clustering of these networks, along with a brief description of each. During 2023, a new working group to communicate and share best practices among those sites which support regional networks was formed and has been meeting (Section 6.2).

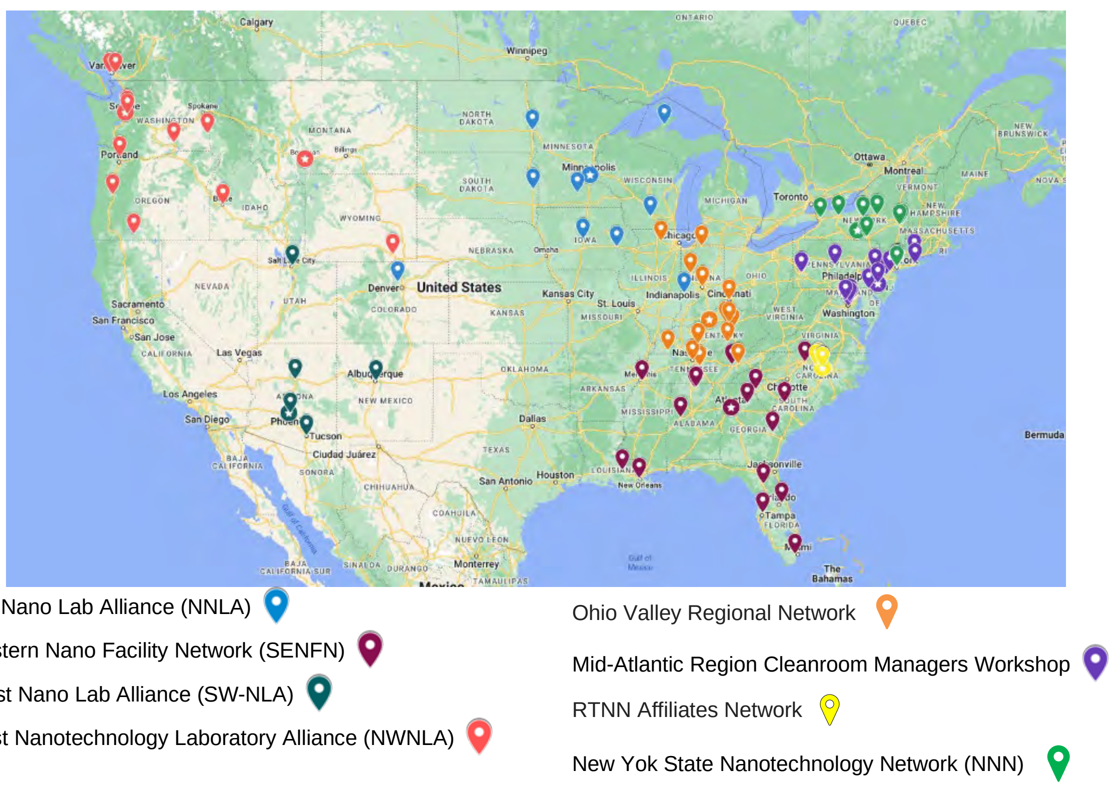


Figure 15: NNCI Regional Facility Networks

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

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

MANTH: The **Mid-Atlantic Region Cleanroom Managers Workshop** began as a gathering of lab managers from the academic and government cleanroom facilities located in the triangle formed between Washington DC, Brookhaven National Laboratory in NY, and Pittsburgh, PA. The Singh Center for Nanotechnology Quattrone Nanofabrication Facility staff at MANTH created these semi-annual meetings in 2016 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 10 live events in 2023-2025 averaged around 32 (range:8-70). Video recordings are then posted on the NNCI YouTube channel (see below). During 2025 only one seminar was held:

Date: May 7, 2025
Speaker: Deborah Stine (Director, Science and Technology Policy Academy)
Topic: "Behind the Curtain: What is happening in US Science & Technology Policy Today?"

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 421 current subscribers (~70 new added in 2025) and 2,650 views during 2025, a 13% decrease compared to 2024. This was expected as only one new webinar video was added in 2025 (see above). Analytics of the top video content during 2025 is shown in Table 12 below, with newly-added videos in bold. Since the start of the channel, there have been more than 14,700 total views with the top 5 videos including those discussing careers, "What is the NNCI", and computation videos from Shela Aboud (Synopsys) and Eric Guichard (Silvaco).

Table 12: NNCI YouTube Video Analytics (2025)

Video*	Views	Average View Duration
The Evolution of Process TCAD in Semiconductor R&D and Manufacturing (Shela Aboud, Synopsys)	489	5:17 (8.9%)
Careers in Nanotechnology: Opportunities for STEM Students (Jim Marti, MiNIC)	379	2:11 (16.0%)
Silvaco Technology CAD, Background, Overview & Future" (Eric Guichard, Silvaco)	262	11.43 (20.8%)
Behind the Curtain: What is Happening in US Science & Technology Policy Today? (Deborah Stine, Science & Technology Policy Academy)	**216**	**14:24 (23.1%)**

What is the NNCI?	206	1:21 (36.9%)
Antiferromagnetic Tunnel Junctions for Spintronics" (Evgeny Tsymbal, Univ. Nebraska-Lincoln)	149	6:20 (9.9%)
From Lab to Launch: Stanford's Entrepreneurial Ecosystem	134	7:19 (12.1%)
X/Nano: The Enabling Potential of a Career in Nanoscience (Matt Hull, NanoEarth)	134	4:13 (14.5%)
Simulation Software Next Door (Dragica Vasileska, ASU)	107	8:32 (13.9%)
Semiconductor Workforce Development through Immersive Simulations on nanoHUB.org (Gerhard Klimeck, Purdue Univ.)	77	13:43 (23.9%)

*Videos added in 2025 are bolded.

10.5. NNCI Outstanding Staff Awards

During 2025, the NNCI Coordinating Office organized the eighth 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 September 2025 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 will receive an engraved desktop plaque and recognition on the NNCI website.

<u>Education and Outreach</u>

- Kyle Nowlin (Director of Advanced Microscopy, University of North Carolina-Greensboro, SENIC)

"Meets learners where they are and elevates them…Demystifying advanced imaging for thousands of users"

- Lydia Parks (Research and Development Engineer III, Duke University, RTNN)

"Engaged more than 1,200 K-12 students last year…Not only showed them images of their own particles, but also explained TEM principles at a level they can grasp"

Technical Staff

- Garry Bordonaro (Research Support Specialist III, Cornell University, CNF)

"Shares his knowledge and is regarded as the go-to-person capable of resolving complex technical issues "

- Jeremy Heath (Cleanroom Senior Technician, University of Texas-Austin, TNF)

"Determining, developing, and implementing a temporary solution to an equipment failure which the vendor could not"

User Support

- Xinwei Wu (Research Associate, Cornell University, CNF)

"Frequently troubleshoots alongside users, developing creative, innovative solutions to technical challenges."

- Christina Newcomb (SPM Lab Manager, Stanford University, nano@stanford)

"Strengthens the broader user community – hosting regular SPM and Raman office hours"

10.6. Global Nanolab

During a visit to Australia in December 2024 by Coordinating Office Director David Gottfried to attend the International Conference on Research Infrastructures (ICRI) discussions began with Australian National Fabrication Facility (ANFF) CEO Jane Fitzpatrick and EuroNanoLab representative Ondřej Hradil about how these nanofacility networks could better collaborate for the benefit of staff and users. Initial concepts for this collaboration were based on similar international efforts Global Bioimaging and the National Ecological Observatory Network.

It was agreed that a workshop to further develop the concept would be organized as a pre-meeting for the European Symposium on Nanofabrication Research Infrastructure (ENRIS) hosted by EuroNanoLab in May 2025 in Bologna, Italy. Delegates from the three original partners, plus CMC Microsystems (Canada) and the Advanced Research Infrastructure for Materials and Nanotechnology in Japan (ARIM) were encouraged to attend. NNCI organized a delegation of 13 people from 9 NNCI sites to attend the workshop and present at the conference, with funding provided by the Coordinating Office, the AccelNet Global Quantum Leap project, or NNCI sites. The agenda for the workshop is shown here and a photo of the group is below.

Global Nanolab Collaboration Workshop	
Welcome by EuroNanoLab chair	Vittorio Morandi
Presentations from each network • Structure • Size and scope	Vittorio Morandi Jane Fitzpatrick David Gottfried

• Brief capabilities or areas of technical strength • One example of a common problem solved through a local initiative	Yoshio Mita Gordon Harling
Presentation from Global Bioimaging • how they got together • what the group does above and beyond an informal network • what the value of the formal structure is	Yara Reis, Strategic Alliances Manager
Development of a 'why' statement. Why are we doing this and what is the purpose of it. (Mission and Vision)	Jane Fitzpatrick
Breakout groups to come up with possible programs that could be coordinated in this partnership. 1. Technical Exchange (sending staff) 2. International Working Groups 3. Education and Training (mentoring, video tutorials, webinars) 4. Programs for low to middle income countries (requires funding sources) 5. Joint conference and how to integrate with UGIM and ENRIS	Group moderators: Vittorio Morandi Jane Fitzpatrick David Gottfried Yoshio Mita Gordon Harling
Presentations in plenary on breakouts Next steps (name, white paper, visual identity, …)	Ondřej Hradil

After further discussion, a steering committee was created it was agreed that the group would meet virtually on a semi-monthly basis and again in-person at the UGIM meeting (July 2026 at

Stanford). It is planned that additional fabrication networks from the international community will be contacted and invited to attend the next meeting at UGIM.

The Global Nanolab steering committee (January 2026) consists of:

ANFF
Jane Fitzpatrick
Chris Gourlay

ARIM
Yoshio Mita
Noriko Kawai

CMC Microsystems
Gordon Harling

EuroNanoLab
Vittorio Morandi
Andris Anspoks
Michal Urbánek
Anna Rissanen
Ondřej Hradil

NNCI
David Gottfried
Gerald Lopez
Mary Tang

Over the course of several followup meetings in 2025 the group developed a name, **Global Nanolab**, and visual identity, as well as a website: https://globalnanolab.org/. Training resources available online from each of the networks were collected and have a page on the Global Nanolab website. In addition, working groups in Etch, Lithography, and Deposition from the member networks were connected to each other and have been developing plans to work collaboratively. From the website, the following describes Global Nanolab's mission and vision:

"Global Nanolab is an international consortium of open-access nanoscale fabrication and characterisation facility networks (a network of networks) dedicated to advancing research, innovation, and collaboration in nanotechnology. By connecting world-class cleanrooms, laboratories, and expertise, Global Nanolab creates an ecosystem that supports technical staff networking, sharing of training resources, and knowledge exchange. The consortium enables access to state-of-the-art equipment, standardised processes, and best practices, to empower academic and industry researchers to accelerate breakthroughs in fields such as microelectronics, quantum information technology, advanced materials, biotechnology, and sustainable energy.

Our Purpose: The Global Nanolab exists to leverage our collective expertise to improve our ability to have local impact.

Our Vision: Global Nanolab is recognised by all of our members as delivering value across common challenges."

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, 2024 - Sept. 30, 2025)

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 10)

	NNCI Network	NNCI Sites Mean (Min - Max)
Unique Facility Users	15,263	954 (280 – 1,962)
Unique Internal Users	11,341	709 (224 – 1,661)
Unique External Users	3,922 25.7%	245 (52 – 621) 25.5% (11.7% – 52.2%)
External Academic	1,442	90 (11 – 329)
External Industry	2,128	133 (28 – 315)
External Government	308	19 (0 – 236)
External Foreign	44	3 (0 – 8)
Average Monthly Users	5,832	365 (88 – 909)
New Users Trained	5,163	323 (43 – 878)
Facility Hours*	1,203,051	75,191 (8,926 – 233,236)
Facility Hours – External Users	271,640 22.6%	16,978 (1,603 – 62,408) 23.4% (6.3% – 53.0%)
Hours/User*	78.8	71.0 (24.7 –124.4)
User Fees Internal Users External Users	 $33.0M $23.6M	 $2.06M ($255K – $7.19M) $1.47M ($65K – $4.88M)

*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 1-10 is shown in Table 14 below. As can be seen, most metrics show positive percentage increases from Year 9 to Year 10, although these are smaller than the increases from Year 8 to Year 9. Nearly all metrics have fully recovered or surpassed 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 10 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 6% 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 16 and 17. These results further illustrate the continued usage growth in Year 10, and the slower rate of usage growth since the pandemic recovery when compared to the first four years of NNCI. In addition, it is possible that some federal funding cancelations and/or constraints in 2025, may also have suppressed external access during NNCI Year 10. 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 1-10 NNCI Aggregate Usage Data

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Δ Year 9-10
Unique Facility Users	10,909	12,452	13,110	13,355	10,501	11,242	13,348	13,722	14,732	15,263	+3.6%
Unique Internal Users	8,342	9,276	9,731	9,503	7,668	8,449	9,967	10,079	10,904	11,341	+4.0%
Unique External Users	2,567 23.8%	3,176 25.5%	3,379 25.8%	3,852 28.8%	2,833 27.0%	2,793 24.8%	3,381 25.3%	3,643 26.6%	3,828 26.0%	3,922 25.7%	+2.4%
External Industry Users	1,413	1,669	1,870	1,961	1,529	1,619	1,882	2,044	2,094	2,128	+1.6%
External Academic Users	1,060	1,295	1,365	1,531	1,064	964	1,238	1,300	1,422	1,442	+1.4%
Average Monthly Users	4,429	4,911	5,001	5,292	3,654	4,381	5,112	5,296	5,679	5,832	+2.7%
New Users Trained	4,116	4,563	4,981	5,194	2,813	4,414	5,151	5,115	5,676	5,163	-9.0%
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	1,204,051	+2.7%
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%	271,640 22.6%	-0.2%
Hours/User	83	75	77	86	73	86	80	78	79	79	-
User Fees											
Internal	$20.6M	$23.0M	$23.6M	$23.2M	$16.3M	$21.9M	$24.4M	$26.0M	$29.4M	$33.0M	+12.2%
External	$13.5M	$14.5M	$16.9M	$20.5M	$13.1M	$17.8M	$20.1M	$19.7M	$22.4M	$23.6M	+5.3%

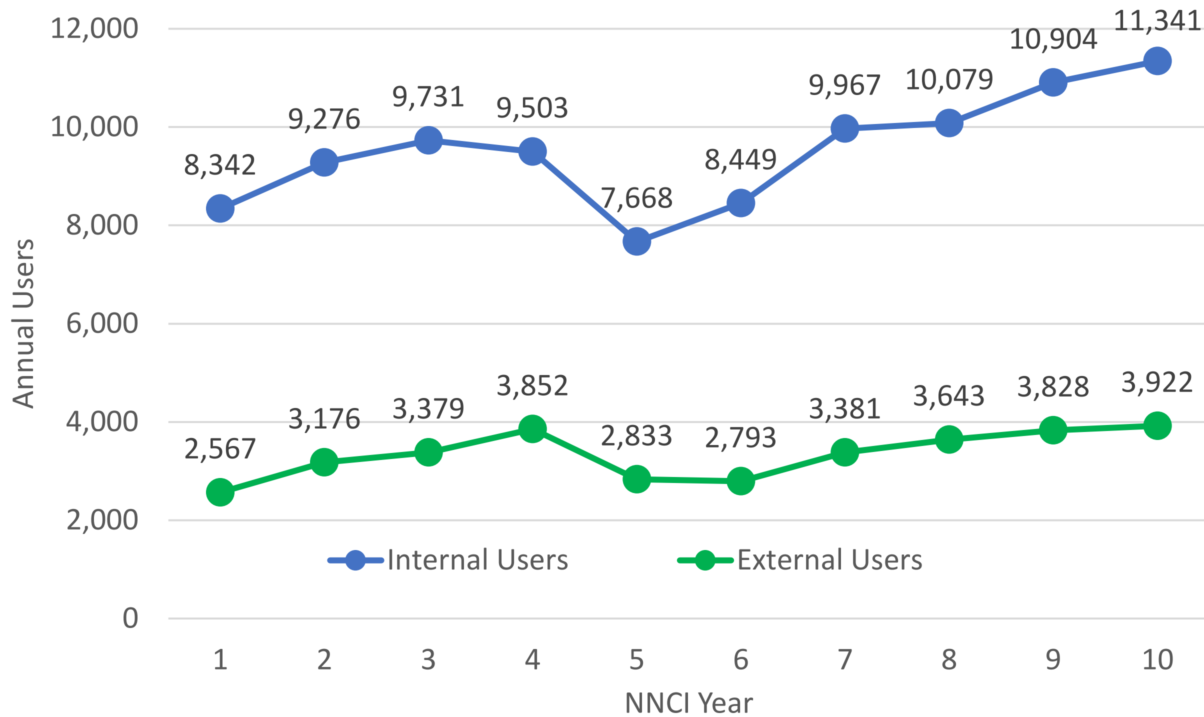


Figure 16: NNCI Users by Year

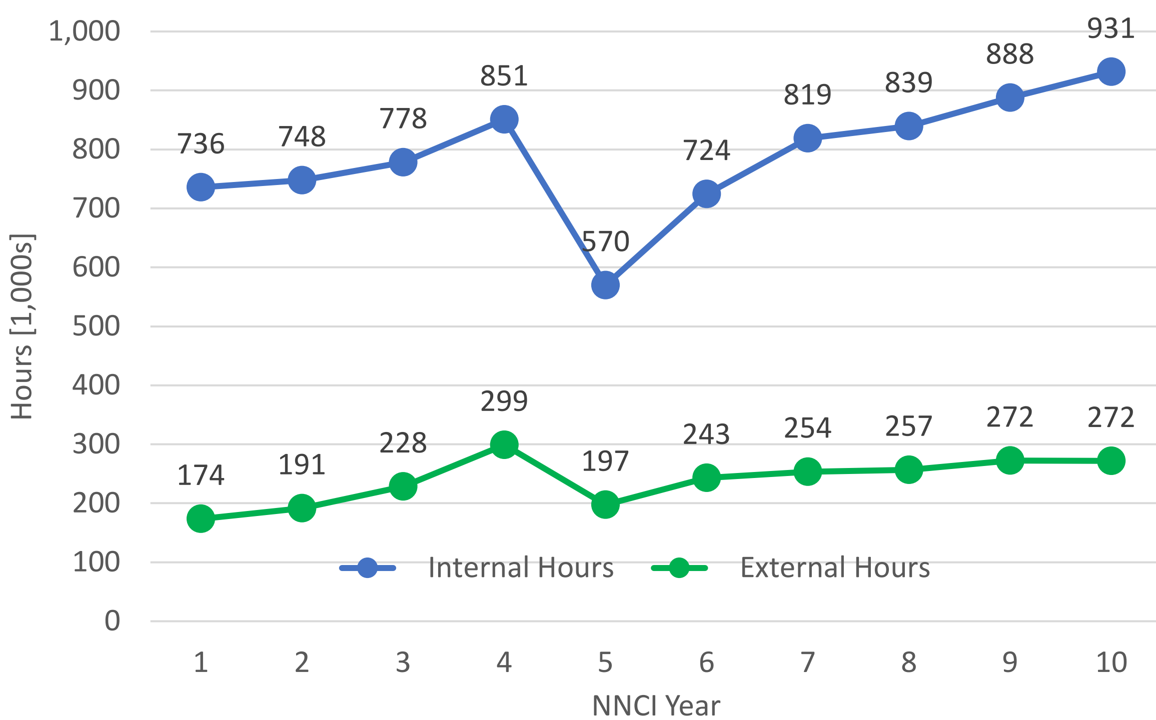


Figure 17: NNCI Usage Hours by Year

The 3,900+ Year 10 external users come from more than 1,100 distinct external institutions (full list shown in Appendix 14.1), including 233 US academic institutions from 47 states plus the District of Columbia (Figure 18), 616 small companies, 210 large companies, 24 US local/federal government organizations, 42 international institutions (from Europe, Asia, North America, South America, and Australia), and 26 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 139 companies that remain anonymous due to contractual requirements with an NNCI site and may or may not overlap with those listed in the appendix.

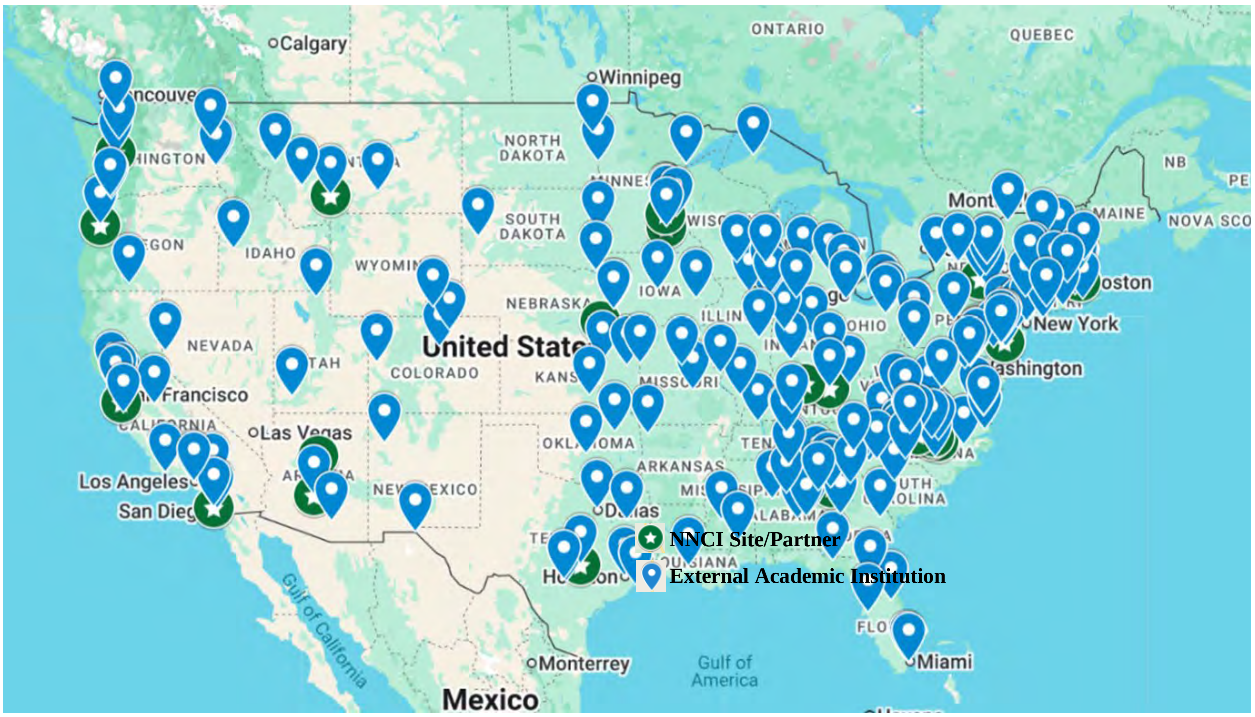
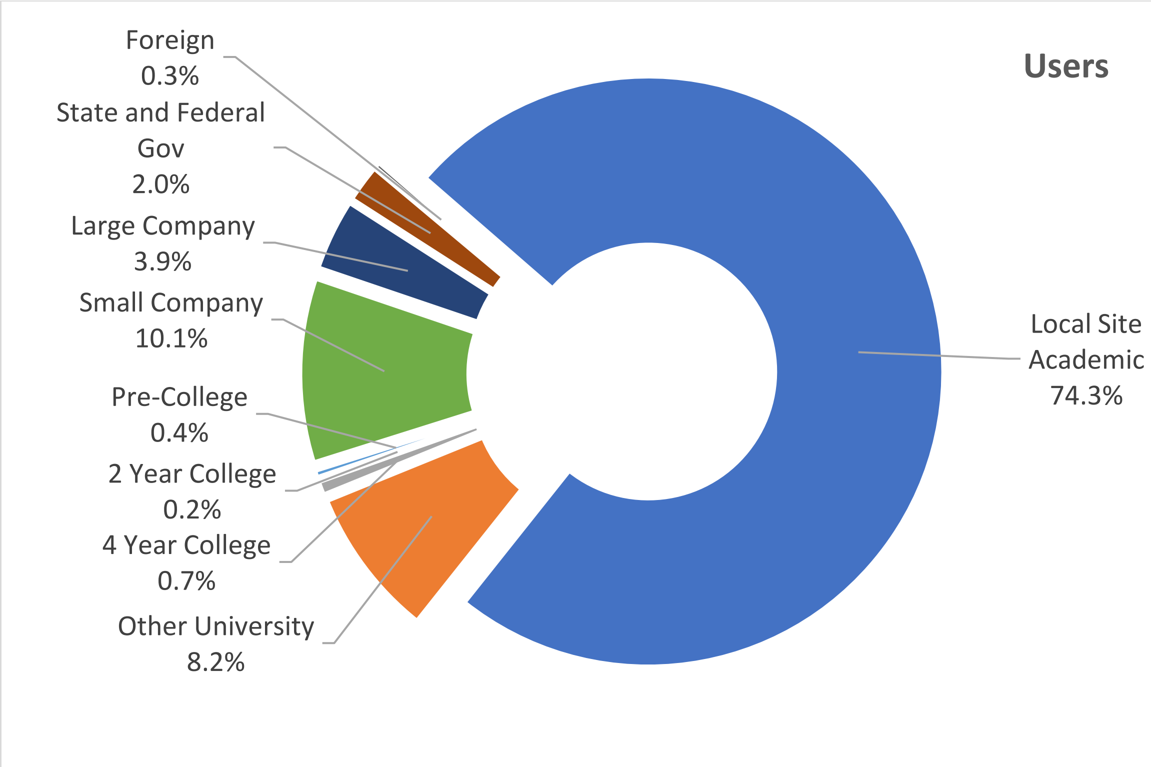


Figure 18: NNCI Year 10 US Academic Institutions (233 External)

Figure 19 shows the distribution of users and lab hours by affiliation for the entire network. Individual affiliation plots are shown for each site in the data of Section 12 below. External users make up 25.7% of total users and external hours are 22.6% of total hours. This difference between external users and hours (3.1%) has increased compared to last year but is in line with similar differences over the NNCI program lifetime. The slightly smaller fraction of external user hours compared to their numbers 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 a decline in Year 9.

External Academic Institution



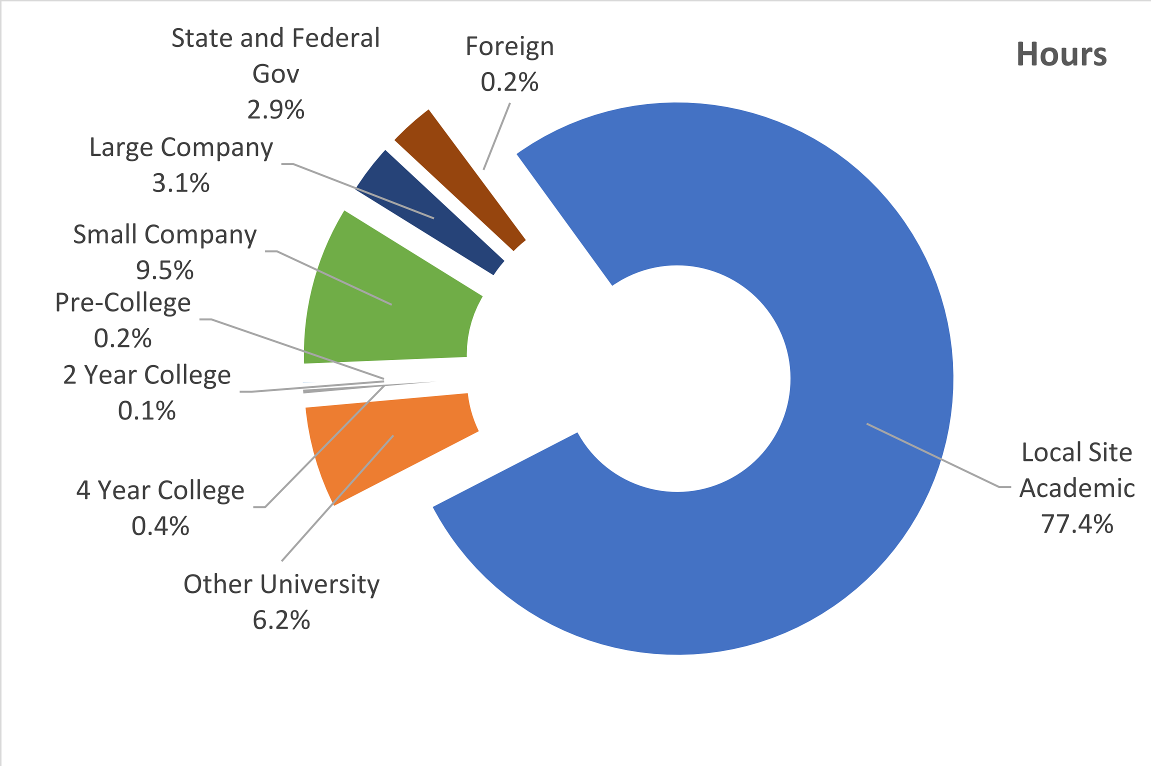


Figure 19: NNCI Users (top) and Usage Hours (bottom) by Affiliation (Year 10)

A comparison of Year 10 cumulative users (by affiliation) by site is provided in Figure 20 for all users and in Figure 21 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.

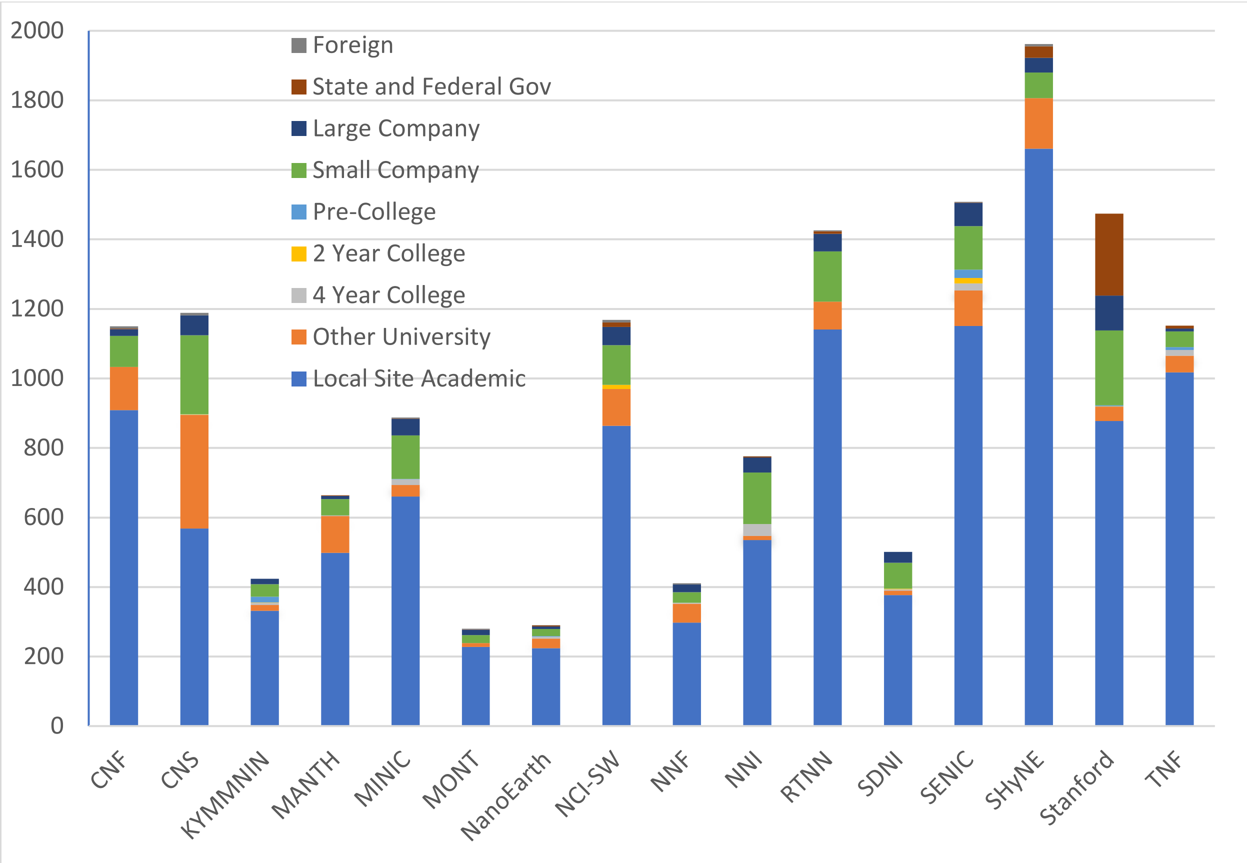


Figure 20: NNCI Cumulative Users by Site (Year 10)

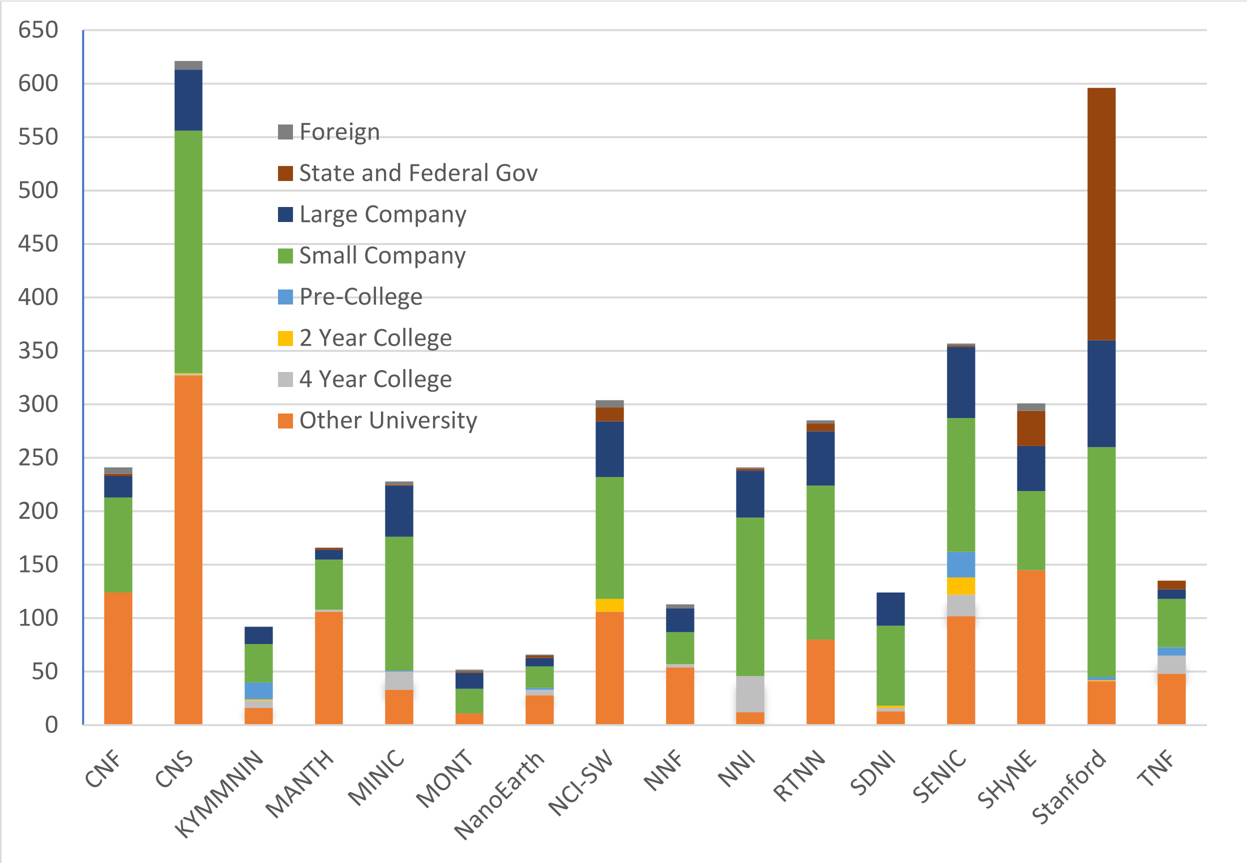


Figure 21: NNCI Cumulative External Users by Site (Year 10)

For academic institutions a network map showing the NNCI nodes and associated US colleges and universities (from 47 US states) is shown in Figure 22 below. The NNCI nodes are shown as green circles connected to its user institutions; red dots are NNCI site universities while blue dots are other US academic entities. Universities with connections to 3 or more NNCI sites are labeled in Figure 22; seven universities had users at 4 different NNCI sites, while MIT and UC-Berkeley 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 reached 378 in Year 10. In addition to the academic usage depicted by the figure, it was also observed that approximately 50 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.

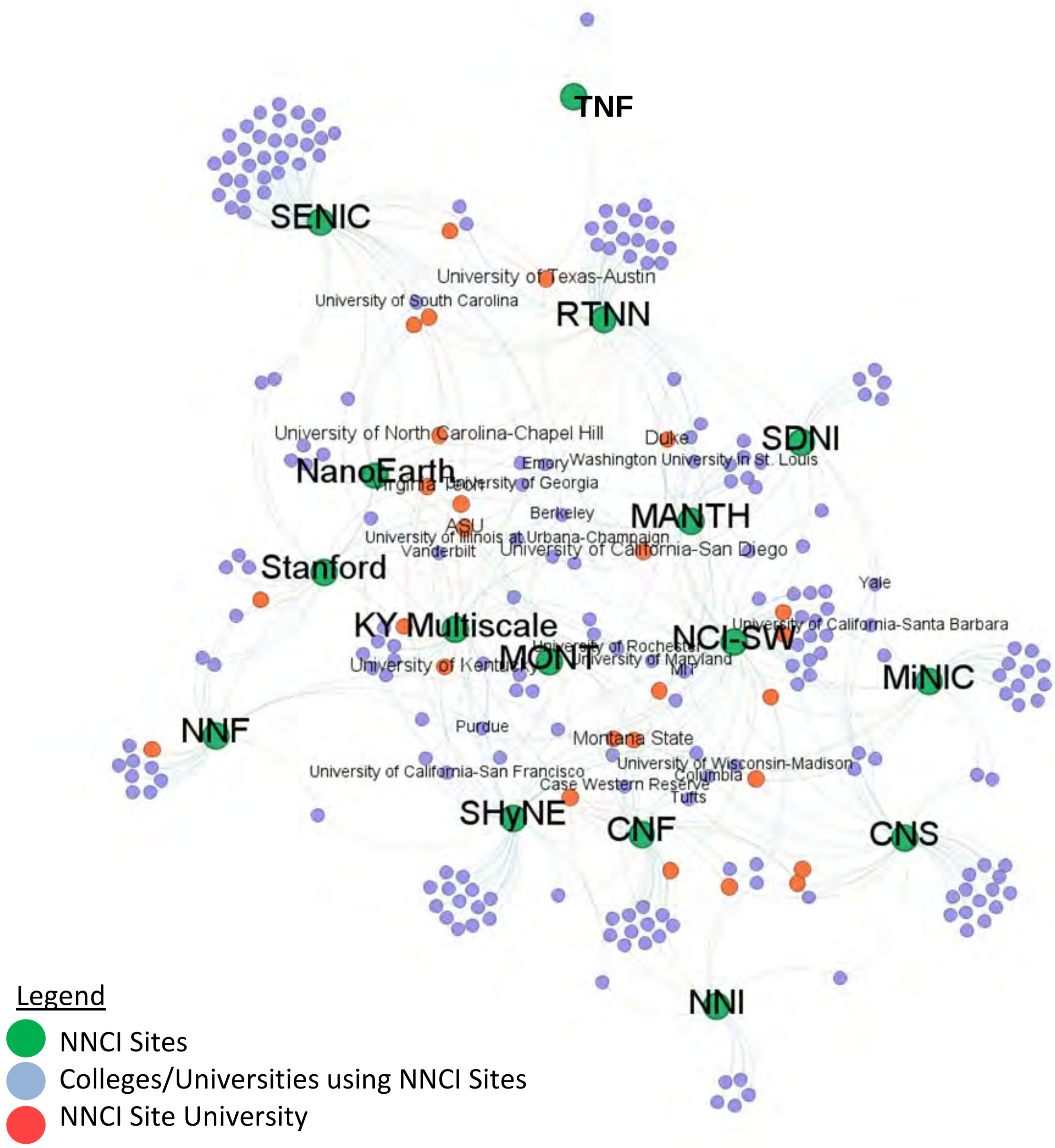


Figure 22: NNCI Academic User Network Map (Year 10)

NNCI Years 1-10 Summary Data

Over the course of the NNCI program (October 2015 – September 2025) estimates of total usage activity and annual averages, based on collation of annual data collections, are provided in Table 15 below. Because the cumulative user count resets every NNCI year in October, it is difficult to track users from year to year. The estimates of Total Unique Users and External Users are based on cumulative users in Year 1 with New Users Trained added in every subsequent year. This method, while a reasonable estimate, undercounts because remote users are not "trained" and thus would not show up in this calculation.

Table 15: NNCI User Metrics (Years 1-10)

Total Unique Users	~54,000
Average Monthly Users	5,000
New Users Trained/Year	4,700
External Users	>13,400 (25%)
External Academic	5,500
Industry	7,000
Government/Foreign	900
Facility/Tool Usage Hours	>10 million
User Institutions	>4,000
US Academic Institutions	461 *158 Minority Serving Institutions (34%), including 24 HBCUs and 57 HSIs* *142 R1 (76% of all R1) and 73 R2 (52% of all R2) Institutions* *246 Other Institutions (53%)*
Small Companies	2,400
Large Companies	850
Foreign Institutions	240 *55 Countries, 67% Academic*

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 23 illustrates the distribution by number of users and usage hours in specific disciplines. Furthermore, Figure 24 illustrates the average number of hours/user across the network based on the user's discipline, demonstrating that the fabrication-heavy disciplines of electronics, optics, and physics, tend to require more lab usage by researchers. Geology/Earth Sciences (primarily characterization activities) ranks third among the hours/user leaders, down slightly from last year. The usage distributions by discipline are similar to those in previous years, continuing the rapid growth in Geology/Earth Sciences users (5.9% in Year 10 compared to 2.4% in Year 1) and usage hours (7.5% in Year 10 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 more than 21% of all NNCI users. The annual changes in number of users in each discipline are graphically displayed in Figure 25 (with "Educational Lab Use", "Process", and "Other" removed for clarity). In Year 10, most disciplines showed small increases in the number of users, with the exception of Optics, which had a slight decline, while larger increases were seen for Electronics (8% increase) and MEMS/Mechanical Engineering (10% increase).

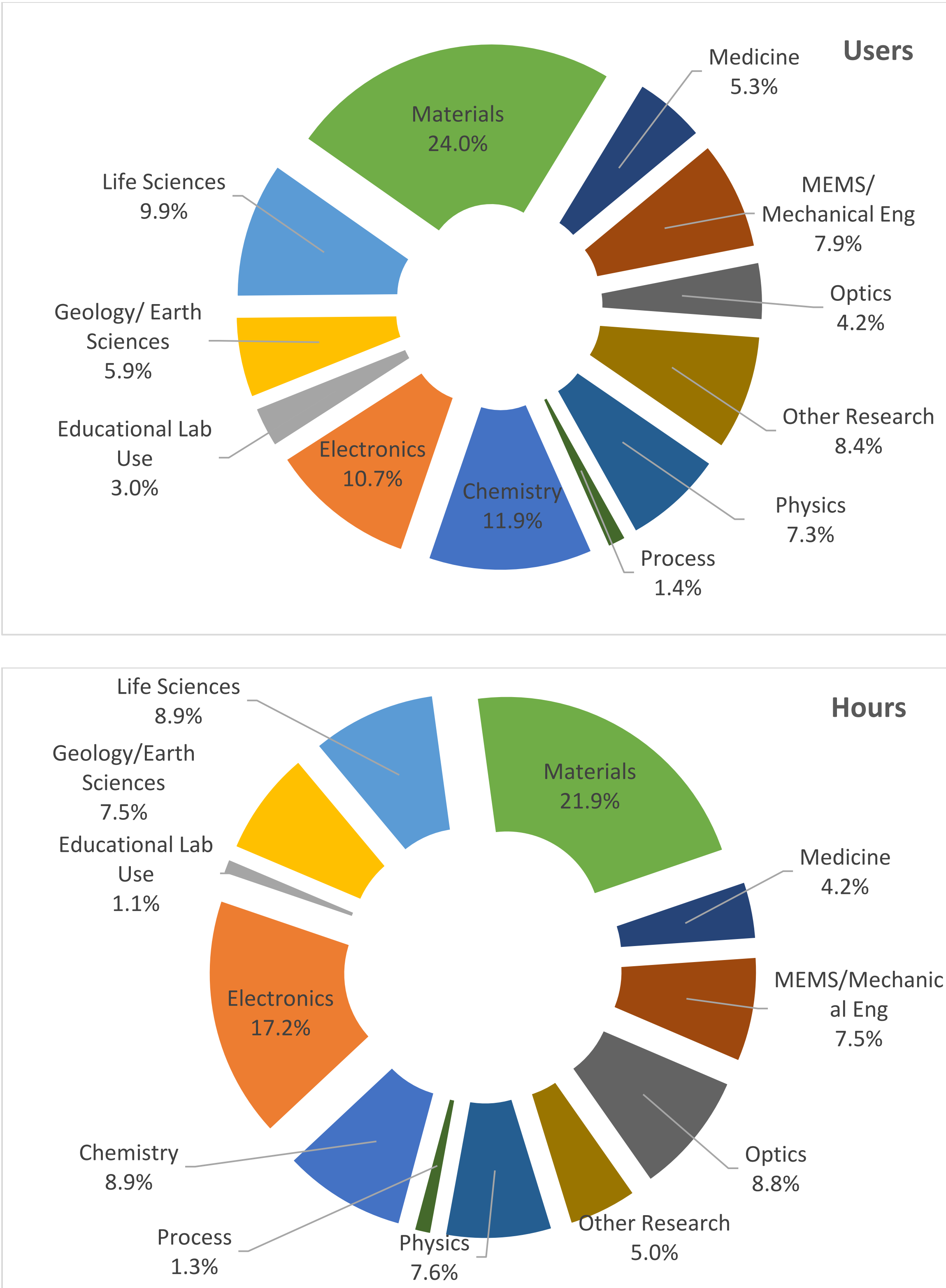


Figure 23: NNCI Users (top) and Usage Hours (bottom) by Discipline (Year 10)

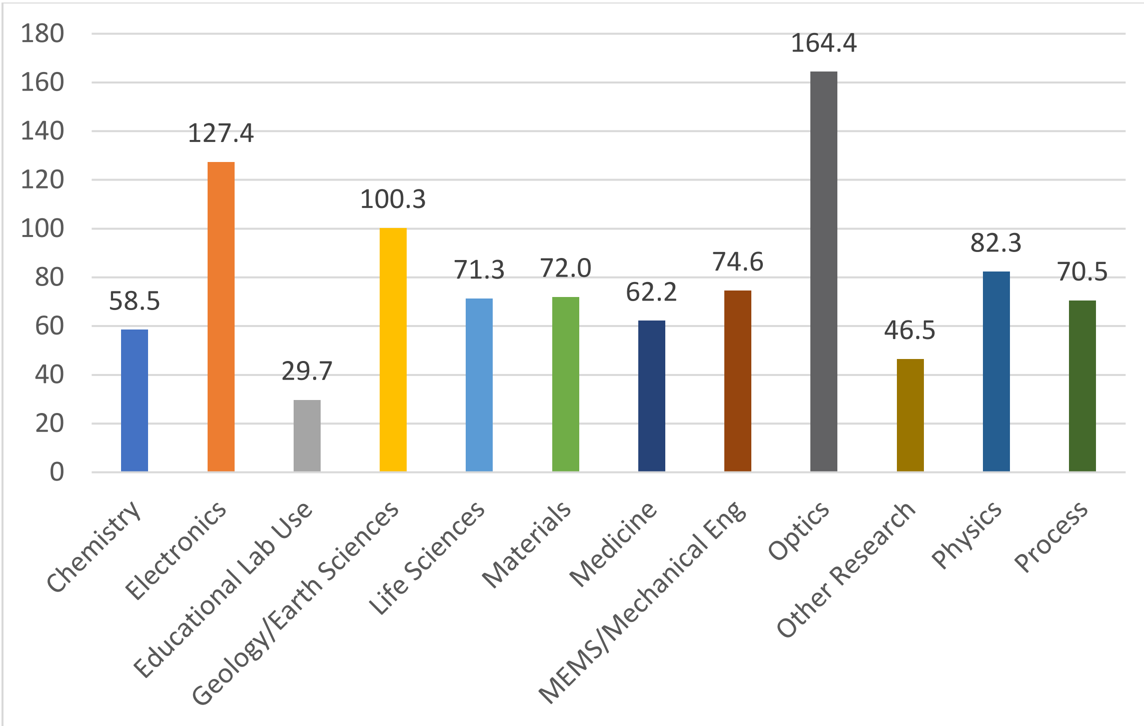


Figure 24: NNCI Hours/User by Discipline (Year 10)

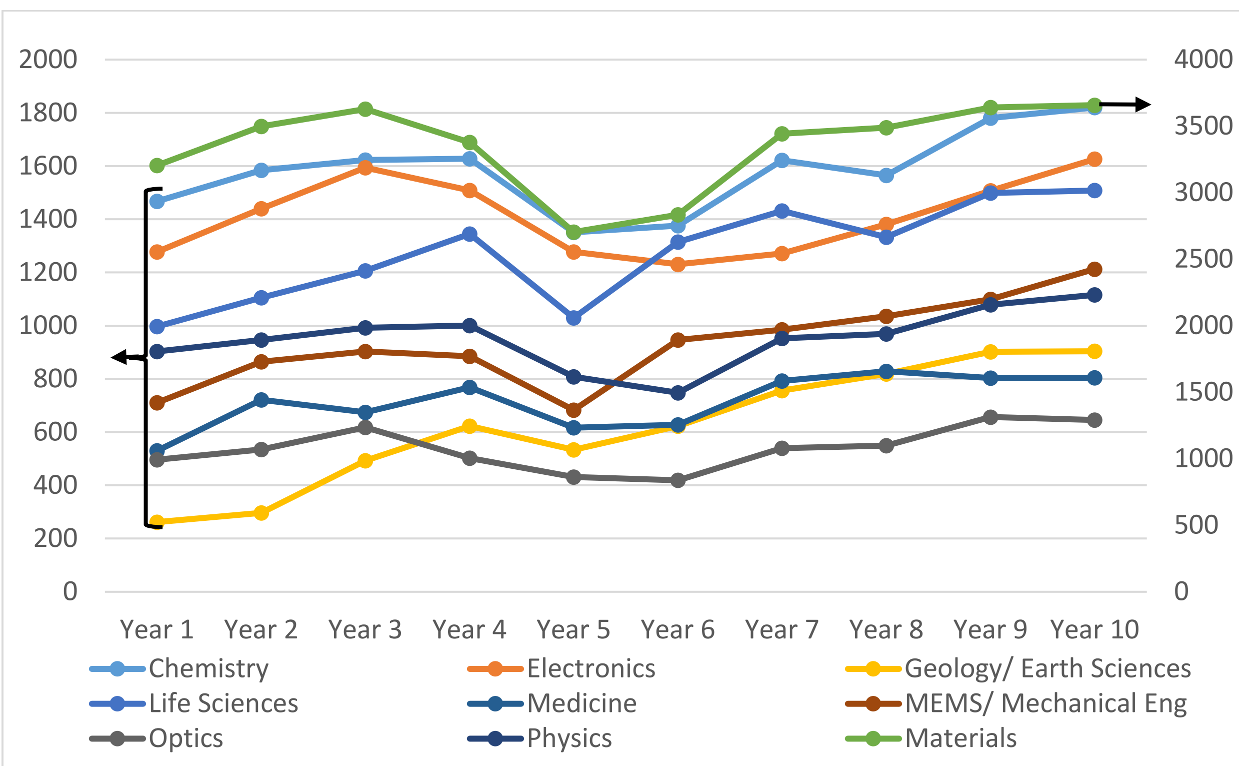


Figure 25: NNCI Yearly Users by Discipline ("Materials" indicated by the right Y-axis for comparison purposes.)

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 16 below compares the relative usage breakdown by number of users and hours for each year of NNCI (with the first five years averaged for simplicity). Using the above definition, the number of users was split evenly between traditional and non-traditional during the first five 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 16: Usage by Traditional and Non-Traditional Disciplines

	Years 1-5 Average	Year 6	Year 7	Year 8	Year 9	Year 10
# of Users						
Traditional*	5,724 (49%)	5,148 (47%)	5,893 (46%)	6,110 (46%)	6,500 (46%)	6,717 (45%)
Non-Traditional**	5,969 (51%)	5,804 (53%)	7,046 (54%)	7,157 (54%)	7,764 (54%)	8,084 (55%)
Hours of Usage						
Traditional*	486,112 (51%)	474,876 (50%)	516,803 (49%)	524,643 (49%)	546,815 (48%)	576,574 (48%)
Non-Traditional**	459,380 (49%)	476,194 (50%)	544,732 (51%)	548,349 (51%)	592,214 (52%)	612,633 (52%)

* Electronics, Materials, MEMS/ME, Process

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

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 NASA Minority University Research and Education Project (MUREP) 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)
  - Arizona State University (NCI-SW), Northern Arizona Univ. (NCI-SW), Rio Salado Community College (NCI-SW), and Univ. Texas-Austin (TNF), *Hispanic-Serving Institution* (HSI, 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. Minnesota (MiNC), 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 10, external academic users came from 91 institutions serving minority students: 24 HSI, 39 EHSI, 16 HBCU, 2 PBI, 30 AANAPISI, and 1 *Tribal Colleges and Universities* (TCU). This total is more than 91, because 21 institutions have multiple designations. Thus, 39% 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 also an increase from the 33% in Year 9.
    - Examples of these institutions are: Bunker Hill Community College, Colorado Mesa University, Elizabeth City State University, Fort Valley State University, Hunter College, Navajo Technical University, Sonoma State University, Tuskegee University, University of Northern Colorado, and University of the District of Columbia.
- Based on the Carnegie Classification of research universities (2025 reclassification), 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 233 Year 10 external US institutions:
    - 129 R1 Universities (out of 187 in the Carnegie list)
    - 39 R2 Universities (out of 140 in the Carnegie list)
    - 65 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 17) was collected by sites for the calendar year 2024. 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 4,087 publications collected for CY 2024 continues the decrease in number collected since the start of NNCI, but only slightly less than the previous four years (2020-2023). 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 2024 journal publications decreased while conferences increased slightly. Publications reported by each site range from 81 to 634. Patents/applications/invention disclosures continued at more than 500, after a decline in 2022. These trends can be observed in Figure 26.

Table 17: NNCI 2024 Publications

Publication Type (CY 2024)	
Internal User (Site) Papers	2,424
External User Papers	278
Internal User Conference Presentations	738
External User Conference Presentations	122
Books/Book Chapters	6

Patents/Applications/Invention Disclosures	519
Total	4,087

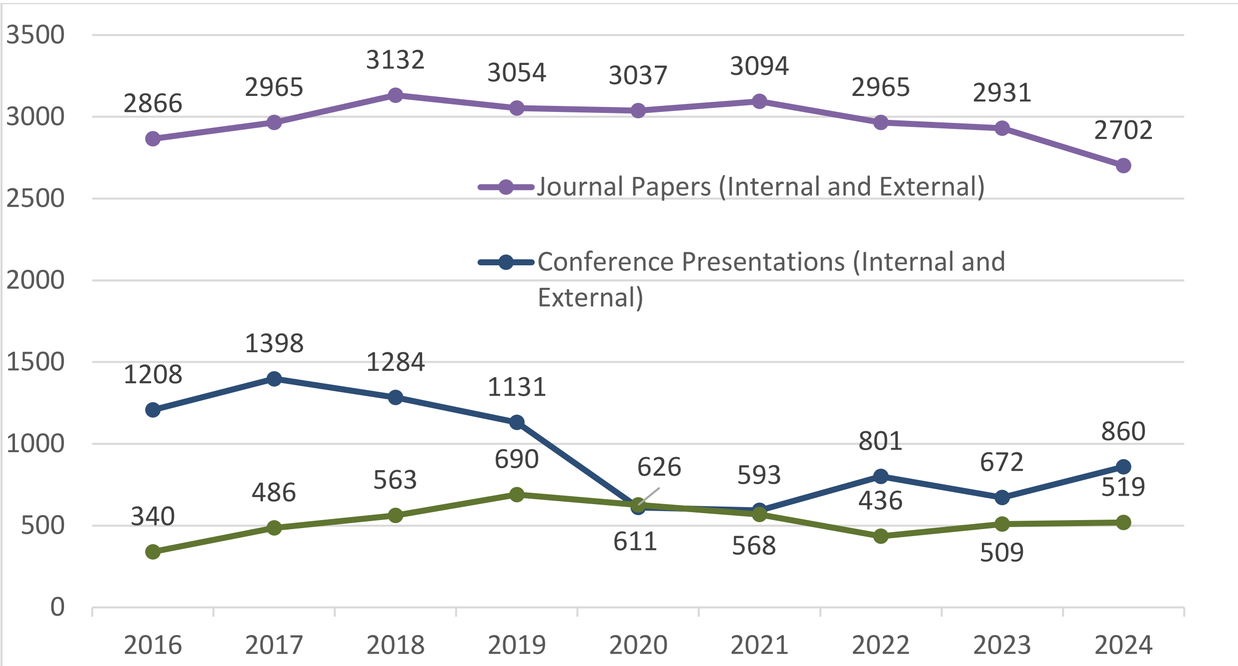


Figure 26: Number of NNCI-enabled Publications by CY.

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 27 below shows continued improvement in this metric. Finally, further detailed searching 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 16,000 journal articles published 2018-2025 that acknowledge the NNCI 2015 or 2020 award numbers (Figure 28). “Semiconductor” is found in 26-32% of publications over that time frame while “quantum” is mentioned by 30-37% of these publications. An earlier version of this analysis, with additional search terms, was featured in the *2021 National Nanotechnology Initiative Strategic Plan.*

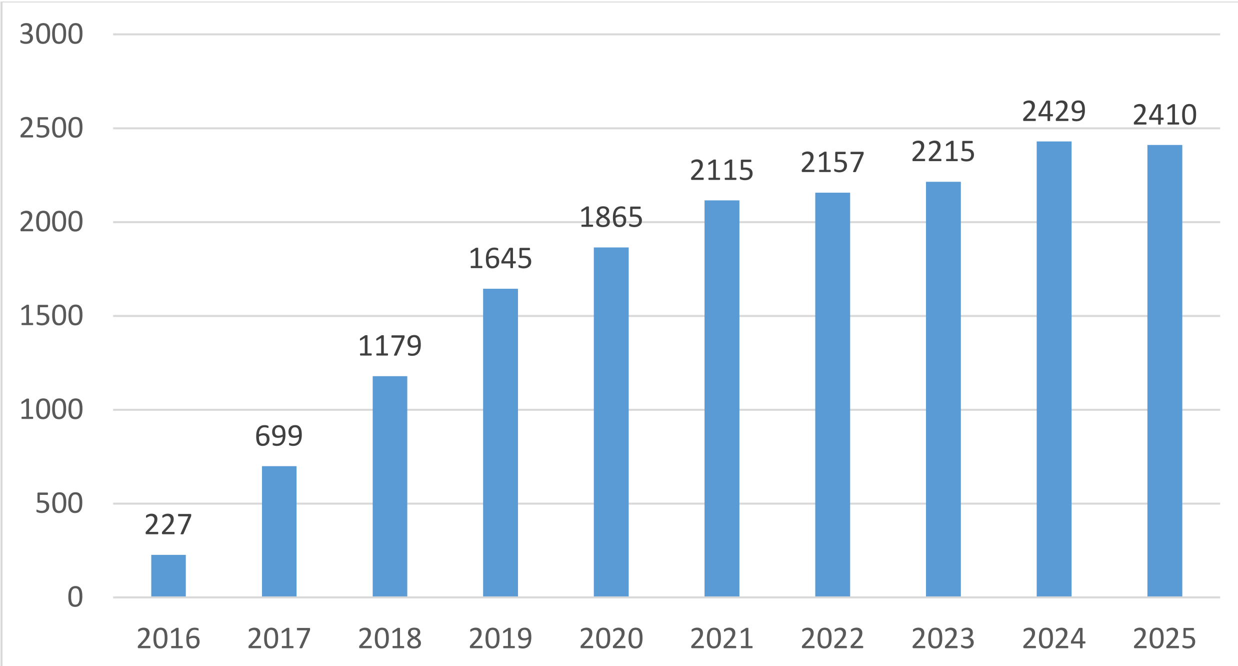


Figure 27: Number of Publications with NSF NNCI Award Numbers based on Google Scholar (NNCI-Award # or ECCS-Award #). Both 2015 and 2020 award #s were used. Search conducted 1/12/2026.

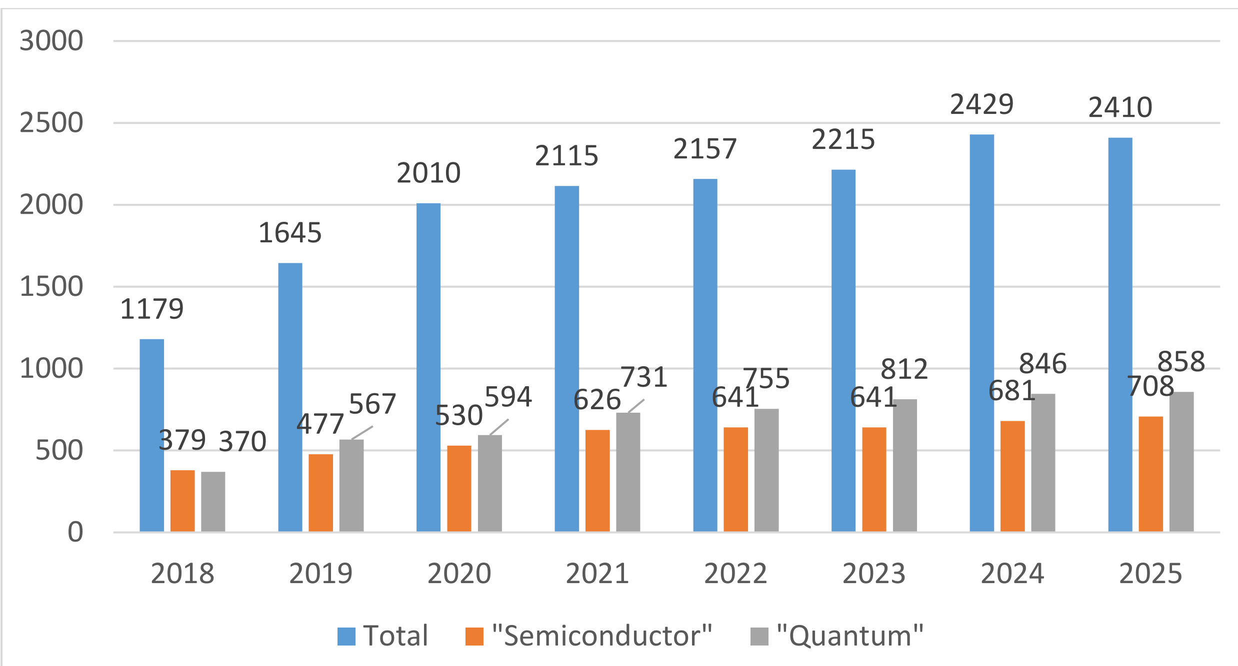


Figure 28: Number of NNCI publications (which cite the NSF award #s) on Google Scholar that also contain search terms "Semiconductor" or "Quantum" (2018-2025). Search conducted 1/12/2026.

11.4. Supported Research Centers

During 2020, the Coordinating Office asked NNCI sites to provide a list of large, multi-PI and/or multi-institution research centers supported by their facilities as a way of demonstrating some of the academic (and even economic) impact of the NNCI program. The list provided in the Year 5 Annual Report included 41 such centers, and this was supplemented in Years 6-9 with 57 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 18 below provides a Year 10 update, indicating 12 *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 18: NNCI Supported Research Centers (New in Year 10)

Research Center	Supporting Site	Funding Source
National Institute for Theory and Mathematics in Biology	SHyNE	NSF, Simmons Foundation
Center for Applied Physics and Superconducting Technologies	SHyNE	DOE, FermiLab
Northwestern Center for Water Research	SHyNE	NSF, DOE, Illinois, Great Lakes Water Consortium
Center for BioInspire Energy Science	SHyNE	DOE
Querrey-Simpson Inst Regenerative Engineering	SHyNE	Querrey Simpson Charitable Foundation
Interdisciplinary Biomedical and Engineering Core (IBEC)	SENIC	State of North Carolina, US Dept. of Education
National Advanced Packaging Manufacturing Program (NAPMP) Glass-Core Packaging Substrate & Materials	SENIC, TNF, SDNI	US Dept. of Commerce
Next-Generation Microelectronics Manufacturing (NGMM)	SENIC	DARPA
KIAT-Georgia Tech Semiconductor Electronics Center (K-GTSEC)	SENIC	Republic of South Korea
Georgia Tech-Advanced Battery Center (GT-ABC)	SENIC	
Battery Research, Innovation, and next-Gen Energy Harvesting Technologies (BRIGHT)	SENIC	
Institute for the Convergence of Optimized Methods for Military Advances and National Defense (iCOMMAND)	SENIC	

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 this funding sources survey was not conducted this past year, previous data suggest the following statements continue to remain true:

- NNCI facilities annually support 2,000-3,000 Principal Investigators (PIs) with nearly 4,000 grants valued at more than $5 billion.
- The top academic departments of primary award PIs (approximately 65% of awards) are: Electrical and Computer Engineering, Materials Science and Engineering, Chemistry, Physics, Chemical Engineering, and Mechanical Engineering.
- NSF remains the largest single external funding source with 20-25% of grants used.
- The NSF Engineering (ENG) and Mathematical and Physical Sciences (MPS) directorates comprise approximately 80% of NSF awards and of total NSF funded value supported by NNCI.

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 that information on these courses and students be collected to demonstrate the impact NNCI has on traditional education and workforce development. The information below was provided by fifteen of the NNCI sites for the academic year Fall 2024-Summer 2025 (corresponding to NNCI Year 10).

Nearly 140 individual courses were supported from 33 different academic departments listed below. Similar department names were combined for simplicity. Each individual NNCI site supported a range of 1-22 individual courses during this time frame with total course enrollment of 4,022 students (site range: 19-1,374). A word cloud of the course titles is shown in Figure 29.

Architecture
Art History
Bioengineering
Biological Sciences
Biology
Biomedical Engineering
Biotechnology
Chemical and Biological Engineering
Chemical and Biomolecular Engineering
Chemical Engineering
Chemistry
Chemistry and Biochemistry
Chemistry and Chemical Biology
Civil and Environmental Engineering
Earth Sciences
Earth System Science
Education
Electrical and Computer Engineering
Electrical and Systems Engineering
Electrical Engineering
Electrical, Computer and Energy Engineering
Engineering and Applied Sciences
Engineering Summer Academy at Penn
Geosciences
Industrial Engineering
Master in Design Engineering Program
Materials Science
Materials Science and Engineering
Mechanical Engineering
Nanoengineering
Nanoscience
Physics
Southwestern College Physical Sciences Department

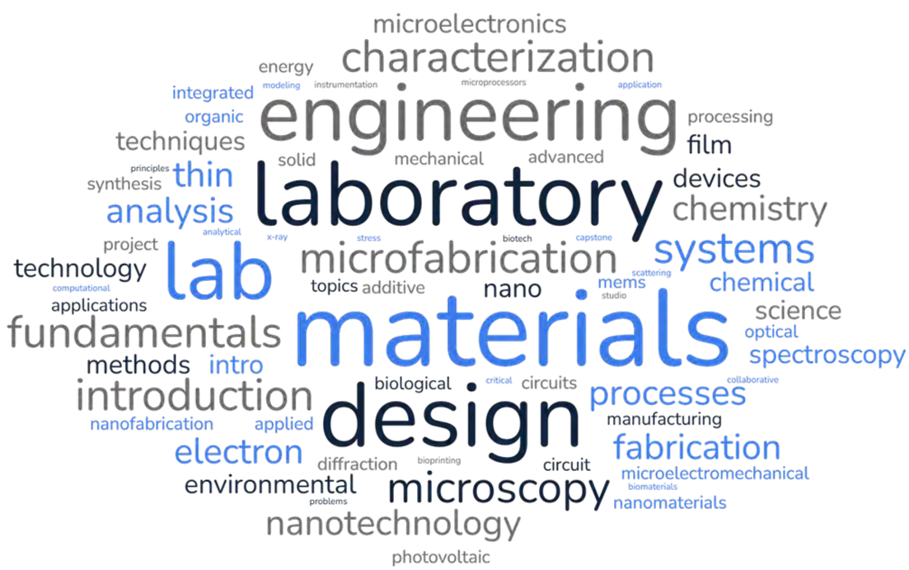


Figure 29: Word Cloud for Course Titles Supported by NNCI Facilities (Year 10)

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. For Year 10, thirteen of the NNCI sites were 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 2024, Spring 2025, and Summer 2025 (corresponding to NNCI Year 10) are shown in Table 19.

Table 19: Degrees Awarded to NNCI Users (Fall 2024-Summer 2025)

Academic Department	BS Degrees*	MS Degrees*	PhD Degrees	Other Degrees**	Total
Aerospace Engineering	8	7	2	0	17
Biomedical Engineering	39	58	67	5	169
Chemical Engineering	46	52	80	6	184
Civil and Environmental Engineering	6	14	16	0	36
Electrical and Computer Engineering	69	137	76	6	288
Industrial Engineering	5	10	4	0	19
Materials Science and Engineering	65	134	176	2	377
Mechanical Engineering	37	62	71	4	174
Nanoengineering	15	25	21	0	61
Nuclear Engineering	0	6	0	0	6
Biology	20	3	19	0	42
Chemistry and Biochemistry	44	29	129	0	202
Earth and Atmospheric Sciences	10	7	9	2	28
Physics	21	28	58	3	110
Nanoscience	9	17	8	2	36
Computer Science	34	16	0	0	50
Medical School	14	3	15	11	43
Veterinary School	0	0	1	0	1
Other	57	33	20	23	133
Total	**499**	**641**	**772**	**64**	**1,976**

*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 1,976 degrees were awarded by the 13 sites (mean=152, range=20-390). NNCI users were awarded 772 doctorates, 641 masters, 499 bachelors, and 64 other degrees (including MD or other graduate certificates) during this NNCI Year 10. These values are significant increases in bachelors (+46%) and masters (+15%) degrees, while a slight decline (-3%) in doctorate degrees compared to the previous year, but this comparison is difficult due a change in the number of sites providing data. For comparison, the NSF "Survey of Earned Doctorates (2024)" indicates that US institutions awarded 10,544 doctorates in Engineering and 5,367 doctorates in Physical Sciences during 2024. For NNCI users, 67% of all degrees (66% for PhD degrees) were awarded by engineering departments. Materials Science and Engineering is the top awarder of all degree types, followed by Chemistry/Biochemistry, Chemical Engineering, Electrical and Computer Engineering, Mechanical Engineering, and Physics for Ph.D. degrees. Disciplines in the "Other" category include Bioinformatics, Entomology, Food Science and Technology, Forest Biomaterials, Mining Engineering, Neuroscience, Robotics and Textile Chemistry/Engineering among many others.

11.8. Industry Success Stories

NNCI typically supports the research efforts of 800-1,000 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 sites and companies.

- Stanford counts numerous success stories among its industry users, including **Unity Semiconductor**, which went public then was acquired by Rambus; **Matrix Semiconductor**, which went public and then was acquired by SanDisk; **Invensense**, which went public and then was acquired by SanDisk; **Grandis**, acquired by Samsung; **LuxVue**, acquired by Apple. In 2017, the startup **Raxium** began using nano@stanford for prototyping and early product development. While one Raxium employee had ties to Stanford, the company did not evolve from Stanford research. Over the next three years, 21 Raxium process engineers joined SNF, received training on numerous tools, and gained hands-on experience with the facility's tools. As Raxium grew and appeared poised for success, the company began building its own lab, continuing to use SNF during the transition. Many of the equipment choices for the new lab were informed by the engineers' experience at SNF. Raxium's cutting-edge micro-LED devices ultimately attracted Google's interest, leading to its acquisition for a reported $1 billion in May 2022.
- **Monolith**, located in Hallam, Nebraska, is developing a methane pyrolysis method to make clean hydrogen affordable and scalable. The carbon black they also produce is used for inks, paints, electronics, and UV absorber applications. Recently, Monolith received approval for a $1.04 billion loan from the DOE to expand their production facilities. Monolith has been a regular user of NNF facilities for more than six years, with access crucial for the company's research and development efforts.
- **CardioMEMS**, which produces an implantable pressure monitor for cardiologic applications, was launched as a startup from Georgia Tech in 2001and was one of the first external users of the NNIN site starting in 2004. In 2014 the company was acquired by St. Jude Medical and then by Abbott Laboratories in 2017. Over the course of the company lifetime the Georgia Tech facilities has provided a continuum of support including student basic research, startup R&D, small batch manufacturing, prototypes for clinical trials, product testing, new product development, and staff technical training.
- At the University of Washington, many companies have used the facilities that otherwise would not have been able to operate. Some of these have moved on and built their own labs,

but all of them still interact with UW. Examples include **Hummingbird Scientific, NLM Photonics, Lumotive, Starfish Neuroscience,** and **VerAvanti**.

- Companies supported by Montana State don't operate their own cleanrooms or characterization facilities, as a rule. Those working in nano or quantum rely on MSU's facilities and expertise. Their industrial users were granted 11 new SBIR/STTR Awards in 2024. One notable example, **AdvR** (Bozeman, MT) received 2 Phase I and 4 Phase II SBIR/STTR awards from DOD and NASA worth $5.45M in funding. AdvR doesn't exist without MONT and were the facility's first external user in 2004. The company has slowly developed some in-house capabilities, mimicking what has been provided at MSU, but they continue to use the NNCI facilities for advanced development and processes they don't have internally.

12. NNCI Site Reports

NNCI sites were asked to provide summary information as part of this Year 10 report. Specific information requested included:

1. A brief narrative corresponding to the NNCI Year 10 (Oct. 1, 2024 - Sept. 30, 2025).
    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 10, separated as follows: Academic, Small company (<500 employees), Large company, Government, International, Other. See Appendix 14.1 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 10 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 2024. The list of publications may have been part of each site's Year 10 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 10 (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 10 period (Fall 2024-Summer 2025). 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 10 (Fall 2024-Summer 2025) per academic department (Section 11.7)

In addition, the user statistics for NNCI Year 10 (Oct. 2024-Sept. 2025) 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. In the “Yearly User Data Comparison” tables, the usage data for NNCI Years 1-5 have been removed for clarity; this data can be found in earlier annual reports.

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

12.1. Center for Nanoscale Systems (CNS)

This past cycle, CNS has continued to operate at full capacity, building on the momentum established in previous years as our laboratories have returned to and exceeded pre-pandemic levels of activity. The facility has welcomed new researchers whose groups are becoming major users of our capabilities, while established research groups continue to explore innovative applications of our nanofabrication and characterization tools. We continue to assess, revamp, and augment the instrumentation available at CNS for advancing transformative nanoscale and quantum science research with a particular focus on integrated photonics and the materials and devices enabling that technology.

The Center for Nanoscale Systems remains committed to its mission as a comprehensive resource for nanoscale and Quantum research, serving both the Harvard community and external users from academia, industry, and government laboratories. Our strategic partnerships, most recently with Amazon Web Services (AWS) in quantum networking and integrated photonics, have enabled significant infrastructure enhancements that benefit the entire user community.

Facility, Tools, and Staff Updates

Instrumentation and Tool Additions

CNS has continued to expand and modernize its instrument portfolio to meet the evolving needs of the nanoscale research community. The following key tools were added or commissioned during the 2024-2025 reporting period:

Major Equipment Acquisitions (items marked with * acquired with AWS support):

- **Cryo-neaSNOM** – Temperature-variable scanning-probe near-field optical microscope with cryogenic capabilities, acquired with DURIP support
- **AJA Sputtering/E-beam evaporator system*** – Specialized deposition system for complex oxide and superconducting thin films
- **Atlas Micro XRF system** – X-ray fluorescence microscopy for elemental analysis and mapping
- **NSF MRI Photonic Wirebonder** – Awarded for integrated photonics packaging applications

Teaching and Training Infrastructure:

- **EMS-plus Sputtering system –** Dedicated thin film deposition tool for laboratory courses
- **Samco RIE-10NR system –** Reactive ion etching system for hands-on student training
- **Heidelberg micro-MLA Lithography system** – Maskless lithography tool for educational applications

These additions have substantially expanded the operational bandwidth of the facility, particularly in the areas of quantum materials fabrication, integrated photonics, and complex oxide heterostructures. The teaching-dedicated instruments enable us to provide comprehensive hands-on training without disrupting research operations.

New CNS Staff

CNS added four new staff members during the reporting period to support expanded operations and new capabilities:

Yumian Zhu, Equipment Engineer-Nanofabrication (Started December 2, 2024)

Seyyed Soroosh Sharifi Asl, FIB Scientist (Started December 2, 2024)

Haojie Ji, Sr. Photonics Integration Engineer (Started November 12, 2024)

These personnel additions strengthen our capabilities in photonic packaging, focused ion beam processing, and general nanofabrication support, enabling us to better serve our growing and increasingly diverse user base.

User Base

User Statistics (October 1, 2024 – September 30, 2025)

The CNS user community has continued to grow and diversify during the reporting period. Based on comprehensive usage tracking data:

Total Lab Hours: 140,681 hours

User Distribution by Affiliation:

Affiliation Category	**Lab Hours**	**Percentage**
Harvard (Local Site Academic)	78,273	55.6%
Other Universities	32,100	22.8%
Small Companies	26,435	18.8%
Large Corporations	2,964	2.1%
Foreign Institutions	889	0.6%
Four-Year Colleges	9	<0.1%
Two-Year Colleges	12	<0.1%

Key Metrics:

- **Non-Harvard Users:** 44.4% of total usage
- **External Academic Users:** 22.8% of total usage
- **Industrial Users:** 20.9% of total usage
  - Small companies represent 89.9% of industrial usage
- **Small Business Participation:** Approximately 19% of total facility usage

The substantial participation of external academic users and small companies demonstrates CNS's role as a regional and national resource for nanoscale and Quantum research and development. The high proportion of small company usage (nearly 90% of industrial activity) reflects our commitment to supporting entrepreneurship and technology commercialization.

Research Highlights and Impact

Work conducted at CNS during the 2024-2025 reporting period resulted in publications in high-impact journals. The following research highlights exemplify the breadth and impact of research enabled by CNS facilities.

Highlight 1: On-chip Multi-Degree-of-Freedom Control of Two-Dimensional Materials

Authors: Haoning Tang, Yiting Wang, Xueqi Ni, Kenji Watanabe, Takashi Taniguchi, Pablo Jarillo-Herrero, Shanhui Fan, Eric Mazur, Amir Yacoby, Yuan Cao

Affiliations: School of Engineering and Applied Sciences, Harvard University; Department of Physics, MIT; Department of Applied Physics and Ginzton Laboratory, Stanford University; Department of Electrical Engineering and Computer Science, University of California-Berkeley; National Institute for Materials Science, Tsukuba, Japan

Journal: Nature, Volume 632, pages 29 August 2024

NSF Support: ECCS-2025158; **National Research Priority:** NSF Quantum Leap

Two-dimensional (2D) materials and their heterostructures offer unprecedented tunability of electrical and optical properties, primarily through electrostatic gating and mechanical twisting. However, existing manipulation techniques rely on scanning microscopes that are limited in scope and scalability, lacking the accessibility needed for device-level applications. This work introduces a revolutionary microelectromechanical system (MEMS) platform that enables on-chip, multi-degree-of-freedom manipulation of 2D materials at the nanoscale.

The platform comprises compact and cost-effective devices with precise voltage-controlled manipulation capabilities, including approaching, twisting, and pressurizing actions. This technology was demonstrated by creating synthetic topological waveguides, such as merons, in the moiré superlattice of twisted bilayer graphene. The ability to dynamically control twist angles and interlayer coupling in situ opens new possibilities for exploring quantum phenomena in 2D materials.

A particularly promising application of this technology is the development of integrated light sources with real-time, wide-range tunable polarization. The work extends the capabilities of 2D materials research beyond fundamental physics into practical device applications, with implications for quantum information processing, tunable photonics, and reconfigurable electronic systems. This research exemplifies how CNS nanofabrication capabilities enable the integration of quantum materials with MEMS technology to create next-generation functional devices.

Highlight 2: A Suspended 4H-Silicon Carbide Membrane Platform for Defect Integration into Quantum Devices

Authors: Amberly H. Xie*****, Aaron M. Day, Jonathan R. Dietz, Chang Jin, Chaoshen Zhang, Eliana Mann, Zhujing Xu, Marko Loncar, Evelyn L. Hu

Affiliations: School of Engineering and Applied Sciences, Harvard University

Journal: Nano Letters, published October 15, 2025, **DOI:** 10.1021/acs.nanolett.5c04169,

NSF Support: ECCS-2025158 **National Research Priority:** NSF Quantum Leap

Silicon carbide (4H-SiC) has emerged as one of the most promising platforms for solid-state quantum technologies, owing to its commercial availability as a wide-bandgap semiconductor, its ability to host optically addressable spin defects, and its excellent mechanical and thermal properties. However, many quantum applications require suspended membrane structures to enable optical access, mechanical isolation, and integration with photonic circuits.

This work presents a comprehensive platform for fabricating suspended 4H-SiC membranes with precisely controlled thickness and geometry. The fabrication process, developed using CNS nanofabrication facilities, enables the creation of high-quality membranes ranging from hundreds of nanometers to several micrometers in thickness, with lateral dimensions from tens to hundreds of micrometers.

The suspended membrane platform addresses several critical challenges in quantum technology development. First, it enables efficient optical collection from color centers in SiC by eliminating substrate-induced optical losses. Second, the mechanical isolation provided by suspension reduces coupling to environmental vibrations, which is crucial for maintaining quantum coherence. Third, the platform is compatible with integration into photonic circuits, enabling on-chip quantum information processing. The research demonstrates the incorporation of silicon vacancy color centers into the suspended membranes, showing that the optical and spin properties of these quantum emitters are preserved or even enhanced in the membrane geometry. The platform has immediate applications in quantum sensing, quantum communication, and quantum computing, and represents a significant step toward scalable quantum technologies based on silicon carbide.

Publications

During the reporting period (calendar years 2025), research conducted at CNS resulted in **83 publications** acknowledging NSF grants ECCS-2025158 and/or ECCS-1541959. These publications span a diverse range of research areas and include: 79 articles, 3 proceedings, and one book chapter.

- **19 publications** in Nature/Science family journals (Nature, Science, Nature Communications, Science Advances, Nature Physics)
- **15 publications** in high-impact specialized journals (ACS Nano, Nano Letters, Advanced Materials, Optics Letters, Applied Physics Letters)
- **Multiple publications** in IEEE proceedings and other technical venues

Research Areas Represented:

- Quantum materials and moiré physics
- Integrated photonics and electro-optic devices
- Quantum computing and quantum networking
- Biomedical engineering and tissue engineering
- Catalysis and materials science
- Nanofabrication and characterization methods

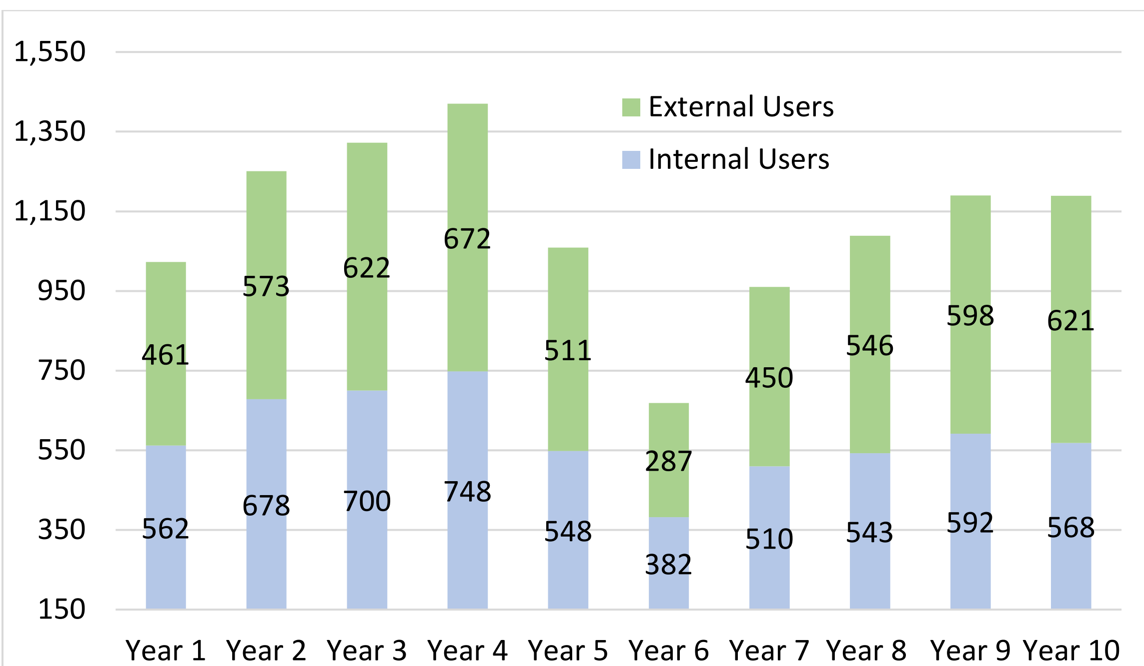
The 2024-2025 reporting period, while challenging, has been highly successful for the Harvard Center for Nanoscale Systems. The facility has operated at full capacity, serving a expansive user community that includes Harvard researchers, external academic users, and a substantial industrial user base. Strategic investments in new instrumentation and staff have expanded our capabilities in critical areas including quantum materials, integrated photonics, and biomedical applications.

Research conducted at CNS has resulted in high-impact publications in leading journals, demonstrating the facility's role in enabling cutting-edge science across multiple disciplines. Our expanded educational programs, including support for nine laboratory courses serving over 60 students, demonstrate our commitment to workforce development.

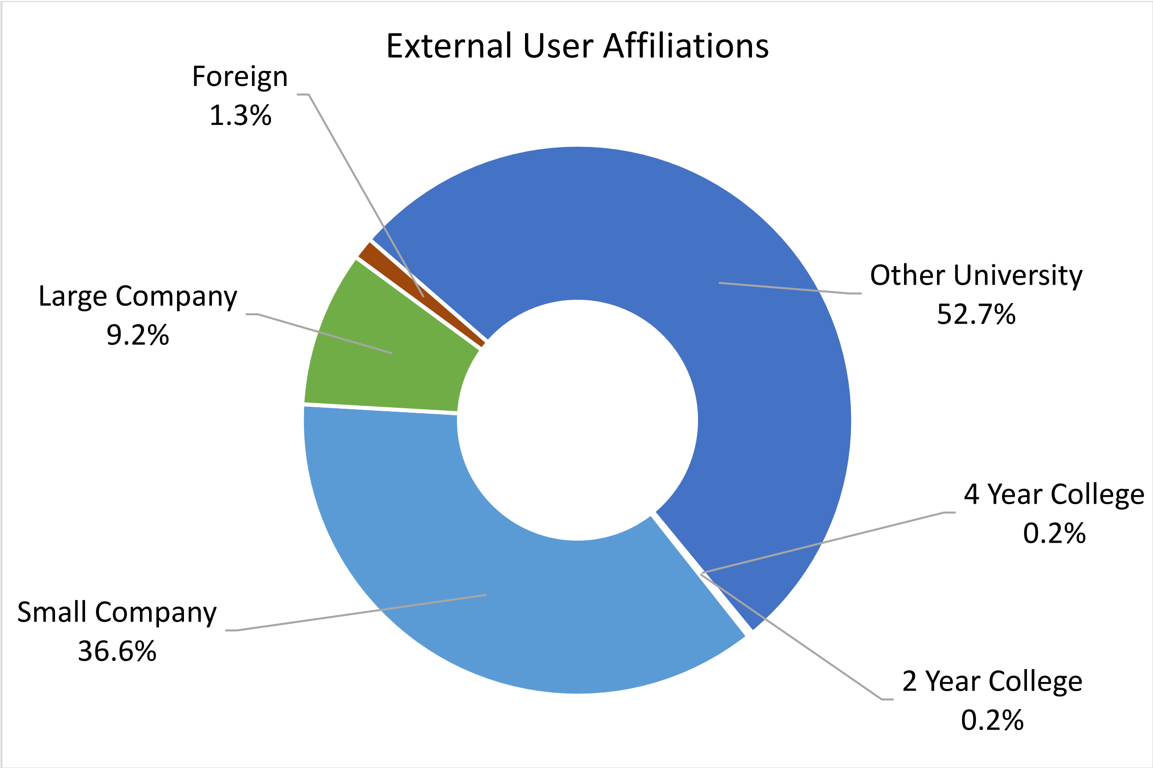
As CNS looks to the future, we remain committed to maintaining world-class facilities, providing exceptional user support, expanding educational opportunities, and fostering the research community needed to address the grand challenges in nanoscale science and technology.

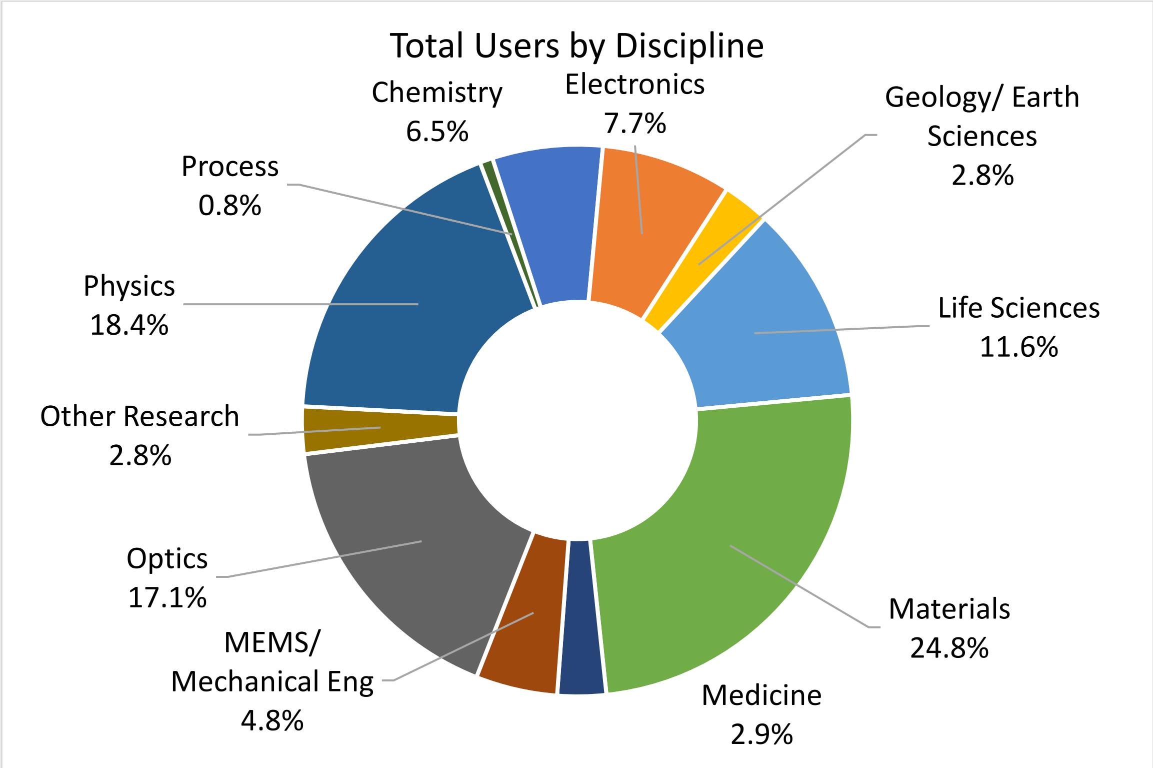
CNS Site Statistics

Yearly User Data Comparison					
	Year 6	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Total Cumulative Users	669	960	1,089	1,190	1,189
Internal Cumulative Users	382	510	543	592	568
External Cumulative Users	287 (43%)	450 (47%)	546 (50%)	598 (50%)	621 (52%)
Total Hours	116,357	142,332	157,121	153,193	140,681
Internal Hours	66,051	75,954	90,924	86,067	78,273
External Hours	50,307 (43%)	66,378 (47%)	66,198 (42%)	67,126 (44%)	62,408 (44%)
Avg. Monthly Users	260	379	442	471	448
Avg. External Monthly Users	102 (39%)	160 (42%)	192 (43%)	213 (45%)	217 (48%)
New Users Trained	116	366	352	386	346
New External Users Trained	43 (37%)	183 (50%)	207 (59%)	198 (51%)	206 (60%)
Hours/User (Internal)	173	149	167	145	138
Hours/User (External)	175	148	121	112	100



CNS Year 10 User Distribution





12.2. Cornell Nanoscale Science and Technology Facility (CNF)

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

The Cornell NanoScale Science and Technology Facility (CNF) enables rapid advancements in science, engineering, and technology at the nanoscale by providing efficient access to nanotechnology infrastructure and expertise. CNF operates as a 24/7 open user nanofabrication facility, supporting researchers from academia, industry, and government across the nation and around the world. CNF is the country's most longstanding micro/nanofabrication open user facility, having operated continuously since 1977. The CNF staff are dedicated technical experts committed to the needs of the user community. Their extensive knowledge ensures optimal equipment performance, thorough training, and invaluable technical guidance. CNF offers an affordable hands-on facility with over 200 tools and capabilities advancing nanoscale research, process development, and prototype fabrication. CNF has consistently demonstrated the ability to bridge disciplinary boundaries, providing innovative solutions to challenging, multi-step, micro- and nanofabrication processes.

CNF possesses one of the most comprehensive selections of nanotechnology fabrication and characterization equipment to support a broad range of technologies enabling successful research projects. Our 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; an extensive array of dry etcher chambers; 11 chemical vapor deposition (CVD) and 10 atmospheric tubes; various physical vapor deposition systems including thermal and e-beam evaporators and sputtering tools; 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.

CNF is a founding partner of the DOW funded NORDTECH ME Commons hub and received $8.2 million in 2023 through the CHIPS and Science Act to expand its fabrication capabilities. This investment supported major upgrades in quantum technologies, heterointegration, and 200mm wafer processing, representing CNF's largest capital expansion to date. In addition, new, more advanced capabilities have been added at CNF to improve the user experience and enable new frontiers of research. The table below lists the tools that have been installed or are currently being installed over the past year and associated funding sources for the tools (see table and figure below).

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

Recent Capital Equipment Acquisitions			
200 mm capable - Zeiss GeminiSEM 560 *Funded by ME Commons*	**Plasma-Therm Plasma Dicing System** *Funded by ME Commons*	**Osiris- Temporary Bonding and Debonding** *Funded by ME Commons*	**Logitech Orbis 200mm CMP Upgrade Kit** *Funded by ME Commons*

AJA UHV Sputter Deposition- quantum applications *Funded by ME Commons*	**YES Polyimide Cure Oven** *Funded by ME Commons*	**Nano- Master SWC-4000** brush cleaner *Funded by ME Commons*	**Heidelberg MLA150**- maskless lithography *Funded by ME Commons*
Angstrom UHV E-beam Evap - superconducting materials and JJs *Funded by ME Commons*	**KLA SPTS E2 XeF2 Etcher** *Funded by ME Commons*	**REYNOLDSTECH Custom Electroplating** *Funded by ME Commons*	**Oxford ASP ALD –** superconducting materials and nitride materials *Funded by ME Commons*
SEKI Microwave Plasma CVD – quantum grade diamond *Funded by ME Commons*	**Oxford PlasmaPro 100 Cobra 300** – oxide and diamond etching *Funded by ME Commons*	**Disco Wafer Back Grinding and DI H20 Recycling Unit** *Funded by ME Commons*	**Keyence Digital Microscope** *Funded by ME Commons*
AJA Q Deposition system - for superconducting materials and devices *Assistant Prof. Start-up package*	**KLA Filmetrics R50-200** – Resistivity *NSF cooperative agreement funds*	**Oxford Cobra ALE**- for quantum device etching *Project funding*	**TPT Semi-Automatic Thermosonic Wire Bonder** *Project funding*

Newly added capabilities at CNF: Oxford ASP ALD, Angstrom UHV Ebeam Dep, Plasma-Therm MDS-100 Plasma Dicer, and REYNOLDSTECH Electroplating

CNF has a dedicated technical management team (2 FTE + Faculty Director and Associate Faculty Director), administrative staff (2.75 FTE), and a laboratory technical staff of 19 (17.5 FTE). The main purpose of CNF is to support the user program, provide instructions, and maintain equipment to ensure the operational success of CNF.

Alan Bleier retired in January 2025 after 24 years at CNF. Alan supported CNF users for both scanning electron microscopy and electron beam lithography. In June 2025 Dr. Roberto Panepucci left CNF to become Managing Director of the Microelectronics Research Center at the University of Texas at Austin, another NNCI Site. And in August 2025 Paul Pelletier, who specialized in the installation of the NORDETCH equipment, left CNF to start Northeast Orbital Welding, a startup business based in the Albany, New York area.

Emma Carlo, Philip Schneider, and Shilling Du

In January 2025, Emma Carlo, a recent graduate from SUNY Oneonta with a degree in Communications, joined CNF as Student Program and Events Coordinator. In her role, she oversees the REU program, manages and updates CNF publications, website, and social media, and coordinates CNF events. Philip Schneider joined CNF in February 2025. Phillip holds a B.S. degree in Nanoscale Engineering from SUNY Polytechnic Institute and a M.S. degree in Materials Science from SUNY Binghamton. He most recently served as a

Metrology Engineer at Wolfspeed in Marcy, NY. Philip supports both CNF's metrology, deposition, and Reactive Ion Etching technology. Lastly, Shilling Du, Ph.D., joined CNF in April 2025 with a Ph.D. from Washington University in St. Louis. She has expertise in quantum devices and will largely support the new NORDTECH quantum deposition tools.

User Base

In the tenth year of the NNCI, CNF hosted 1119 users, with 23% representing external users. Internal Cornell users utilized 51,183 hours, while external users accounted for 17,354 hours (25% of total usage hours). External user fees accounted for $2.0 million of the total $3.7 million in user fees.

Facility lab hours exceeded 68,500, with an average monthly user count of 405 consistent with the previous year. Additional user statistics are available in the NNCI coordinating site's report.

The research disciplines represented at CNF span a broad spectrum, with 21% of the users working in life sciences, 15% in materials, 10% in physical science and 13% specifically focused in electronics.

Research Highlights and Impact

CNF compiles annual technical research reports in the **CNF Research Accomplishments** document available online.

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 calendar year 2024, CNF-supported research resulted in a minimum of 195 publications, 190 presentations (this number is vastly under-reported), and 21 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 ninety-six companies, comprising 147 small startup companies and 49 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).

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**	**PixelExx**	**SNOChip**	**Lit Thinking**

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, NOKIA Bell labs, Fujifilm Electronic Materials, Onsemi, 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, 49 small U.S. companies and 11 large U.S. companies benefitted from this access.

Education and Outreach Activities

CNF has a comprehensive education and workforce development effort that spans K through 12, post-secondary, professional, and public audiences. CNF views traditional education and outreach programs as critical pipeline for developing a skilled high-tech workforce. There has been an increased focus on workforce development brought about by programs such as the CHIPS & Science Act and the DOW ME Commons programs. This past year CNF reached over 9,000 individuals through 139 events, offering hands-on learning and engagement opportunities to build awareness and interest in nanotechnology. CNF programs include: Nanooze, a kid-friendly science magazine distributed to over 100,000 readers annually; our biannual "Technology and Characterization at the Nanoscale" (TCN), a three-day course that covers core nanotechnologies taught by CNF staff; our New Visions Engineering Accelerated Training for Labor Advancement in Semiconductors (ATLAS) program in collaboration with Tompkins Seneca Tioga (TST) Boards of Cooperative Educational Services (BOCES), which provides high school students access to the CNF cleanroom; Micron "Chip Camps" that provide middle school students with cleanroom and nanotechnology experiences; and a High Purity Welding program that introduces vocational students to high tech career paths, in partnership with BOCES. CNF also supported internships and Research Experience for Undergraduates (REUs) as well as an International Research Experience conducted in conjunction with the National Institute for Materials Science in Tsukuba, Japan. CNF staff members played key mentoring roles, ensuring the interns and REU students gained valuable skills and experience to support their career development. CNF also continued its annual outreach events, including Tompkins County Expanding Your Horizons, 4-H Career Explorations, New York State Fair, alumni reunion tours, STEM EXPO (Junior First Lego League 2.0), Kangaroo Math, and various science classroom visits.

2025 REU students

CNF has been working with Tompkins-Cortland Community College (TC3) to establish a Micro-Nanotechnology (MNT) concentration within their existing A.A.S. degree program. This past year CNF staff have assisted with the procurement of vacuum and metrology equipment that will enable additional micro-credentials within the existing A.A.S degree programs at TC3. In addition, CNF and TC3 also collaborate in the NSF funded Microfabrication and Nanotechnology Certificate Program (MNCP) for veterans in partnership with Penn State University, providing veterans with pathways into the semiconductor industry.

Participants in the Microfabrication and Nanotechnology Certificate Program for Veterans

Our most compelling and recent 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. And over the last two years the CNF has been working with the staff at the Cornell Center for Teaching Innovation, to develop a series of short (~20 minutes) VR cleanroom training experiences which bring learners directly into the CNF using high resolution, immersive 360-degree video with embedded interactive content and quizzes. This effort, led by CNF Workforce Development Program Manager Tom Pennell, will ultimately produce 20 – 30 modules that create a unique, immersive learning experience accessible from anywhere, expanding Cornell's educational reach far beyond the walls of the CNF cleanroom facility. To date, CNF has had over 1,600 users of our VR educational content with over 1,000 hours of combined time spent in VR. The VR modules were also used as supplementary materials in Cornell engineering courses, such as MSE5410/ECE4360 "Nanofabrication and Characterization of Electronics."

CNF hosted its 2025 Annual Meeting on November 18th at the Statler Hotel, bringing together researchers, industry partners, faculty, students, and national collaborators to spotlight CNF's leadership in micro- and nanotechnology. The program showcased advances in photonics, quantum devices, semiconductor fabrication, sustainability, life sciences and workforce development. Cheryl Strauss Einhorn, Cornell Graduate, author and founder of Decisive, a decision sciences company, chose to address the audience through an informal interview/Q&A led by Prof. Judy Cha, Director of the CNF. It was an engaging conversation providing insight into complex problem solving and decision-making process. Dr. Dirk Pfeiffer, Director of IBM's Microelectronics Research Laboratory (MRL), was a plenary speaker at the CNF Annual Meeting. In his presentation, Dirk outlined MRL's core mission of accelerating semiconductor technologies from early-stage innovation to wafer-scale development and manufacturing, bringing concepts effectively from "lab to fab". The meeting proceedings can be found at https://www.cnf.cornell.edu/events/annual_meeting/2025.

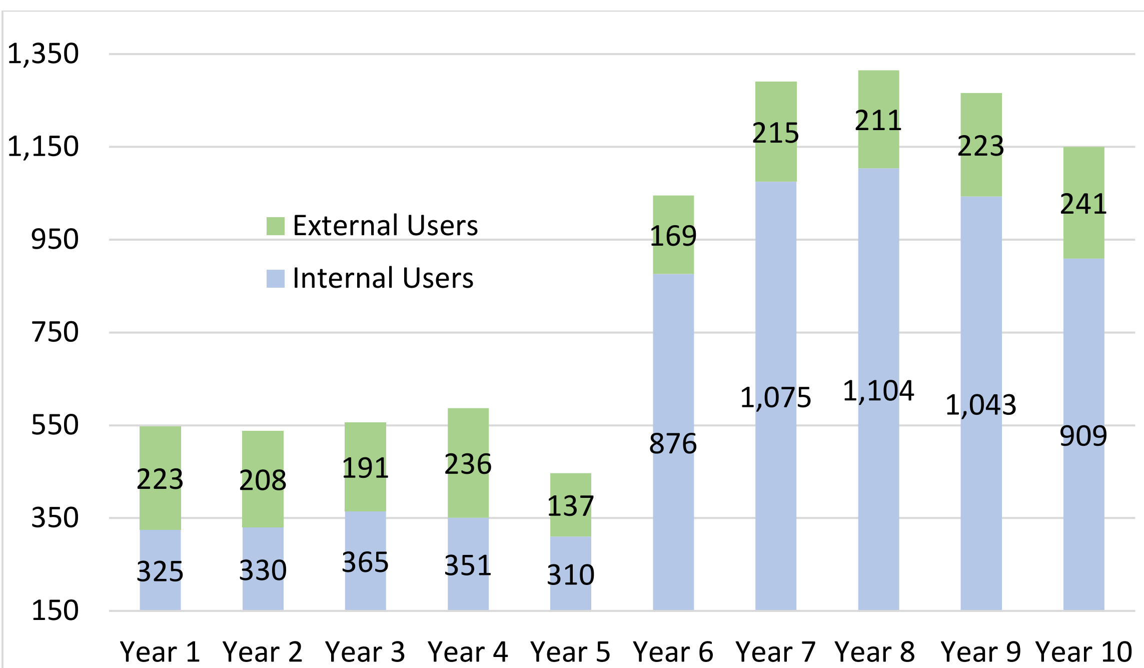
2025 Nellie Whetten Award winner

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 Yeryun Cheon from Department of Physics, Cornell University (Figure 5).

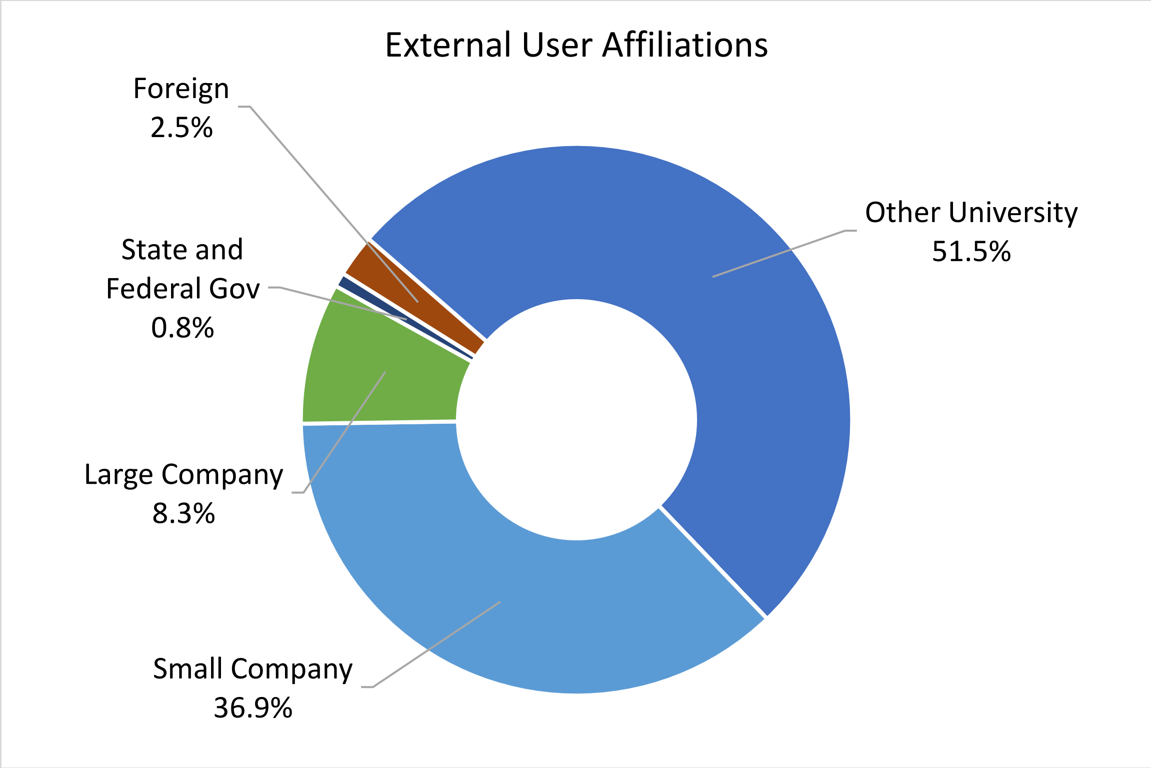
CNF is committed to advancing education, outreach, and workforce development in micro- and nanotechnology. We are proud to innovate, strengthen partnerships, and help drive this growing U.S. industry.

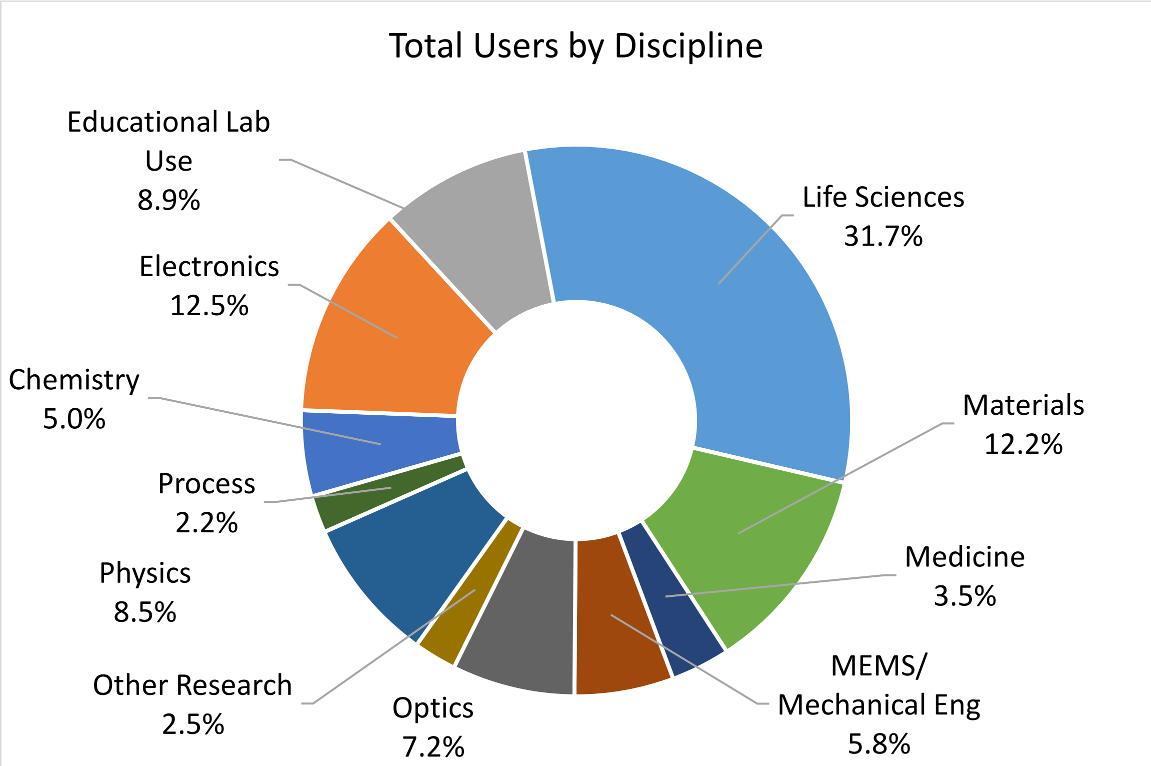
CNF Site Statistics

Yearly User Data Comparison					
	Year 6	Year 7	Year 8	Year 9	Year 10
Total Cumulative Users	1,045	1,290	1,315	1,266	1,150
Internal Cumulative Users	876	1,075	1,104	1,043	909
External Cumulative Users	169 (16%)	215 (17%)	211 (16%)	223 (18%)	241 (21%)
Total Hours	53,688	63,421	62,069	71,925	69,909
Internal Hours	38,571	46,695	47,544	53,356	51,632
External Hours	15,117 (28%)	16,726 (26%)	14,525 (23%)	18,570 (26%)	17,377 (25%)
Average Monthly Users	332	396	397	410	400
Average External Monthly Users	59 (18%)	65 (16%)	55 (14%)	63 (15%)	66 (17%)
New Users Trained	355	361	338	487	408
New External Users Trained	42 (12%)	77 (21%)	72 (21%)	81 (17%)	95 (23%)
Hours/User (Internal)	44	43	43	51	57
Hours/User (External)	89	78	69	83	72



CNF Year 10 User Distribution





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

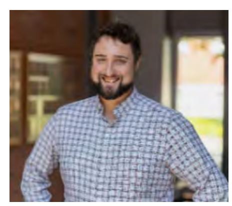
<u>Facility, Tools, and Staff Updates</u>

Facilities: The University of Louisville opened a new Engineering Student Success and Research Building (ESSRB) on Aug 1, 2025. This 4-story, 120,000 sq ft, $90M building took 4 years from design phase to final completion. The ESSRB also serves as the new home for the UofL Conn Center for Renewable Energy Research (CCRER), which is one of the 8 cores of KY Multiscale. The Conn Center Core occupies the top 2 futuristic floors of the building. The new central location of the Conn Center will enhance its visibility and better attract researchers, core users, and undergraduate participation.

UofL New Engineering Building

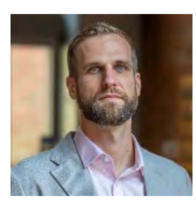
Tools and Equipment: In Year 10, several key equipment upgrades were made across the University of Kentucky and University of Louisville facilities, significantly enhancing research and training capabilities. The UK Electron Microscopy Center added a high-performance Olympus DS-100 scanning optical microscope, a fast elemental-analysis LIBS system, an inert-atmosphere MBraun glovebox for air-sensitive materials, and a new Bruker Dektak XT surface profiler essential for thin-film metrology. At UofL, the Micro/Nano Technology Center replaced its profiler with the Bruker B527 Dektak Pro 2024, offering industry-leading precision for surface characterization. The Additive Manufacturing Institute of Science & Technology focused on educational enhancements, acquiring multiple advanced 3D printers—including two Phrozen Sonic Mega 8K S printers for large, high-detail prints, the professional-grade Bambu Lab X1E for high-performance materials, and the multi-color Bambu Lab P1S—to support training programs and expand additive manufacturing capabilities.

Faculty & Staff Updates:

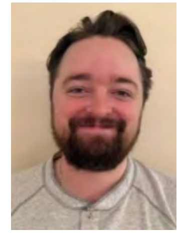


Dr. Michael Hovish joined the University of Kentucky as an Assistant Professor in the Department of Chemical and Materials Engineering. He holds a B.S. in Nanoscale Science from SUNY Albany and M.S./Ph.D. degrees in Materials Science & Engineering from Stanford University. Dr. Hovish's research focuses on nanomaterials, functional thin films, environmental barrier coatings, and materials for clean-energy applications, including hydrogen technologies. His lab emphasizes scalable synthesis techniques and materials design "from atom to application" to address sustainability and energy challenges. Dr. Hovish is currently building a new research program and laboratory at UK dedicated to advanced materials innovation.

Mechanical and Aerospace Eng, University of Kentucky



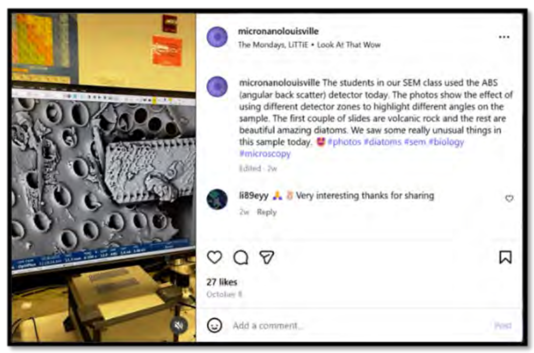
Dr. Jonathan Zuidema joined the University of Kentucky as an Assistant Professor in Mechanical and Aerospace Engineering, with a joint appointment in Physiology. He earned his B.S. in Biomedical Engineering from Michigan Technological University and his Ph.D. from Rensselaer Polytechnic Institute. Dr. Zuidema completed postdoctoral training at UC San Diego and was a Marie Skłodowska-Curie Fellow at the Mario Negri Institute in Italy before joining UK in 2024. His research focuses on multiscale biomaterials, integrating nano- and microscale structures into engineered scaffolds to improve neuromuscular regeneration, drug delivery, and tissue repair. His lab develops advanced fabrication methods, including spray-based techniques and 3D printing, to create functional materials for neural and musculoskeletal applications.



R. Nic Quammen is a Senior Research Associate in the U.K. College of Engineering supporting both the Electron Microscopy Center and Center for Nanoscale Science and Engineering. He supports nanofabrication and nanoscale imaging for research across the university with expertise in thin film deposition, lithography, and electron microscopy, enabling faculty, staff, and students to access advanced fabrication and imaging capabilities.

<u>User Base</u>

In Year 10, KY Multiscale continued to expand its visibility, user base, and educational impact through a broad set of marketing, outreach, and workforce initiatives. <u>*Marketing efforts*</u> remained strong, with the KY Multiscale Newsletter and targeted email campaigns reaching nearly 16,000 recipients, supported by a consulting service that provides analytics and professional templates. Social media engagement also grew substantially across LinkedIn, Facebook, Instagram, and YouTube, with each core facility managing its own channels to highlight equipment, capabilities, events, and educational opportunities. Short videos and SEM imagery remained especially effective in attracting new followers (see figure at right).



Video post on MNTC's Instagram Page.

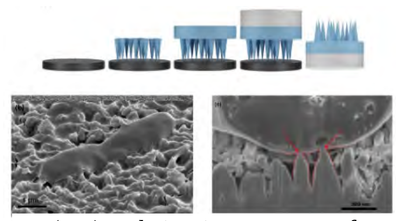
The KY Multiscale Seed Programs continued to stimulate new research activity by offering limited free access to facilities for first-time users, while the CeNSE Nanoscribe program at UK provided free nanoscale 3D prints to academic institutions. Educational and workforce development expanded through <u>*new and enhanced courses*</u>, including UofL's ECE-500 advanced electron microscopy class and a new microfabrication course for Chemical Engineers, as well as ongoing semiconductor curriculum development at UK. Additional training and outreach opportunities were supported through continuous <u>*imaging facility workshops*</u>, <u>*seed funding for non-traditional users,*</u> and robust <u>*K–12 and undergraduate programs including 3D printing camps*</u>, the <u>*IMPACT and AM NSF REU programs*</u>, and a <u>*Semiconductor Rapid Certification Program*</u> developed with OASiS and the University of Cincinnati. Year 10 also marked the second annual <u>*Chips Camp for high school students*</u>, supported by NSF, focused on semiconductor processing fundamentals.

A major highlight was <u>*KY Multiscale hosting the 2024 NNCI Annual Conference in Louisville*</u>, bringing together site directors, NSF officers, and representatives from all 16 NNCI sites to discuss progress, challenges, and future directions. The event featured technical sessions, cross-site collaboration discussions, and a social event at Churchill Downs, including recognition of NNCI staff award winners.

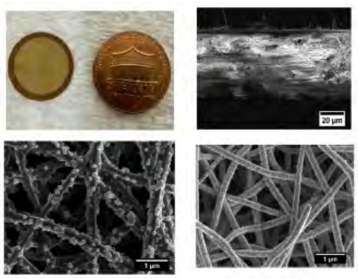
<u>Research Highlights and Impact</u>

KY Multiscale users achieved a diverse set of impactful research accomplishments this year, ranging from advanced antimicrobial surfaces to scalable materials for clean energy.

A team of interdisciplinary researchers at UofL led by **Dr. Chuang Qu (ECE Dept)** developed artificial mechano-fungicidal coatings composed of nanoneedles fabricated by a new patented process called Inverted Glancing Angle Deposition or I-GLAD. This new engineered material mimicked the antibacterial and antifungal properties found in nature with the moth eye. Teaming with biology, the group demonstrated the I-GLAD material was effective at physically rupturing fungal cells and offers a promising platform for antimicrobial surfaces in healthcare settings.



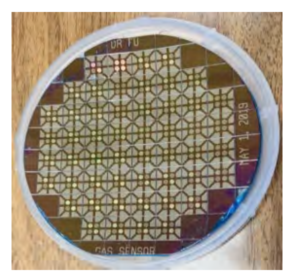
(top) Fabrication sequence for making the Inverted Glancing Angle Deposition nano-needle arrays. (bottom left) Fungi placed on the I-GLAD surface. (bottom right) SEM cross-section showing physical rupture of fungal cells at the nanoneedle/cell interface.



Metal coated electrospun mats that enhance nanoparticle trapping via dielectrophoresis.

Another UofL group led by **Prof. Stuart Williams (ME Dept)** created metal-coated electrospun nanofibers that dramatically enhance nanoparticle trapping via dielectrophoresis, enabling higher-throughput, non-contact nanoparticle filtration. The figure shows the patterned nanofiber mat (top left), a SEM image of the mat's cross-section showing the thin metal coating on top and bottom (top right), and SEM images of dried sputter-deposited NF mat depicting trapped particles: 100 nm particles (bottom left) and 40 nm particles (bottom right).

At the University of Kentucky, **Prof. Alexandra Paterson (ECE Dept)** and collaborators advanced the stability of organic electrochemical transistors by identifying oxygen-induced degradation pathways and introducing a pre-doping strategy that yields more robust, high-performance devices. UK researchers led by **Prof. Todd Hastings (ECE Dept)** also pioneered a method for generating wavelength-tunable fluorescent nanopatterns in polystyrene through controlled electron-beam irradiation.



4 inch silicon wafer containing an array of microfabricated gas sensors for detecting VOCs.

UofL investigators **Prof Xiao-An Fu (Che Dept)** and **Prof. Michael Nantz (Chem)** developed a microfabricated gas-sensor array using thiol-functionalized gold nanoparticles to detect harmful VOCs and cofounded **Breath Diagnostics** to commercialize the technology.

<u>Education and Outreach Activities</u>

During this reporting period, the KY Multiscale NNCI site engaged in a wide range of impactful education, outreach, workforce development, and academic initiatives that strengthened regional research capacity and broadened participation in STEM.

The site hosted several **major events,** most notably the *<u>NNI Shared Infrastructure Network Collaboration (SINC) Quarterly Meeting</u>* in October 2024, which brought federal agency representatives and nanotechnology infrastructure leaders to the University of Louisville for strategic discussions and tours of KY Multiscale facilities. KY Multiscale also welcomed the *<u>2024</u>*

Midwest Association of Core Directors (MWACD) Meeting, which convened research infrastructure professionals for technical sessions, facility tours, and strategic dialogues designed to advance shared research resources across the Midwest.

The site continued **advancing academic programs** aligned with national semiconductor workforce needs. Multiple new educational pathways in semiconductor manufacturing were developed or expanded, including a new *Semiconductor Manufacturing concentration within UofL's M.S. in Electrical and Computer Engineering program*, a newly approved *undergraduate Applied Engineering degree with semiconductor and robotics specializations*, and strengthened collaborations with the University of Kentucky's Computer Engineering Technology program, which utilized KY Multiscale cleanroom facilities to build chip-fabrication teaching capabilities. KY Multiscale also expanded its collaboration with Transylvania University, enabling undergraduate research in nanoscience and supporting the transition of students into graduate engineering programs.

Training programs and workshops remained a strong emphasis throughout the year. KY Multiscale's AMIST core delivered multiple *metal additive manufacturing training courses* for industry, offering both safety-focused and advanced production-focused modules. The site also hosted a *Kurt J. Lesker Vacuum Technology Workshop*, a *Bio-Imaging Workshop* centered on electron microscopy, and a multi-site *virtual training program called NanoSIMST* for middle school teachers through a collaboration of NNCI institutions. Additional outreach included a middle and high school *summer camp in 3D printing and additive manufacturing*, the AMIST "Nuts, Bolts, and Thingamajigs" camp for younger students, and continued statewide imaging workshops led by the MNTC in partnership with KY INBRE.

Undergraduate research experiences were a major success area. The NSF-supported *IMPACT REU program in micro/nano/additive manufacturing* provided ten weeks of hands-on research, technical training, professional development and educational seminars such as the *NNCI REEU Workshop on Entrepreneurship*, and conference participation for students nationwide. Participants presented their work both at UofL and at the *NNCI REU Convocation at UC San Diego*. KY Multiscale also supported two additional REU programs at the University of Kentucky—*Research in Symmetries and Engineered Bioactive Interfaces & Devices*—by providing equipment access, training, and process development guidance. The site additionally hosted *a Japanese graduate student from the National Institute for Materials Science (NIMS)*, continuing NNCI's long-standing international exchange and strengthening collaborations between U.S. and Japanese nanotechnology research networks.

Teacher engagement also grew through two *NSF Research Experience for Teachers (RET) programs*: one focused on renewable energy and engineering design, and another focused on additive manufacturing, robotics, and automation. Both programs provided high-school teachers and community-college faculty with hands-on research experiences to help translate advanced technologies into classroom curricula.

Throughout the year, KY Multiscale reinforced its commitment to **statewide partnerships**, particularly through its ongoing collaboration with the *KY INBRE network*, which has expanded access to imaging facilities, training, and workshops for biomedical researchers across Kentucky.

Collectively, these activities demonstrate KY Multiscale's broad and growing impact on regional research infrastructure, STEM education, semiconductor and manufacturing workforce training, teacher preparation, and undergraduate research. Through extensive partnerships, targeted academic programs, and accessible training opportunities, the site continues to strengthen the pipeline of students, educators, and researchers engaged in micro/nano/additive manufacturing and related technologies across Kentucky and the broader Midwest region.

Computation Activities

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

The state-of-the-art core facilities of KY Multiscale have been used by many startup companies to help develop their commercial products, as highlighted at right. These include both university-affiliated startups founded by university professors and researchers who transitioned their grant-funded projects into new companies, as well as a host of regional non-university-affiliated startups who heavily rely on KY Multiscale's extensive core facilities, equipment, and experienced staff for their prototyping fabrication and characterization needs.

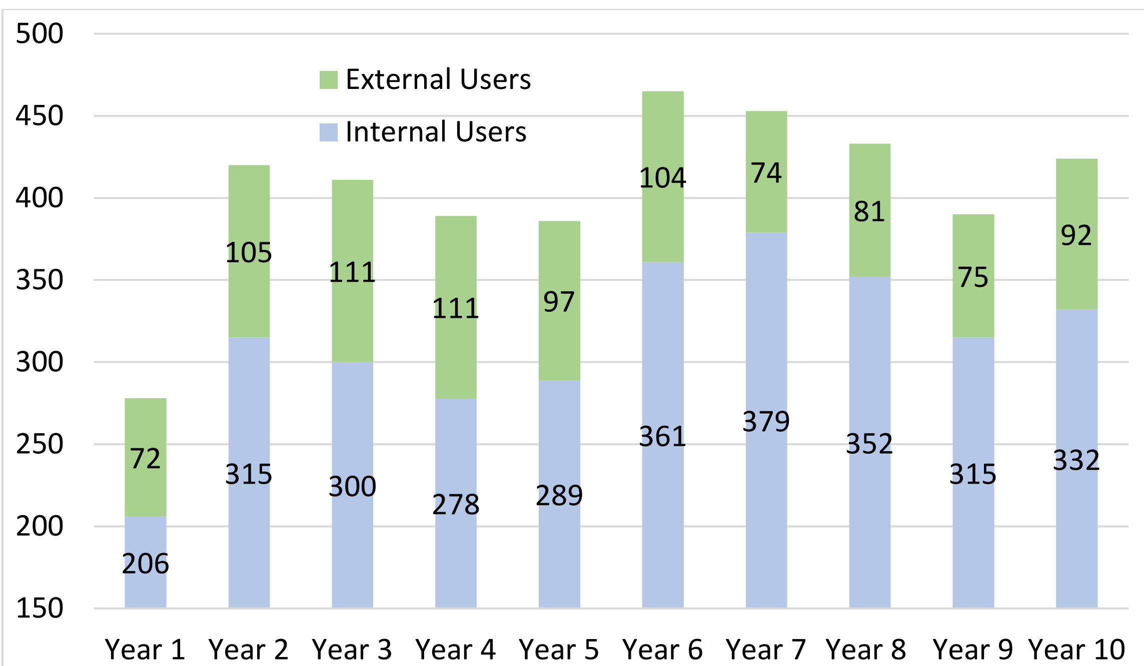
Some of the local and regional startup companies which leverage the KY Multiscale core facilities and their staff.

Since the summer of 2023, KY Multiscale has been an active participant in the NNCI Research and Entrepreneurship Experience for Undergraduates (REEU) initiative. This includes participation in a workshop on entrepreneurship offered by the NNCI NanoEarth site at Virginia Tech led by Dr. Mathew Hull. We leverage this partnership to enrich our IMPACT NSF REU Program by integrating a one-hour seminar focused on helping undergraduates explore alternative career paths enabled by nanotechnology research and innovation. This opportunity is especially valuable for our REU participants because it broadens their understanding of how scientific and engineering skills translate beyond academia. By introducing students to entrepreneurial thinking, technology commercialization, and real-world problem-solving, the workshop empowers them to envision diverse futures in industry, startups, and innovation-driven research environments.

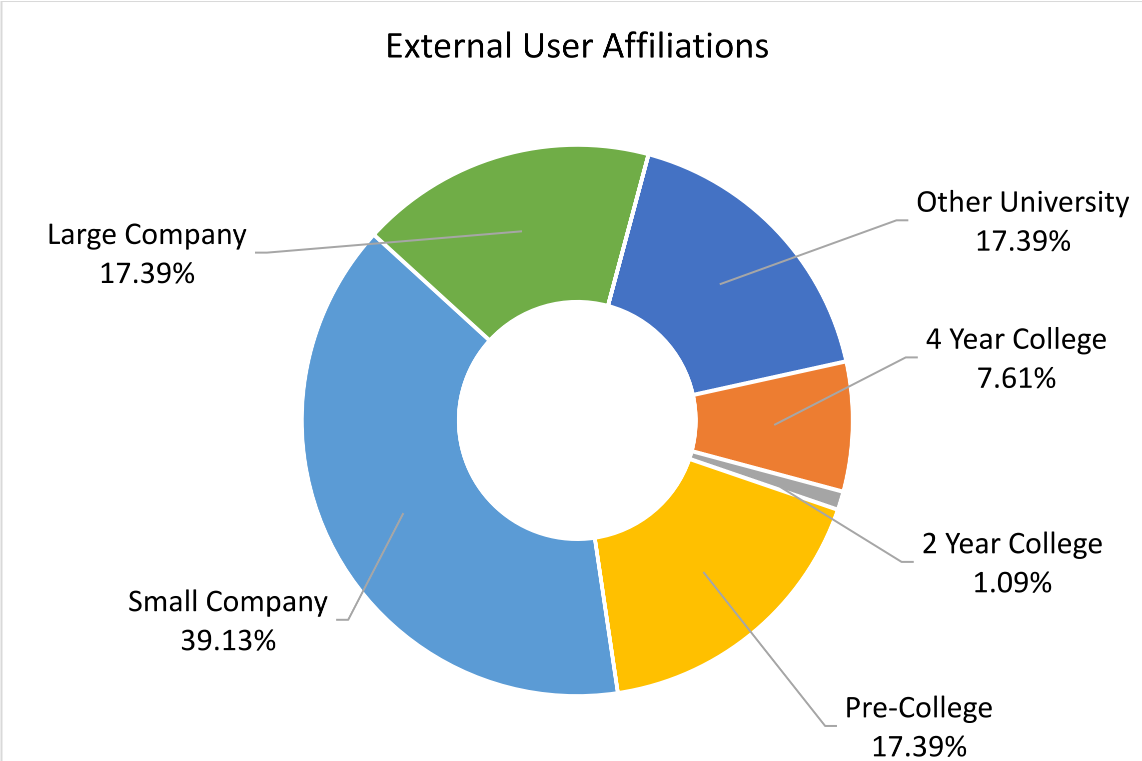
Kentucky received a $500,000 grant from the U.S. Tech Hubs Program to establish REBECCA (Regional Energy Business, Education, and Commercialization Convergence Accelerator) in Louisville, focusing on advanced materials science and energy innovation, including research in composites, batteries, hydrogen, and solar power. REBECCA 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.

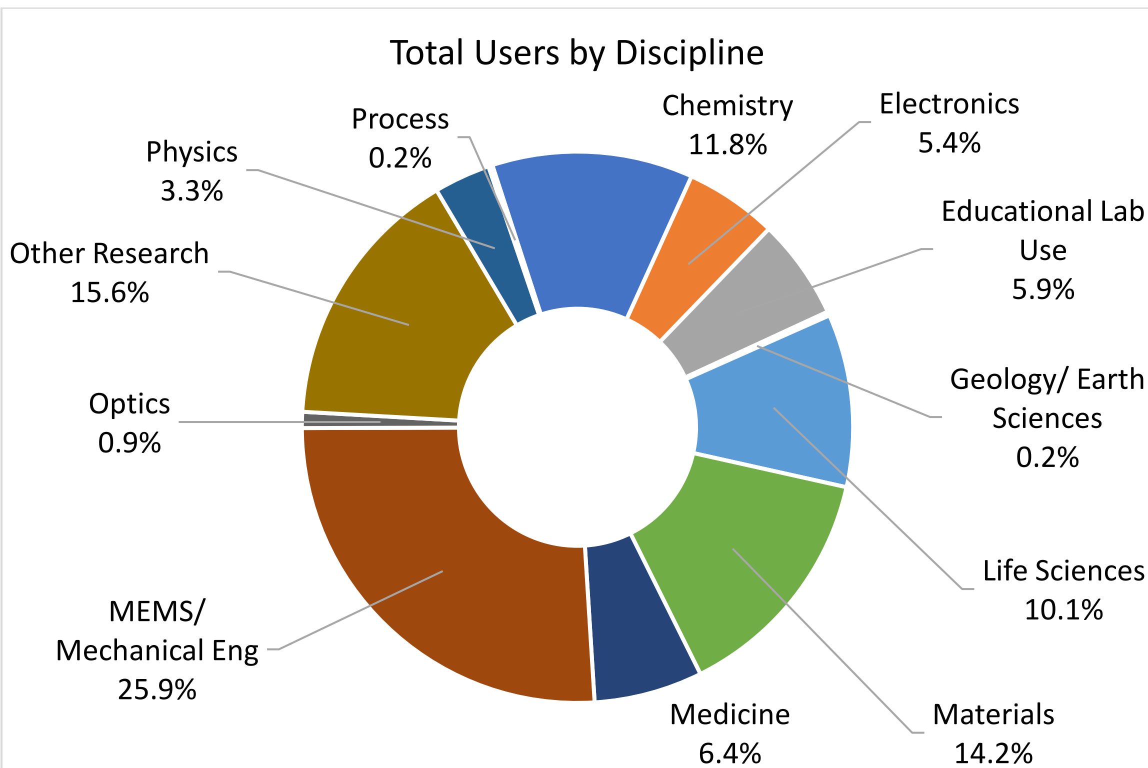
KY Multiscale Site Statistics

Yearly User Data Comparison					
	Year 6	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Total Cumulative Users	465	453	433	390	424
Internal Cumulative Users	361	379	352	315	332
External Cumulative Users	104 (22%)	74 (16%)	81 (19%)	75 (19%)	92 (22%)
Total Hours	14,220	12,387	14,440	14,816	10,477
Internal Hours	10,282	10,128	11,884	12,452	7,451
External Hours	3,938 (28%)	2,259 (18%)	2,557 (18%)	2,364 (16%)	3,026 (29%)
Average Monthly Users	127	121	137	135	119
Average External Monthly Users	25 (20%)	17 (14%)	22 (16%)	19 (14%)	19 (16%)
New Users Trained	165	151	125	129	254
New External Users Trained	19 (12%)	17 (11%)	10 (8%)	6 (5%)	6 (2%)
Hours/User (Internal)	28	27	34	40	22
Hours/User (External)	38	31	32	32	33



KY Multiscale Year 10 User Distribution





12.4. Mid-Atlantic Nanotechnology Hub (MANTH)

Facility, Tools, and Staff Updates

Quattrone Nanofabrication Facility

The QNF cleanroom has recently installed the **IntlVac NanoQuest 1 IBE**, an ion mill capable of etching small mm-scale samples up to full 4″ wafers. Similarly, another etching system newly installed in the QNF cleanroom is the **PIE Scientific Tergeo-Plus Cleaner**, an RF etcher designed for sample cleaning and ashing of resist with a maximum power of 500 W. These tools significantly enhance the QNF cleanroom's capabilities in precise material processing and sample preparation, supporting a wide range of applications.

In addition to new etching tools, the cleanroom has installed a new tool for deposition. The **IntlVac Nanochrome Electron Beam Evaporator** has a base process chamber pressure in the low e-8 Torr range with substrate heating and ozone purging capabilities. Additionally, the cleanroom has installed the **Rapid Thermal Annealer**, an advanced bench-top rapid thermal processing system with multi-gas capabilities. The integrated process control system features real-time graphics, recipe management, data acquisition and display and has a comprehensive diagnostic function.

Scanning and Local Probe

The scanning and local probe facility installed a **Keyence VK-X300 laser profilometer** in the spring of 2024. This fast-imaging (about 30 seconds per image) microscope generates topographic maps of specimens with sub-micrometer resolution, as well as film thickness measurements. Our researchers use it to measure critical dimensions and roughness of samples and as an inspection tool in preparation for more detailed examination in AFMs and SEMs. It was purchased via a consortium of professors with matching funds from the School of Engineering and Applied Science.

Nanoscale Characterization

A **Zeiss Orion Nanofab Helium Ion Microscope (HIM)** was donated to the university this year by the Exxon/Mobile Corporation, and is now housed in our characterization facility. Additionally, the NCF acquired a **Gatan Model 626 Cryo-Transfer TEM holder**. This holder allows for the introduction of cryogenic samples into the TEM, but can also accommodate in Situ cooling in the microscope.

The data handling resources of the facility were dramatically increased with the installation of a 300 Tb storage server. Funding for this server was provided by the LRSM/MRSEC grant. Although the installation and configuration of this new server are still ongoing, it will ultimately house a centralized location for the new Nexus-LIMS storage and archiving infrastructure. The Nexus-LIMS system will provide a fully customizable platform with which to collect, organize, query, and disseminate scientific data. In addition to the Nexus-LIMS usage, the storage server will provide for much-needed storage space for data archived from our instruments.

User Base

Hands-On Workshops

We continue to offer our popular Microfluidic Soft Lithography Workshops. The six-hour session consists of a lecture followed by a hands-on device fabrication tutorial in the MANTH soft lithography cleanroom. These workshops were found to be an effective form of outreach to local such as Penn Medicine, Drexel, Temple, and Jefferson, as well as to other researchers in the region. Researchers in MD/PhD programs were our traditional target audience, but we have found that industrial researchers also avail themselves to these workshops. Most recently, several researchers from Villanova University attended one of these microfluidics workshops in April 2025.

Additionally, MANTH conducted nanofabrication hands-on laboratory sessions that included lithography, etch, and deposition. Participants included all Singh REU students and several REU students in other programs, undergraduates from Jefferson University, professionals participating in Manufacturing Career Acceleration Program (MCAP) at Drexel University. Additionally, a lithography laboratory was provided to high school students attending the Penn LENS program. A cleanroom demo and tour were given to RET program participants and Clark Scholar.

Wednesday Open Forum Process Sessions

Staff members continue to hold an open forum for users in the MANTH community each Wednesday afternoon from 2pm to 4pm. These forums connect Singh Center staff members with researchers in an informal setting in order to provide solutions to fabrication or characterization problems. Researchers with a limited background in fabrication can get advice from staff and their community peers to work through the challenges from one of 4 half-hour slots that are fully subscribed each week. MANTH offers virtual forum discussions as well in-person. This hybrid approach has proved to be especially helpful to new external users who must travel far to participate.

Singh Center Seminar Series

The Singh Center Seminar Series is a forum designed to strengthen collaboration and knowledge-sharing between facility users and staff.

Each session features two focused, 15-minute presentations:

- User Presentation: A facility user shares their most recent project results, discussing achievements, experimental challenges, and successful solutions developed using the Singh Center resources. This provides a vital platform for users from diverse, interdisciplinary backgrounds (e.g., microfluidics, ferroelectric devices, additive nanoimprinting, microsensors) to share their work.
- Staff Presentation: A staff member presents on a topic aligned with their technical expertise (e.g., photoemission spectroscopy, electron beam lithography, ellipsometry, photolithography) or a live tool demonstration to showcase practical application.

This combined approach facilitates fruitful and productive discussions. It offers staff the opportunity to strategize process optimization and envision laboratory improvements, while users gain valuable insight into the center's operations and can leverage the staff's deep scientific and technical expertise.

<u>Research Highlights and Impact</u>

During the calendar year 2024, the Singh Center enabled 319 scientific publications, 45 conference presentations, and 106 patents filed, disclosures filed, or patent applications submitted by our users. Additionally, MANTH NNCI contract (ECCS-1542153 or NNCI-1542153 or NNCI-2025608) was acknowledged 224 times since January 2024 and 704 times in total (since 2018), according to Google Scholar statistics. This represents a record high number of acknowledgements in a single reporting year. These research activities represent a broad range of research areas, covering many of the NSF 10 Big Ideas (including *Understanding the Rules of Life*, *Growing Convergence Research*, and *Quantum Leap*.)

Notable works published with the support of our facilities include Modi et al. 2024, which was published in *Nature*. In this paper, the authors discuss an energy-efficient long-range solid-state amorphization in a new ferroic β″-phase of indium selenide nanowires through the application of a direct-current bias rather than a pulsed electrical stimulus. By identifying previously unknown multimodal coupling mechanisms of the ferroic order in materials to the externally applied electric field, this research can be useful to design new materials and devices for low-power electronic and photonic applications. Device fabrication work and electron microscopy for this project was conducted at the Singh Center for Nanotechnology, which is supported by the NSF National Nanotechnology Coordinated Infrastructure Program under grant no. NNCI-2025608 and through the University of Pennsylvania Materials Research Science and Engineering Center (MRSEC) (grant no. DMR-1720530).

Education and Outreach Activities

2024 NanoDay@Penn

Since 2022, MANTH has provided in-person, hands-on laboratory sessions at local middle/high schools instead. The presentations at students' schools enabled students to attend the NanoDay in their classrooms without a field trip.

On NanoDay @ Penn 2024, MANTH has collaborated with Drexel University, Villanova University and Geoppert LLC, to provide 40 in-person lab sessions at elementary/middle/high schools and 7 online sessions.

The topics include semiconductors, energy, nanomaterials, quantum dots, levitation, neural devices, electron microscopy, scanning force microscopy, material design, hydrogels, nano-kiri/origami, machine learning and career development.

Over the past two years, the event was scaled-up. Whereas about 100 students attended in the past years, over 400, 600 and 1100 participants attended in 2022, 2023 and 2024 respectively. According to the post-survey, 27.3% and 66.1% of students answered the NanoDay elevated and maintained their interest in pursuing a STEM career in the future (N=436). Meanwhile, 6.6% of students answered they have less interest in STEM career, respectively.

Research Experience for Undergraduates (REU)

Seven students were selected for the Summer 2025 program, which will begin in June 2025. Their faculty mentors all have active research projects utilizing MANTH facilities.

As in previous years, these students come from both local institutions such as Johns Hopkins University and Wesleyan, and from those further away, including the University of South Florida and the University of California, Davis. Additionally, the students come from a diverse mix of scientific subdisciplines, reflecting the interdisciplinary spirit of the program.

CCP Nano Internship

The Singh Center hosted its third cohort of Community College of Philadelphia (CCP) interns from May 12 through August 15, 2025. Over the 14 weeks, 20-hours/week, the four interns moved through basic safety and nanofabrication training (lithography, etching, deposition, soft-lithography) and on to working on a project of choice. Their internship required hands-on work with their devices and samples, attending lectures, assisting instructors with education programs, and presenting ongoing and final work in the GSF-Nano Intern-REU joint weekly meetings.

Engineering Summer Academy at Penn (ESAP)

Penn Engineering hosts highly motivated and talented high school students throughout the world to the Engineering Summer Academy at Penn (ESAP) every year for 3 weeks in July. The ESAP Nanotechnology concentration is one of six courses designed to introduce nanotechnology to selected high school students at the college level.

MANTH developed new content to enhance both theoretical background and hands-on processing lab modules in the cleanroom. Additionally, the students attended career and research talks from Penn faculty and graduate students, as well as industry speakers. These sessions provided students with exposure to a wide range of career paths and demonstrated the breadth of nanotechnology applications.

Graduate Student Fellow Program

MANTH launched the Graduate Student Fellow (GSF) program in 2015 in order to provide Master's degree students with a hands-on nanofabrication experience in our research cleanroom. The program starts in June and ends in May of the following year. Since the start of the program, a total of 142 awardees have been selected based on their research interest and motivation, but without taking into account previous nanofabrication expertise. This number includes 13 students, the newest GSF cohort for FY 2026, who have not yet graduated. The students develop skills in nanofabricating devices and establishing advanced processes. They develop and run educational programs for MANTH in the form of lab course modules, workshops, and outreach events for Penn and high school students. They also mentored interns from the Community College of Philadelphia.

Over past years, GSF students have created MEMS devices, graphene transistors and pH sensors, CdSe quantum dots, and directed self-assembly templates for a graduate lab course; a solar cell for an undergraduate lab course; and they created processes to create metalens, neural devices, resistive memory, spin-orbit torque magnetic random-access memory, high altitude flight, greyscale lithography, ferroelectric device, structural color, nanomembrane, artificial microtubules, structural microvalves, a high throughput drop generator, microheaters, multi-directional 3D microchannels, and nanowells. The most recent projects include the fabrication of memristors for AI, machine learning for micrograph image analysis, and the prediction of quantum dot size.

<u>Innovation and Entrepreneurship Activities</u>

Innovation Seed Grant Program

The Innovation Seed Grant (ISG) Program continues to offer academic research groups and startups a seed for their first-time engagement with MANTH at the Singh Center for Nanotechnology with non-dilutive funding. MANTH leverages the ISG to invite external users to realize ideas and innovation independently of the University of Pennsylvania's research enterprise. This year MANTH's Innovation Seed Grant Competition received 20+ entries. The applicants range from undergraduate students to faculty from Johns Hopkins, NJIT, Rowan, Rutgers, Swarthmore, Temple, University of Central Florida, Delaware, UMBC, and Villanova. Of the applicants, seventeen (17) were selected as finalists.

This year's program showcases a broad range of interdisciplinary research projects that leverage the advanced nanofabrication and characterization tools at the **Singh Center for Nanotechnology.** The proposals reflect pressing research needs across sectors of healthcare, energy, computing, environment, and advanced materials.

MANTH's microscopy (TEM, SEM, AFM), lithography, confocal imaging, and wet bench capabilities are extensively used. Notable was an emphasis on interdisciplinary applications: nanomedicine, energy systems, materials engineering, and quantum devices reflecting the critical role of shared nanotechnology infrastructure in enabling transformative, cross-sector research. MANTH's unique toolsets and expertise remain essential in advancing the region's research competitiveness and innovation capacity.

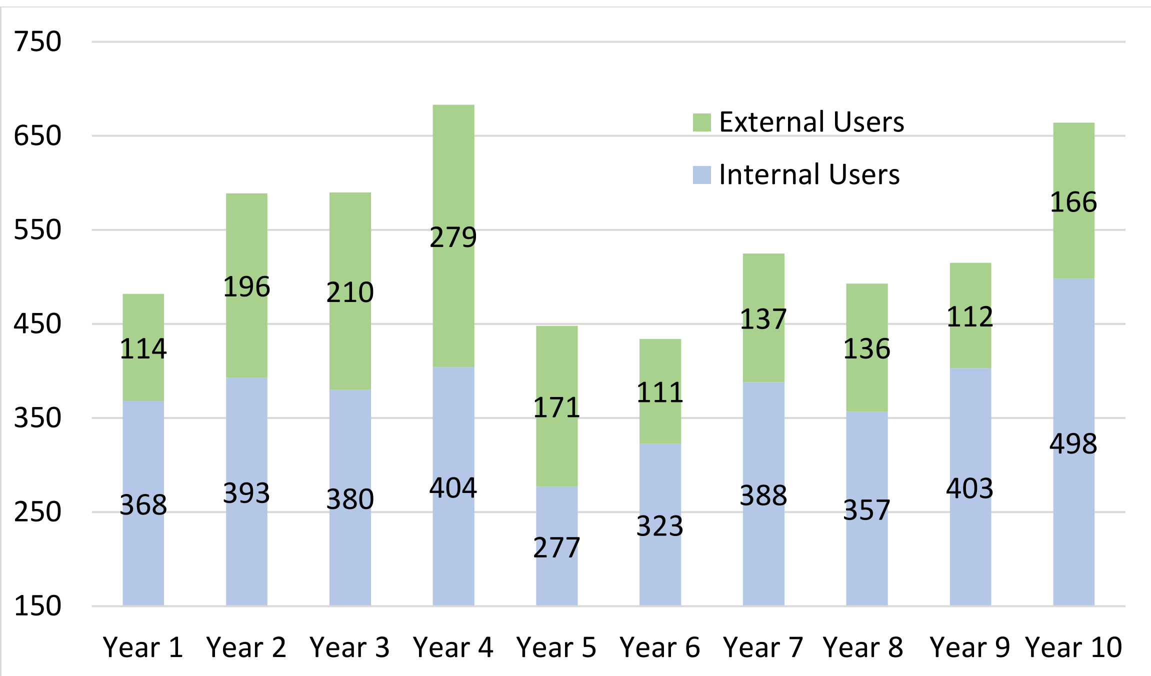
CLUB Nano Edge Membership Program

The CLUB Nano Edge Membership Program de-risks the cost of exploratory research and development for the nanofabrication of novel devices. The program is geared toward startup companies and larger corporate organizations. CLUB Nano Edge provides exclusive access to MANTH's QNF tools, instrumentation, and general lab space, along with a platform to support a variety of materials and substrates of various shapes and sizes while providing world-class service from our full-time professional staff. We promote our non-predatory intellectual property (IP) policy as a multi-user facility and service center.

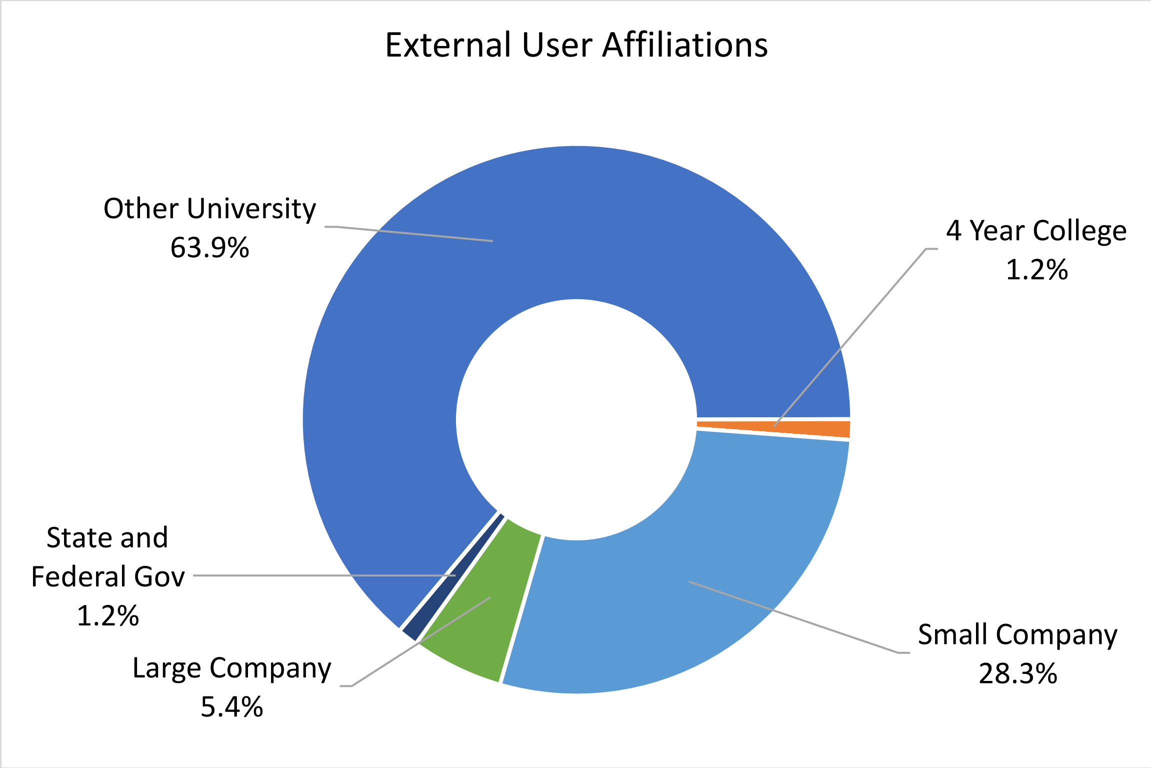
Affordable access to micro/nanofabrication resources is achieved by providing publicly traded organizations a competitive industry rate with a 25% match to deposit that is used towards incurred lab and tool use. Smaller private start-ups and small businesses are defined as not publicly traded with less than 50 employees and participate with a 100% match to deposit that is credited to the use of any incurred lab or tool use. Initial engagement requires a minimum of three months. Both the deposit and match must be used within the specified membership term. To date, over a dozen companies have participated in our program.

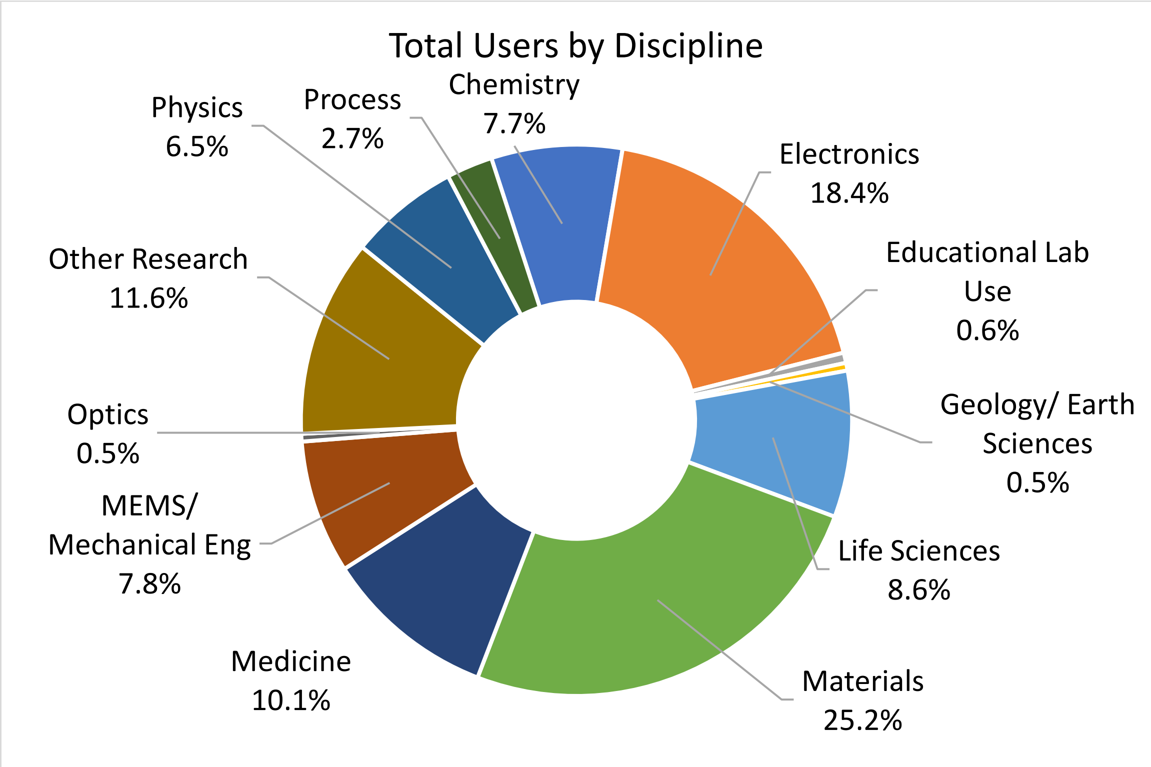
MANTH Site Statistics

Yearly User Data Comparison					
	Year 6	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Total Cumulative Users	434	525	493	515	664
Internal Cumulative Users	323	388	357	403	498
External Cumulative Users	111 (26%)	137 (26%)	136 (28%)	112 (22%)	166 (25%)
Total Hours	63,945	56,729	63,902	60,536	82,600
Internal Hours	58,094	50,921	56,042	55,610	71,494
External Hours	5,851 (9%)	5,807 (10%)	7,860 (12%)	4,926 (8%)	11,106 (13%)
Average Monthly Users	180	216	212	210	239
Average External Monthly Users	25 (14%)	37 (17%)	36 (17%)	29 (14%)	41 (17%)
New Users Trained	186	215	213	237	170
New External Users Trained	52 (28%)	72 (33%)	79 (37%)	64 (27%)	55 (32%)
Hours/User (Internal)	180	131	157	138	144
Hours/User (External)	53	42	58	44	67



MANTH Year 10 User Distribution





12.5. Midwest Nanotechnology Infrastructure Corridor (MiNIC)

Facility, Tools, and Staff Updates

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 **(15 at MNC and 10 at CharFac)**, 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 installed the Raith Picomaster 200 configured with backside alignment, dual laser sources of 375 nm and 405 nm, and multiple write-heads. This capability enables customized patterns to be written that blend high write-speed with a resolution limit of 0.3 µm. The new direct-write system replaces 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.

The MNC also acquired a 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) in a cleanroom setting.

The MNC was awarded Grant-in-Aid funding through University of Minnesota, Research & Innovation Office (RIO) to support the purchase of a Solaris 200 Rapid Thermal Processing (RTP) system. The Solaris 200 is a compact, research-grade system capable of processing wafers up to 200 mm and reaching temperatures up to 1200°C. In addition to enabling new research capabilities, this system will help prevent costly downtime and research interruptions by providing a more reliable and accessible processing option. Once installed, it will support a wide range of interdisciplinary nanoscience research projects across multiple departments.

The MNC was also selected as a recipient of the 2025 Research Infrastructure Investment Program award through RIO. This award will support the acquisition of a $1.75M next-generation Electron Beam Lithography (EBL) system. The new EBL tool will significantly enhance nanoscale patterning capabilities for users working in nanotechnology, microelectronics, and materials science by enabling higher throughput, finer resolution, and more complex pattern generation compared to the existing system. This investment will strengthen the facility’s role as a regional hub for advanced lithography research. MNC staff are currently evaluating EBL systems from Elionix and Raith and working with internal and external users to ensure that this infrastructure meets our current and future needs. We plan to initiate this purchase in early 2026.

Tool Updates: CharFac

During this reporting period, the CharFac acquired and installed 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 and LabSpec 6 software for instrument control, data acquisition and analysis.

Thermo Scientific Glacios 2 cryo TEM for Life Sciences: This system used to anlayze 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.

Thermo Scientific Aquilos 2 cryo FIB/SEM: This dual-beam cryo-FIB includes 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. This tool will support sample preparation for the new cryo TEM.

New MNC and CharFac staff

2025 has brought significant changes to the MNC leadership staff. The MNC hired Ms. Krista Ostrom as the administrator in January 2025 after the departure of Kristina Pearson. Ms. Claire Dietz was also hired in January as the Education and Outreach Coordinator following Jim Marti's retirement. Claire has expanded engagement with K-12, community colleges, and industry. Additionally, she supports workforce programs connected to the MNC and coordinates the RET program, SCALE, Quantum + Chips, and Global Quantum Leap programs. Finally, Prof. Sarah Swisher was named as the new MNC Director in May 2025, succeeding Prof. Steve Koester following his departure from UMN. The leadership of the MNC officially transferred to Prof. Swisher in July 2025, and she will serve as the MiNIC PI for the duration of the award period.

CharFac hired Dr. Ryan Abdella as the CryoEM Facility Manager. His background is in structural biology with over ten years of electron microscopy experience. He earned a B.A. from St. Olaf College in Chemistry and a Ph.D. from Northwestern University in Interdisciplinary Biological Sciences. He has worked on diverse topics, including eukaryotic and viral transcription, host-pathogen interactions, and enzymes with biotechnology applications.

User Base

User recruitment and outreach

During this reporting period, MiNICs successful user incentive program, *Explore Nano,* wound down as the funds were exhausted. The program offered a $2000 credit against fees for lab and tool use and training. However, 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. 2024); exhibits at the 2025 Design of Medical Devices conference connecting MiNIC capabilities to local and national companies working with medical devices and pharmaceuticals (April 2025); 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. 2025); increased outreach efforts using our LinkedIn page doubling our following this year and establishing bi-annual newsletters for both facilities.

Research Highlights and Impact

Below are brief summaries of some of the cutting-edge, high-impact research projects that were enabled by MiNIC during this reporting cycle. More details and figures are found in the separate highlight slides.

Efficient control of in-plane and out-of-plane spins in low-symmetry materials

In devices fabricated and characterized at MiNIC, a material with low crystal symmetry (Ni_4W) was shown to have efficient control of magnetization in electronic devices using spin-orbit torque (SOT). Unlike conventional high-symmetry materials, Ni_4W can more efficiently generate out-of-plane spin components. This breakthrough work was led by JP Wang (UMN ECE), and could enable smarter, more sustainable devices from smartphones to data centers. (Yang *et al.*, *Advanced Materials*, 2025)

Incipient ferroelectricity in freestanding nanomembrane FETs

In a collaboration with Penn State University, a UMN team led by Bharat Jalan and Andre Mkhoyan (CEMS) fabricated and characterized FETs using monolayer MoS_2 films integrated on freestanding $SrTiO_3$ nanomembranes. The STO exhibits incipient ferroelectricity between a traditional dielectric and true ferroelectric, giving the device tunable characteristics that may be beneficial for in-memory computing and neuromorphic applications. (Sen *et al.*, *Nature Communications*, 2024)

Inertia induced mixing in porous media flows

Fluid flow through porous media is important to understand for a wide range of systems including groundwater, aquifers, carbon sequestration, hydrogen storage, and contaminant transport. Using microfluidic devices fabricated at MiNIC, a team of researchers lead by Peter Kang (Earth & Env. Sci. Dept.) showed that, contrary to conventional wisdom, inertial recirculating flows significantly impact solute mixing and reaction rates within porous media. (Chen *et al.*, *Proceedings of the National Academy of Science*, 2024)

Selective chemical looping combustion of acetylene in ethylene-rich streams

A team from the CEMS department at UMN led by Aditya Bhan have described a new approach to remove acetylene during the purification of ethylene, an important raw material to produce comment plastics. An inexpensive Bi_2O_3 catalyst was used to remove acetylene (C_2H_2) with >99% efficiency. A collection of advanced materials characterization techniques (XRD, SEM, STEM, etc.) at MiNIC were used to understand the catalytically relevant surfaces. (Jacob *et al.*, *Science*, 2025)

Education and Outreach Activities

Microfabrication Technology Short Course

MiNIC is very involved with supporting workforce development for the microelectronics industry. Responding to the training needs identified by local semiconductor companies, in early 2023 MiNIC began working with these companies and the University of Minnesota's Technological Leadership Institute (TLI) to develop a short course to train new and incumbent workers on the basics of microfabrication technology. The course was intended to be hybrid, with ten self-paced online modules to be complemented by several weeks of hands-on training on the tools of microfabrication at the MNC. This initiative was bolstered when MiNIC and TLI applied for and received a grant from the state of Minnesota Department of Employment and Economic Development to help develop and disseminate the course materials. Representatives from three prominent local manufacturers joined this effort: Polar Semiconductor (Bloomington, MN), Honeywell Aerospace (Plymouth MN), and Collins Aerospace (formerly United Technologies, with facilities in Burnsville MN). The three companies helped to identify training priorities, and each pledged to enroll 20 of their employees as students in the initial run of the course, which came to be titled the Microfabrication Technology Short Course (MTSC).

The first cohort of enrolled company employees began the online MTSC content on December 1, 2023; hands-on training sessions were carried out between January – April 2024. The second cohort completed the Short Course between August 2024 through January 2025. The second iteration of the MTSC aimed to reach more employees from prominent local microfabrication and technology companies. In collaboration with our industry partners from Polar, Honeywell, Medtronic, Seagate and Collins Aerospace, we have successfully trained almost 100 of their employees through the MTSC.

Research Experience for Teachers (RET) Program

During the reporting period, MiNIC kicked off its first year of the Research Experience for Teachers (RET) program. Four educators were recruited from a mix of urban and suburban high schools and community colleges in the Twin Cities metro area. The educators were paired with four University of Minnesota faculty research groups, where they were immersed in cutting edge academic research. They also compiled a collection of activities, lessons, and resources on some aspect of nanoscience and technology to implement into their own classrooms this year. These activities have been compiled into a shared toolkit and after some editing will join the educational resources available via the NNCI website. RET program was professionally evaluated by Dr. Mary White of ASU, and Dr. White’s report for the 2024-25 cohort will be available to the NNCI Coordinating Office.

Facility Tours, Workshops, Tabling, and Teacher PD

MiNIC expanded its K-12 education offerings during the current reporting period, maintaining regular introductions to microelectronics and full cleanroom tours for visiting student groups but adding additional engagement with community STEM events like STEM Day at the State Fair and tabling at the State Science Fair. Over the past year the MNC collaborated with several organizations and school districts to reach more educators and students across the state including IEEE, SciMathMN, Minnesota STEM Ecosystem, Bloomington Public Schools, St. Paul Public Schools, and Minnesota Academy of Science; A total of 801 K-12 students and teachers were reached by our outreach effort during the reporting period.

Quantum+Chips Program

In the summer of 2025, MiNIC hosted another iteration of 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, cleanroom tours and hands-on workshops, and talks by industry and academia experts on the frontiers of quantum computing devices and technologies.

Minnesota SCALE Program

The Minnesota Scalable Asymmetric Lifecycle Engagement (SCALE) program continued to grow this year at the University of Minnesota after renewed funding. 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 from UMN, Metro State University, and University of St. Thomas aimed at targeted microelectronics specialty areas and to meet local semiconductor workforce needs of the defense sector.

The SCALE program added 15 students to the program this year and held two networking events with local employers in April 2025 and September 2025. These provided students with opportunities to speak directly with employers to learn about internships and hiring opportunities. Employers like Honeywell also visited the University to give guest lectures in courses. In the summer of 2025, MNC trained 16 students from St. Thomas and UMN with a week-long introduction to semiconductor fabrication course. Peggy Williams visited UMN, Metro State and St. Thomas in Sept. 2025 to discuss expansion of the SCALE program in MN and expressed her support for this program to receive increased appropriations.

Innovation and Entrepreneurship Activities

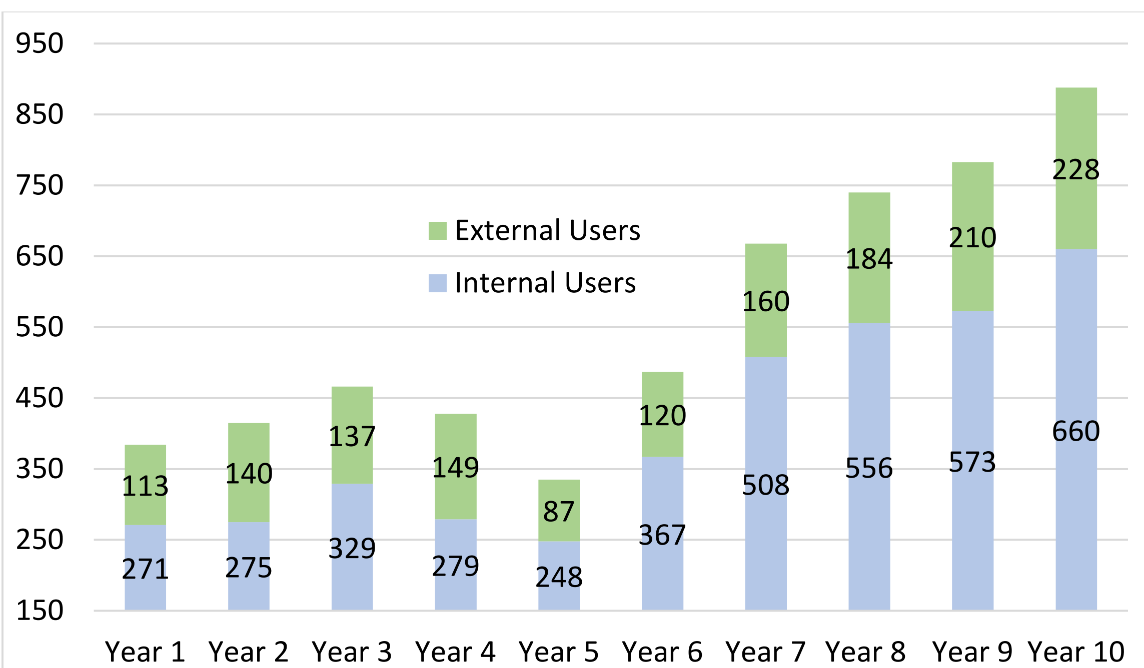
MiNIC supported the R&D efforts of over two dozen small companies and several UMN biotech startups during the reporting period. Below, we highlight two innovative local small companies using MiNIC who we have not highlighted previously.

FemtoFluidics is developing digital microfluidics technology built on thin film transistors. By leveraging the scale of nanofabrication, we're building high-density microfluidic devices capable of exploring vastly larger chemical spaces for data generation in drug discovery and biological research. We've been using MNC facilities for both nanofabrication and device assembly—particularly lithography and material deposition, as well as cleanroom space for final device assembly. FemtoFluidics is supported by both private venture capital and an NSF SBIR award.

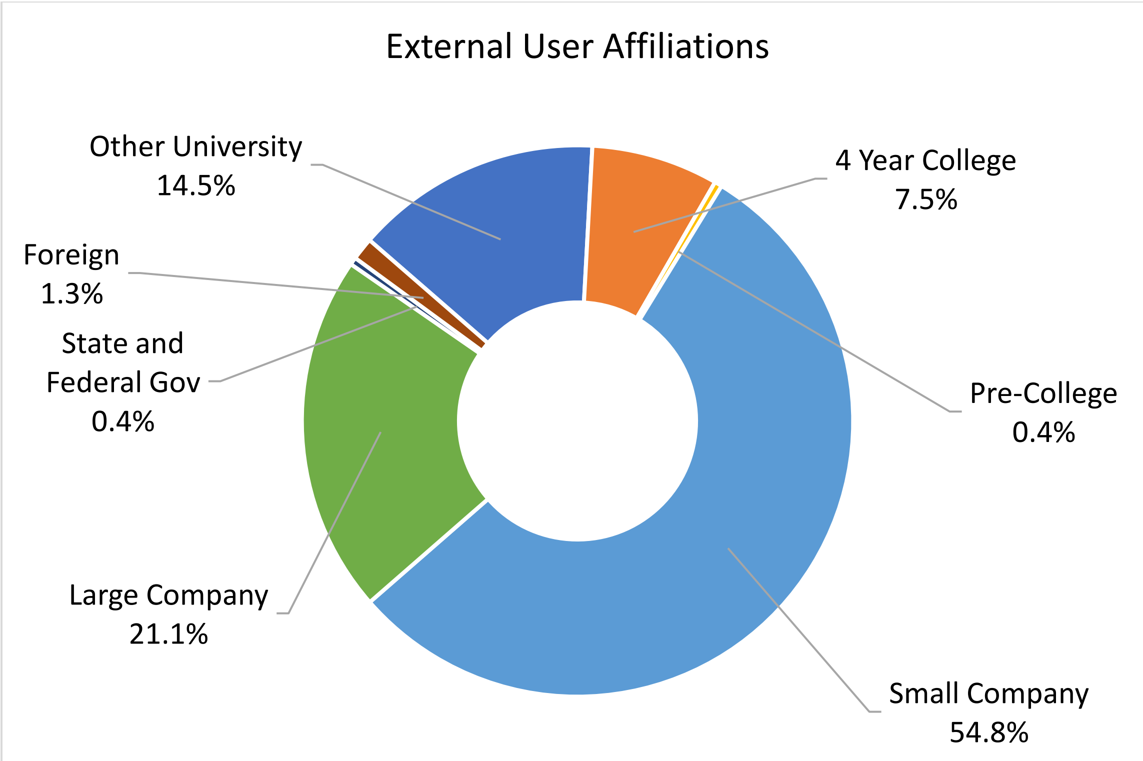
Niron Magnetics, a University of Minnesota start-up, is developing the world's first high-powered, permanent magnet made without the use of rare-earth materials and instead using iron and nitrogen. Niron utilizes CharFac for specialized analytical capabilities and high-tech services and instruments—such as electron microscopes and X-ray scattering machines—to engineering, earth, and biological scientists.

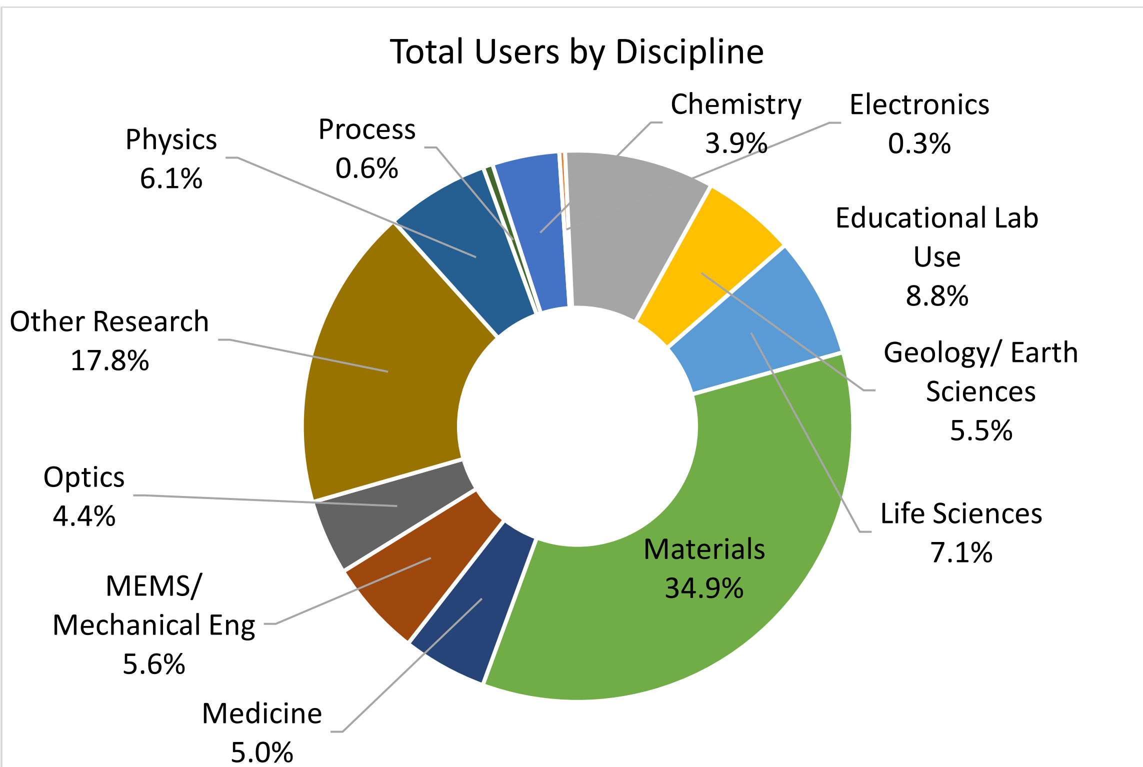
MiNIC Site Statistics

Yearly User Data Comparison					
	Year 6	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Total Cumulative Users	487	688	740	783	888
Internal Cumulative Users	367	508	556	573	660
External Cumulative Users	120 (25%)	160 (24%)	184 (25%)	210 (27%)	228 (26%)
Total Hours	27,317	31,916	32,707	34,358	29,009
Internal Hours	21,303	27,384	26,540	28,584	23,071
External Hours	6,014 (22%)	4,532 (14%)	6,167 (19%)	5,774 (17%)	5,938 (20%)
Average Monthly Users	165	235	254	277	230
Average External Monthly Users	31 (19%)	36 (15%)	38 (15%)	46 (17%)	44 (19%)
New Users Trained	213	280	298	313	43
New External Users Trained	39 (18%)	87 (31%)	118 (40%)	137 (44%)	16 (37%)
Hours/User (Internal)	58	54	48	50	35
Hours/User (External)	50	28	34	27	26



MiNIC Year 10 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-Y10 with the addition of about $12M in new instrumentation.

ICAL's NSF proposal for a new XPS was funded by the Division of Materials Research. The $833k instrument was much needed as the old XPS stopped working as has been unrepairable since 2020. The new Physical Electronics PHI Genesis features small (5 um) spot size, is fully automated, has SXI and an ion gun for depth profiling.

Scanning XPS/HAXPES PHI Genesis to be installed in ICAL. (PHI Genesis stock image)

MMF received a $1.1 million grant from the U.S. Economic Development Administration through its Regional Technology and Innovation Hubs program to support the rapid development of photonic integrated circuits. MMF will now be able to support the entire prototyping cycle, from inception to assembly to testing.

MMF's new RAITH Voyager electron beam lithography tool install is underway ($1.6M). Funding was awarded in 2024 by MSU's Quantum Core (funded by USAFRL).

In staffing updates, co-PI Dave Mogk retired in 2024 but is back on a temporary appointment to finish a few tasks related to online curriculum and web resources. These tutorials and lessons will continue to be available after MONT funding has expired.

User Base

We are pleased that the Year 10 user count has again reached an all-time high. MONT served 280 users, which is an increase from the Year 9 user count of 264 users. MONT served 52 external users who are 19% of user base and account for 26% of usage hours.

MONT awarded 11 **user grants to seed new projects** in Year 10

Eight internal user grants were awarded to:

- Yagmur Keskin, graduate student, Engineering Living Materials
- Dr. Robin Gerlach, Quantifying and Controlling the Motility of Ureolytic
- Jay Graham, graduate student, Device-Specific Etch Development for Wire Grid Polarizers
- Dr. Matt Jaffe, Nanotextured Cavity Optics
- Owen Satzman, graduate student, Process Development for Anti-Reflection Coatings
- Lea Molacek, graduate student, Method Development of PFAS Detection at the Mass Spec Core Facility

- Jordan Baker, graduate student, Process Development for Metal-Dielectric Multilayer Nanostructures
- Brueklyn Opp, graduate student, MALDI imaging of biosurfactant/cell aggregates under UV irradiation

Three external user grants were awarded to:

- Bret Davis, Wild Ideas, Characterizing parasites on wolverine hair
- Ana Barbosa, University of Porto, Portugal, Development of mRNA PNA-FISH for studying High-resolution Gene Expression and the Spatial Ecology of Legionella Pneumophila Biofilms.
- Roos Goedhart, Delft University of Technology, Netherlands, Minerals Meet Microbes, Illuminating Sand Grain Coatings in Groundwater Filters

Northwest Nano Lab Alliance (NWNLA) a 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. The 2025 meeting was held at the University of Washington with about 60 participants.

MONT is an active participant in **Micron's Northwest University Semiconductor Network. MONT received a $85k in funding from Micron** through this new network to support MMF student interns and for curriculum development for workforce preparedness. Micron has hired 5 interns and one permanent employee from MMF student staff.

Among other employment opportunities, MMF students toured the VACOM facility in Lewistown, MT. VACOM, a German company, opened the Lewistown facility in 2024. The company is a leader in vacuum technology and precision measurement systems and is hiring.

MONT is working to increase the student workforce. **The MMF now employs 22 undergraduate students**. 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 68 journal papers and 61 other products. MONT users had several outstanding accomplishments during the reporting period.

Doctoral student Nate Burman, Department of Microbiology and Cell Biology, has paper published in Nature. The paper, titled "A virally-encoded tRNA neutralizes the PARIS antiviral defense system," was fast-tracked for publication by the journal due to the importance of the findings. MSU doctoral student Nate Burman is the lead author, along with Professor Blake Wiedenheft, six other MSU scientists and collaborators from France, Russia and Sweden. The research explores the PARIS immune system, which bacteria use to protect themselves against viral infections. Work with PARIS, which stands for Phage Anti-Restriction Induced System, builds on Wiedenheft's ongoing CRISPR research, a field in which Wiedenheft is an internationally leading scientist. One of the crucial new findings in the paper is the first complete image of what the PARIS system looks like. To generate that image, Burman used MSU's cryo-EM, part of the MONT suite of tools. The structure of PARIS reveals a propeller-shaped complex that consumes ATP in search of invading viral proteins. Foreign protein detection triggers the release of a toxin that shuts down viral replication, protecting healthy cells.

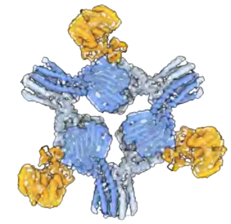


Image of PARIS molecule, captured by the cryo-EM at MSU. Image by Nate Burman

Dr. Bill Inskeep, Department of Land Resources and Environmental Sciences, along with other MSU faculty, has published an article in Nature Communications with new insights on how ancient microorganisms adapted from a low-oxygen environment an aerobic environment. The paper, "Respiratory Processes of Early-evolved Hyperthermophiles in Sulfidic and Low-oxygen Geothermal Microbial Communities," details how the team studied three thermophiles found in Yellowstone National Park in contrasting environments with differing oxygen and sulfide levels. The thermophiles in their respective environments can shed light on how life evolved prior to and through the Great Oxidation Event, the period roughly 2.4 billion years ago when Earth's atmosphere transitioned from having almost no oxygen to the nearly 20% oxygen content it has today. Inskeep used MONT's ICAL facility for electron microscopy and elemental analysis.

Bill Inskeep in his lab. Photo by Adrian Sanchez-Gonzalez

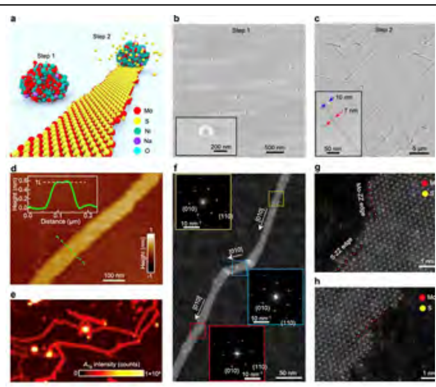
Dr. Anja Kunze, **Department of Electrical and Computer Engineering,** was featured in MSU's quarterly publication, Mountains and Minds. Kunze's work is focused on understanding what happens when the brain's neural networks break down due to neurodegenerative diseases like Alzheimer's. "We take these tiny cells and align and connect them to make a circuit, then a network," said Kunze, "Then we modify them to mimic neurodegeneration and learn about what is actually going on in the brain." Kunze's team uses MONT's MMF to etch and deposit thin films. Kunze and her team have shown they can also use magnetic nanoparticles to shape neuron growth.

Kunze, left, doctoral student Mackenna Landis, center, and undergraduate student Madeline Conrad examine a microfabricated device. Photo by Kelly Gorham

Dr. Madison Myers, Department of Earth Sciences, was awarded a NSF grant to study the Okmok volcano on Umnak Island in the Aleutian Islands, in collaboration with Dr. Anita Moore-Nall for the department of Native American Studies. Okmok erupts fairly frequently but with as little as four to five hours of warning. Because its eruptions are not preceded by strong warning signals, such as earthquakes, a goal of the MSU study is to improve scientists' ability to forecast imminent volcanic events to reduce risks to humans and property. Myers will oversee the analysis of rocks produced by the volcano during eruptions. Moore-Nall, who holds a doctorate in earth sciences from MSU, is developing an advanced seminar course she will teach on Indigenous ways of knowing in volcanic landscapes. ICAL will be used for geological analysis of volcanic material.

MSU students with earth sciences professor Madison Myers, second from right, and Native American Studies professor Anita Moore-Nall, right, study images related to Alaskan volcanic activity in ICAL. MSU photo by Colter Peterson

MSU's MonArk Quantum Foundry researchers, in collaboration with Columbia University and the Honda Research Institute, completed experiments that have resulted in the emission of single photons of light in a new type of quantum material which could lead to the development of controllable light sources for use in quantum technologies. A paper on the findings was published in **Nature Communications**. Samuel Wyss, a co-author and one of two MSU doctoral students who worked on the nanoscale manipulation of the 2D materials, said these nanoribbons are unlike any other materials that have been studied to date. "Studying the fundamental physics and these interactions in 2D semiconductors will allow us to engineer these materials for new electronic devices and unseen and unthought of applications," Wyss said. *Nat Commun* **15**, 10080 (2024). https://doi.org/10.1038/s41467-024-54413-9



Selected figure from paper Width-dependent continuous growth of atomically thin quantum nanoribbons for nanoalloy seeds in chalcogen vapor. The figure details the growth of nanoribbions on an F-mica substrate.

MONT continues to impact regional companies. During Year 10, MONT served the needs of 29 external companies (52 individual users from 10 large and 19 small entities).

Notable successes for our industrial users include 10 new SBIR/STTR Awards granted in 2024, totaling over $12M.

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 updated instrumentation modules on TEM and pXRF.

The SERC web collection continues to be a valuable resource, with the most traffic visiting the Methods pages. Google searches researching specific Instruments and Analytic Methods pages saw over 80,000 intense visitors. Overall, the site has had 102,177 visits during this reporting period. https://serc.carleton.edu/msu_nanotech/index.html

We continue working with the **Salish Kootenai College (SKC)** high school Upward Bound program to incorporate nanoscience/technology education on the Flathead Reservation in northwestern Montana. This year, SKC brought a small group of STEM interested students for facility tours and a lunch Q&A with MMF undergraduate student workers.

MONT was a key participant in MSU's **Quantum Summer Academy.** This weeklong camp introduced high school students and educators to the world of quantum, starting at the nanoscale. Students made silver nanoparticles and looked at their particles in the SEM. The camp hosted 30 students and 11 teachers.

Quantum camp student visitors in ICAL.

The **MONT Empower Scholars program** awarded five scholarships to place undergraduate students with MONT researchers for a research experience and tool training. Projects ranged from characterization of Ophiolite to brain on a chip device development.

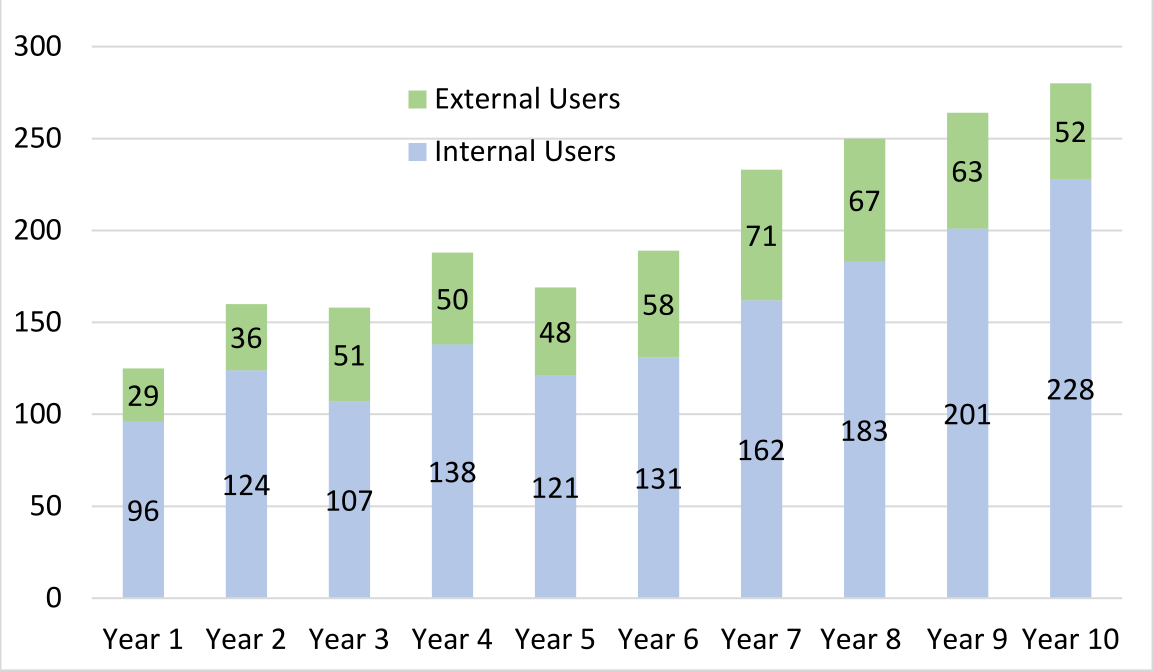
MONT sponsored three Montana teachers to attend **Stanford's virtual NanoSIMST** course for middle school teachers. The teachers have all implemented their lesson plans created in the course, reaching over 250 students with an introduction to nanoscience.

We trained 8 students from different MSU REU programs in our facilities and 5 of the students participated in the **NNCI REU** Convocation at SDNI.

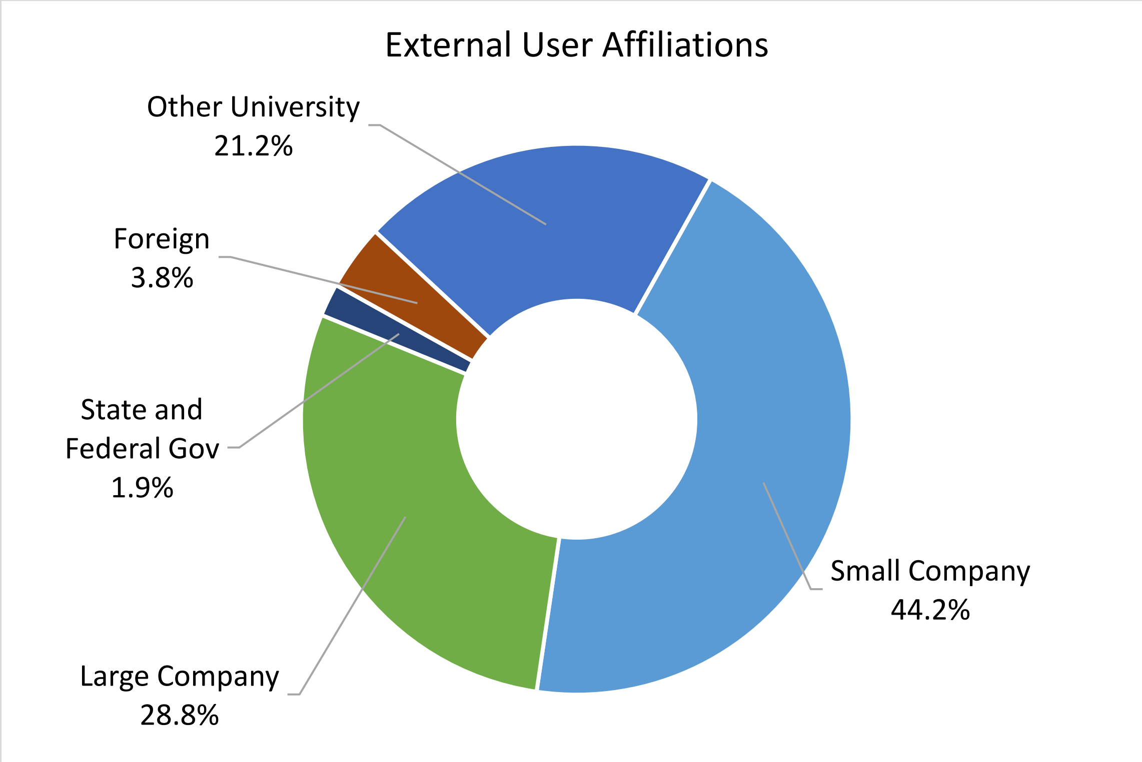
Once again, MONT sponsored and helped to organize MSU Science Day. In addition to hosting 223 4th and 5th graders, this year's event included MSU Science Night, an evening for the public to experience research on our campus. The main attraction of both events is **NanoLand,** which includes our cleanroom display and a talk about items made there. Over 300 people attended the evening event.

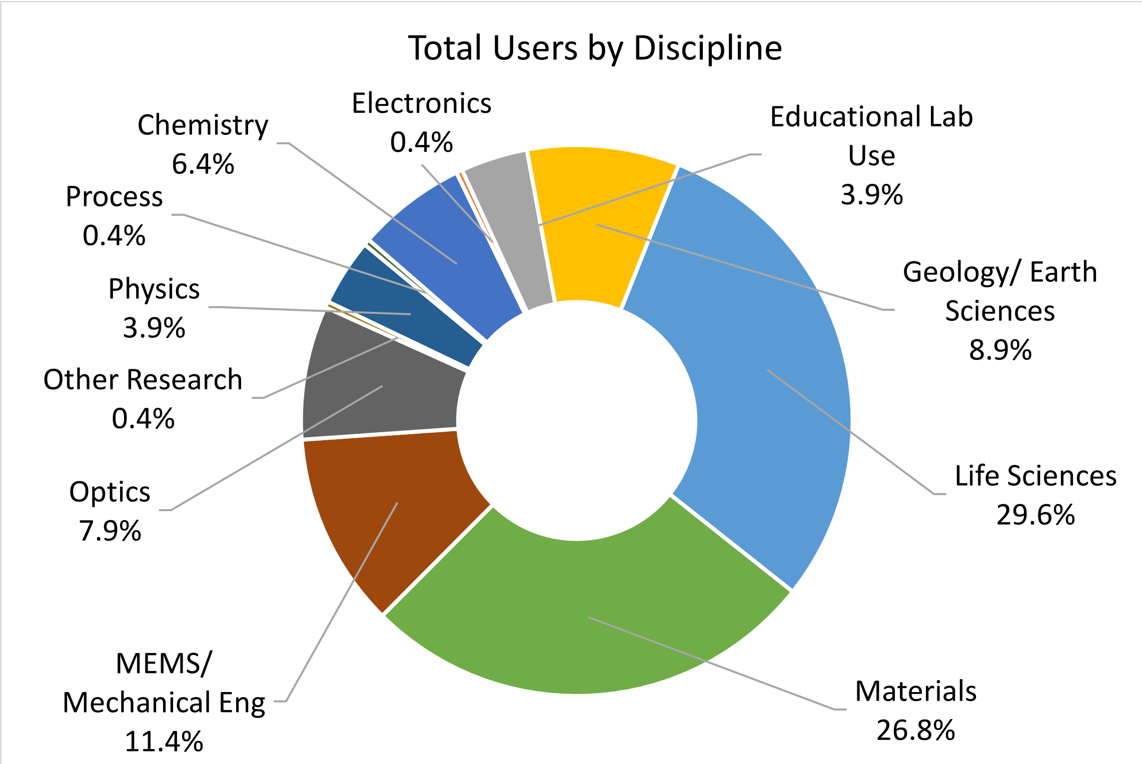
MONT Site Statistics

Yearly User Data Comparison					
	Year 6	Year 7	Year 8	Year 9	Year 10
Total Cumulative Users	189	233	250	264	280
Internal Cumulative Users	131	162	183	201	228
External Cumulative Users	58 (31%)	71 (30%)	67 (27%)	63 (24%)	52 (19%)
Total Hours	7,735	9,142	9,548	9,387	8,926
Internal Hours	6,550	7,512	7,881	7,173	7,204
External Hours	1,185 (15%)	1,630 (18%)	1,667 (17%)	2,214 (24%)	1,822 (20%)
Average Monthly Users	57	75	68	79	97
Average External Monthly Users	13 (23%)	17 (22%)	14 (20%)	16 (20%)	12 (13%)
New Users Trained	86	86	87	124	141
New External Users Trained	20 (23%)	17 (20%)	8 (9%)	34 (27%)	6 (4%)
Hours/User (Internal)	50	46	43	36	31
Hours/User (External)	20	23	25	35	35



MONT Year 10 User Distribution





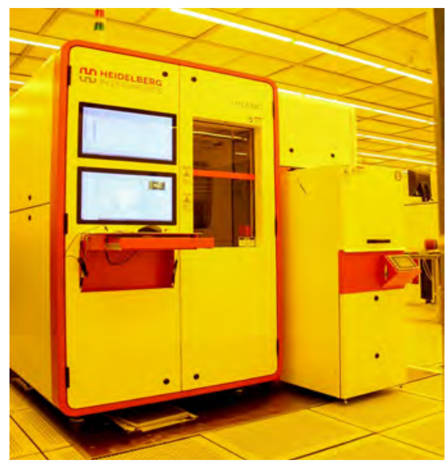
12.7. Nanotechnology Collaborative Infrastructure Southwest (NCI-SW)

Facility, Tools, and Staff Updates

During Year 10, the NCI-SW Advanced Electronics and Photonics (AEP) core facility has undergone substantial upgrades as part of the Microelectronics Commons investments in the Southwest Advance Prototyping (SWAP) Hub at ASU. While the SWAP Hub consortium is not an open network like the NNCI, NCI-SW users have access to the new tools within the AEP core facility, some of which are described below.

The AMAT Centura cluster tool installed in the AEP core facility on the ASU science park

New Tools and Capabilities: 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. The first of the AMAT tools to be installed is a Centura AP reactive ion etch tool, a cluster etch system with two process chambers.



MLA-300 direct-write optical lithography tool.

To support fast turnaround optical lithography, a Heidelberg MLA-300 mask aligner is now available at the ASU science park. Because of the direct exposure from mask data, the overhead and expense of the procurement of physical masks along with storing, handling, and cleaning of masks is eliminated. Writing performance for lines and spaces is 2 microns and minimum feature size is 1.0 micron. Substrate sizes currently supported: 5", 6", and 9" square as well as 100mm, 150mm, 200mm, and 300mm round.

The ASU Nanofab on the main university campus has acquired a desktop diffusion furnace for boron doping. The tool, acquired with funding from Taiwan Semiconductor Manufacturing Corporation (TSMC), will support our flagship CMOS fabrication course as well as general R&D processing that requires p-type doping. The desktop furnace will complement the existing diffusion furnaces but will be easier to use with lowering operating costs, making it more suitable for teaching purposes.

Northern Arizona University (NAU) is in the midst of establishing a Metrology Core Facility with funding from the State of Arizona that will increase materials research capacity at NAU significantly. New instrumentation includes a Joel TEM and SEM, spectroscopic ellipsometry, focused ion beam, precision stress analysis, and associated tools totaling nearly $3M in new capabilities. The NCI-SW Center for Materials Interfaces in Research & Access (¡MIRA!) at NAU will play a central role in oversight and maintenance of the core facility capabilities.

New Staff: Three new staff members have been hired to support users of the Nanofab and AEP core facilities. Carson Gockley has been hired as a Process Engineer in the Nanofab with particular responsibility for developing a PMOS process flow for education and R&D purposes. He manages the new desktop diffusion furnace. The Nanofab has also hired Sai Manohar Guduru as a Process

Engineer, sr. He has 10+ years working in industry and will focus on process development for Nanofab customer applications. Joshu Fernandez is a new Senior Test Engineer in the AEP core facility and will train users, maintain equipment, and manage test setup for AEP users.

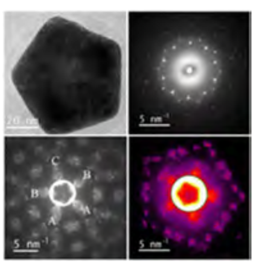
User Base

Our focus for user growth has always been external academic users and small business users, followed by large business users. The Year 10 cumulative user totals (>1100) and revenue (>$4.2M) will break previous records. In Year 10 we supported users from 47 US universities, 48 small businesses, 18 large businesses, and 8 overseas labs. A significant number of users come from the geological, astronomical, health science, and environmental science communities.

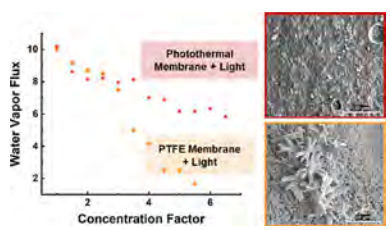
Research Highlights and Impact

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.

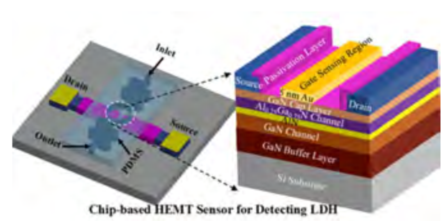
During Year 10 the NCI-SW supported user projects that were published in Nature, IEEE Transactions, Applied Physics Letters, and ACS Materials Letters, with 20 archival publications from external users and more than 70 from internal users in 2024. Examples of external user projects are included in the montage below.



Electron microscope images and computational modeling of AuCuNiPd nanoparticles (Universidad de Chihuahua)



SEM images of coated (top) and non-coated membrane (bottom) and their impact on water vapor flux (University of Quebec in Montreal)



Detection of Lactate Dehydrogenase Using GaN HEMT Sensors (Iowa State University)

The NCI-SW contributes to economic impact and workforce development in the regional southwest through multiple training programs. A partnership with Rio Salado College (RSC) is supported with a "New to ATE" award from the NSF Advanced Technological Education (ATE) program. The ATE award enables RSC to offer certificate programs, and a 2-year associates degree in Nanotechnology. The NCI-SW works with Penn State University and RSC to offer a 12-week Microelectronics and Nanomanufacturing Certificate Program (MNCP) in semiconductor manufacturing for US veterans. The MNCP is also supported by an ATE award and to date more than 40 veterans have graduated from the program.

Veterans gain experience in semiconductor manufacturing.

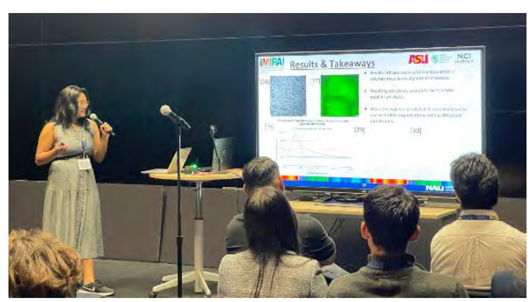
Education and Outreach Activities

NNCI offers a rich suite of K-16 educational resources designed to support teachers, families, and informal education providers. Integrating these into local programming aligns NCI-SW's efforts with NNCI's goal of empowering educators and cultivating the next generation of nano-technology learners and practitioners. NCI-SW aims to enhance regional Science, Technology, Engineering & Math (STEM) education and workforce readiness by equipping teachers and students with hands-on experiences to foster STEM awareness and literacy.

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 STEM disciplines. In Year 10, CBP-STEM partnered with Microchip to host two hands-on workshops for engineering students. These full-day events featured participation from Microchip's CEO and provided students with practical learning experiences. CBP-STEM participated in the STEM Inclusion Summit at ASU, an event designed to connect students across the university with research opportunities and careers in STEM fields, particularly in Micro- and Nano-Technology and engineering. CBP-STEM facilitated NCI-SW's presence at the SACNAS National Diversity in STEM (NDiSTEM) Conference in Phoenix. Participation in NDiSTEM supported both organizations' missions by fostering professional development, strengthening networks, and inspiring students from rural and underserved regions. Notably, the NCI-SW undergraduate intern and former REU participant, Sierra Monreal, presented her research on flexible perovskite solar cells for space applications.

To help address critical gaps in the STEM and semiconductor workforce pipeline, NCI-SW collaborates with Rio Salado College (RSC), part of the Maricopa County Community College District (MCCCD), to deliver multiple hands-on training pathways. 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. Enrollment increased substantially, from 25 lab classes completed for 17 RSC students in Year 9, to 157 lab classes completed by 62 RSC students in Year 10. These enrollment totals include the 12-week Microelectronics and Nanomanufacturing Certificate (MNC) Program, which follows a blended model of instruction. In collaboration with Penn State's Center for Nanotechnology Education and Utilization (CNEU) faculty, the program is designed specifically for veterans, hosts daily, 4-hour live-streamed lectures from CNEU staff, and twice-weekly, half-day, hands-on 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 42 students. PBS NewsHour recently highlighted the critical efforts led by NCI-SW to prepare students and professionals with the skills needed to support the rapid growth of this essential industry. https://www.youtube.com/watch?v=uR6xaHmqsDM.

Research Experiences for Undergraduates (REU): In partnership with Dr. Inès Montaño and Dr. Gabriel Montaño of Northern Arizona University, ¡MIRA! Research Center, NCI-SW hosted undergraduate students for the summer 2025 REU program. We welcomed seven participants from a range of local and regional institutions, including Cal State Channel Islands in California, Adams State University in



Colorado, and Phoenix College within the Maricopa Community College system in Arizona. Students were paired with research mentors at their home institutions and also met with the NCI-SW PI and co-PIs. NCI-SW E&O Coordinator Jessica Hauer (ASU) scheduled weekly Zoom team meetings to ensure REU participants had productive experiences and were ready to present at the summer-ending Convocation in San Diego. Pictured here, an REU participant presents her research at the convocation.

Public Events: NCI-SW outreach teams at ASU and NAU have built a southwest-wide reputation for creative, committed efforts to change the future face of STEM, particularly in quantum and nanotechnologies. NCI-SW collaborates with the SciTech Institute, whose vision is to establish a prosperous and equitable world where STEM is within reach of every person. SciTech events included the City of Tempe's Geeks Night Out, Barrett-Jackson STEMfest, and Arizona State University's Open Door. NCI-SW Year 10 road shows were also a part of Girls STEM Day at the University of Texas, Austin; World Quantum Day in Albuquerque, New Mexico; Dine STEM Festival; and the Navajo Nation STEM Camp with the Girl Scouts. Our deliberate approach also includes programming efforts that generate opportunities to reach the community during public, non-STEM events such as sporting events, cultural fairs, and street festivals. These events continue to draw thousands of visitors curious about STEM research and university-based innovations that impact our community. In addition to promoting semiconductor manufacturing, special attention has been paid to informing the public of workforce development opportunities that include quantum technologies, and integrate artificial intelligence.

K-14 School Events and Teacher Professional Development: In Year 10, the NCI-SW expanded the in-person K-14 impact, reaching over 13,500 students. Hands-on activities included using an optical microscope to view patterned silicon wafers, remote real-time access to a scanning electron microscope to image samples with micro- and nanoscale features, and demos in optics, photonics, and laser technologies. Notable events include Cartwright District College and Career Fair; outreach in Fort Collins, Colorado; Hugs for the Holiday for Chandler Unified District; and SACNAS Community College Day in Phoenix, Arizona. We also continued our support for four middle school teachers' participation in the NanoSIMST virtual workshop with NNCI host nano@Stanford. Pictured here, NCI-SW presented to K-12 educators at the SEMI Foundation and Arizona State University Microspark conference.

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 2025 we brought together 14 graduate students representing 9 NNCI universities. In addition, the SEI team held a faculty cohort in the SOtL program during the week preceding the graduate student program, from May 28-30, 2025.

The participants included 10 faculty and postdocs from 6 NNCI universities. The focus of the faculty version is slightly different from the graduate student program. We start with the assumption that unlike graduate students, faculty participants have a pretty good idea of how the traditional university/ government funding process works and likely have served as reviewers of NSF proposals and other similar funding streams. We therefore shift the focus to help participants better understand how to increase the chances that the work done in their labs can better inform the policy process and have a positive impact on the world. The long-lasting impact of the SOtL program can be seen in the fact that between the two weeks we met with a dozen SOtL alums who now have high ranking science policy jobs in the federal government.

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 although she is not funded by a nanoHUB contract. As part of her support for the NCI-SW, Dr. Vasileska is involved in the following external user collaborations:

- Dr. Michael Povolotskyi (employed at NRL) on several topics related to self-heating effects, hole transport in GeSn layers, 2D Schrödinger-Poisson solvers development that utilize spatially varying and non-diagonal mass tensor, etc.
- Prof. Edmundo Gutierez (INAOE, Puebla, Mexico) on characterization of low-temperature self-heating effects in partially depleted SOI MOSFETs from Global Foundries.
- Prof. Gilson Wirth from UFRGS in Porto Alegre, Brazil on the topics of RDF and RTN fluctuations in the on-current in both n- and p-channel devices, quantum correction models for nanoscale devices.
- Prof. Alan Rossetto (Universidade Federal de Pelotas, Brazil) on modeling of hole transport in p-channel fully-depleted SOI devices.
- Prof. Katerina Raleva (University Sts Cyril and Methodius, Skopje, Republic of North Macedonia) on the topic of self-heating effects in nano FinFETs.

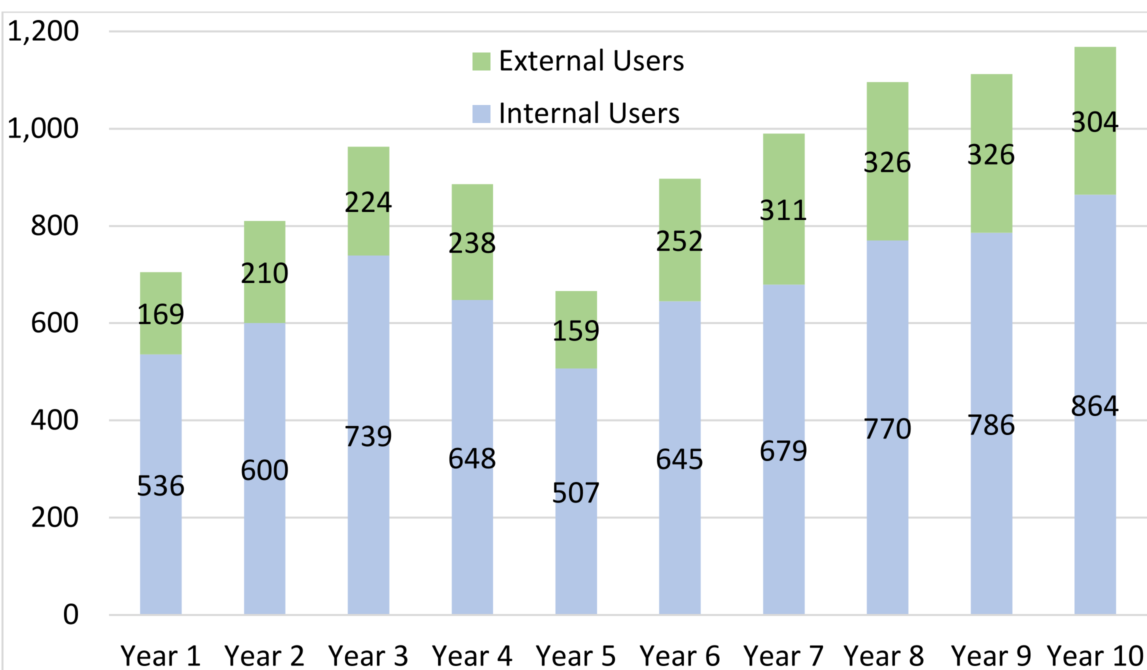
Innovation and Entrepreneurship Activities

The NCI-SW supports small business users including SBIR and government funded 'spin-out' companies. Small business user, Advent Diamond, is developing diamond-based radiation detectors and high-power RF components. Dr Manpuneet Benipal, the CEO and Founder of Advent Diamond is a member of the NCI-SW External advisory Board. Another ASU spin-out company, Swift Coat, is developing thin-film deposition technology for functional coatings that provide high performance anti-reflective, anti-fog, and anti-soiling applications.

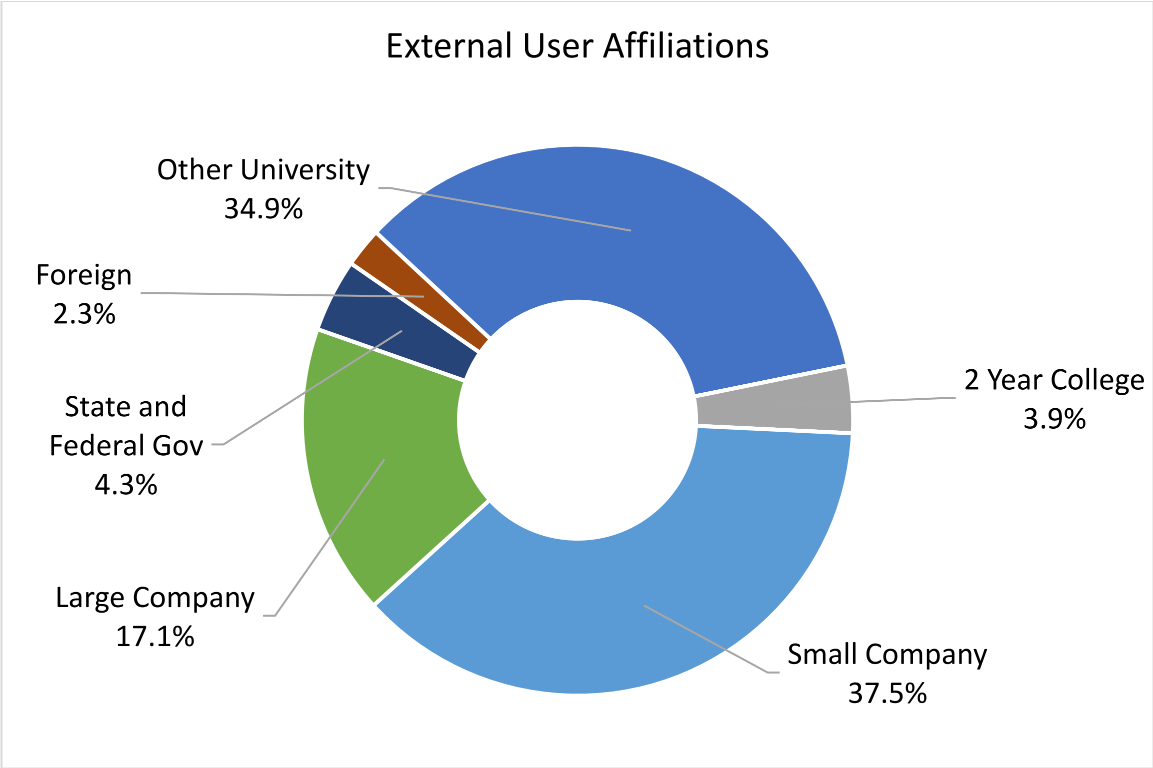
Because we have been using the annual Winter School on Emerging Technologies to help graduate students better understand how their research can have a lasting impact beyond academia we have been including a significant emphasis on entrepreneurship. In 2023 we first invited NNCI Coordinating Office associate director Matt Hull to meet with the student participants. In 2025 he guided the students through a workshop on business impact, research, and entrepreneurship.

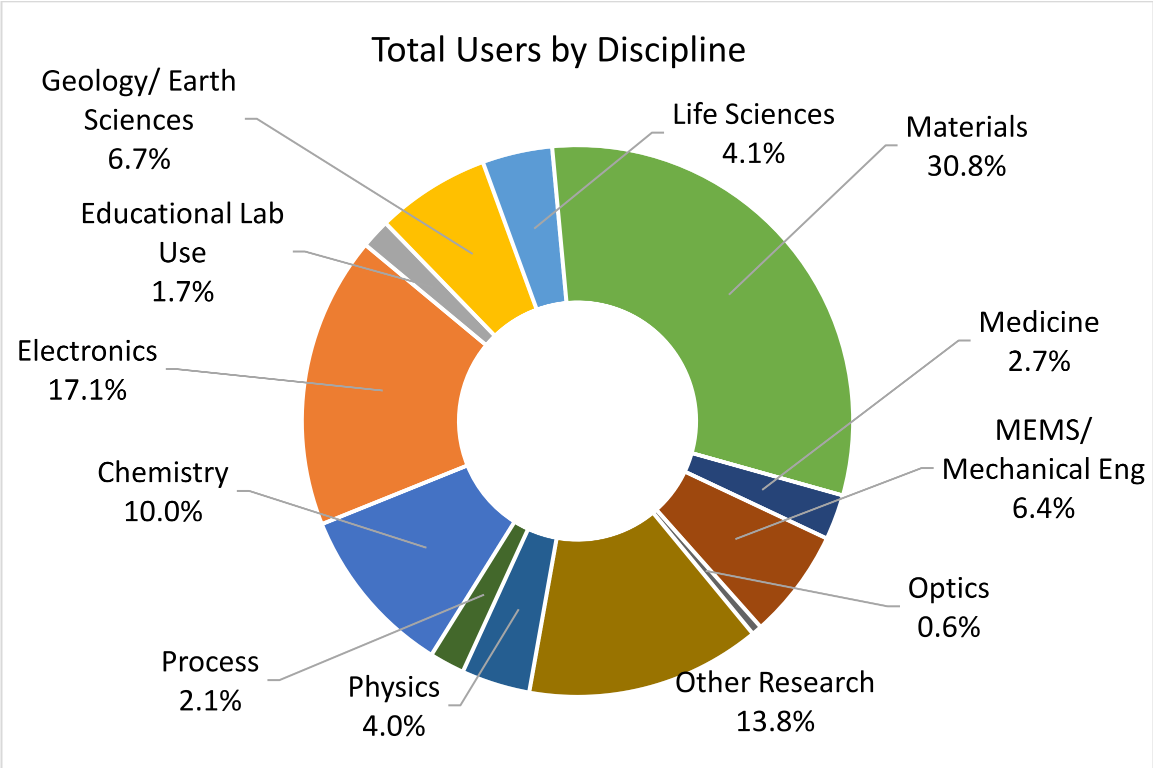
NCI-SW Site Statistics

Yearly User Data Comparison					
	Year 6	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Total Cumulative Users	897	990	1,096	1,112	1,168
Internal Cumulative Users	645	679	770	786	864
External Cumulative Users	252 (28%)	311 (31%)	326 (30%)	326 (29%)	304 (26%)
Total Hours	51,029	71,372	76,759	75,433	80,323
Internal Hours	43,124	60,568	63,214	60,185	62,289
External Hours	7,904 (15%)	10,804 (15%)	13,545 (18%)	15,248 (20%)	18,034 (22%)
Average Monthly Users	311	328	386	409	409
Average External Monthly Users	68 (22%)	86 (26%)	98 (25%)	103 (25%)	83 (20%)
New Users Trained	692	628	754	834	878
New External Users Trained	187 (27%)	180 (29%)	193 (26%)	158 (19%)	234 (27%)
Hours/User (Internal)	67	89	82	77	72
Hours/User (External)	31	35	42	47	59



NCI-SW Year 10 User Distribution



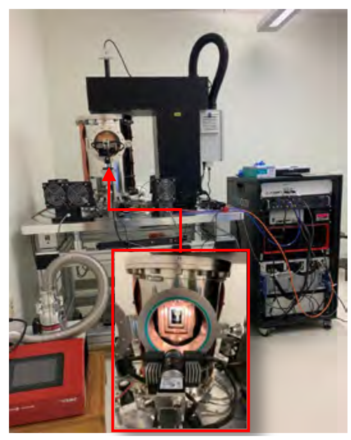


12.8. Nebraska Nanoscale Facility (NNF)

The Nebraska Nanoscale Facility (NNF) strives to achieve international acclaim as a center of excellence in nanoscience and to serve as a NNCI research hub specializing in integrated fabrication, characterization, and education in nanotechnology for the western US Midwest. NNF offers open and cost-effective access to cutting-edge facilities, along with expertise, training, and services in nanoscience, nanotechnology, materials science, and engineering. This access is available to academic institutions, industry professionals, and government laboratories. General *goals* of NNF are to: (a) assist NNCI in strengthening the quality and quantity of research and applications of nanoscience, nanotechnology and materials in the United States, (b) engage new university and industry users in our region in fabrication and characterization of nanoscale materials and structures, (c) provide critical assistance to companies and start-ups in order to benefit commercialization of nanotechnology, and (d) stimulate more students, including under-represented groups, to enter engineering and science careers. NNF's strong education-outreach (E/O) programs helped attract students to engineering and science careers. We target underrepresented groups and create greater awareness about the importance of nanoscience and nanotechnology in modern society.

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

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 installed the first low temperature NV scanning microscope in the US. This was made possible because of a successful NSF MRI proposal led by NNF/NCMN Director Prof. Christian Binek. The Qnami ProteusQ – LT system (right) 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 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. The X-ray Facility also installed a new SAXS system (Fig. 2). With the addition of this new NRI-funded facility, NCMN expands its capabilities to support the soft matter and biochemistry research community, attracting new users and empowering them to compete globally through advanced research. Functionally, the SAXS system (left) operates much like a compact, table-top synchrotron beamline. 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,



First commercial, low-temperature NV scanning probe microscope in the US.

SAXS facility established with NRI funding. The instrument supports a previously underserved user base. The table-top synchrotron alternative broadens access to advanced structural characterization.

Dr. Wen Qian, Dr. Ather Mahmood, Dr. Xingzhong Li, Dr. Steven Michalski, Dr. Lanping Yue, Bibek Tiwari and Abhilash Mishra; 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 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; ConAgra, Omaha, NE; General Dynamics, Lincoln, NE; and SLD Photonics, Wyoming, are some of them. **Minicourse: Free Equipment Training for External Students and Industry Engineers:** Our annual 3-day Minicourse for external users was held on October 7-9, 2024. 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. **NNF Seed Grant/Free Usage Program for External Universities/Companies During Campus Visits:** The NNF Facilities Seed Grant program aims to provide resources to small companies, start-up companies, and students from smaller regional universities and colleges for facilitating development of new nanotechnology enabled products, proof-of-concept development that involves characterization of nanomaterials, fabrication of devices and testing that require access to the instrumentation facilities.

Dr. Binek with NNF Minicourse participants from South Dakota, Wyoming, Kansas, Nebraska, and Missouri.

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. UNL hired four faculty in QMT in the Departments of Physics, Chemistry, Electrical and Computer Engineering, and Mechanical and Materials Engineering. These new faculty, along with several present faculty, form a strong research group in the era of the NSF Big Idea: Quantum Leap. Because of UNL's commitment to a quantum materials cluster hire, expertise in this forward-looking field is on an upward trajectory in NE. UNL's Chancellor selected in 2021 Quantum Science and Engineering as one of seven grand challenge themes which see significant $40M funding over the next five years. 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.** *ConAgra, Omaha, NE*: The NNF staff scientists investigated the causes of failure in one of the materials used by ConAgra for processing. The NNF employed XPS, XRF and EDX to thoroughly investigate the failing parts and the findings were conclusive. The ConAgra scientists thanked NNF staff for identifying the issues and the findings will enable them to implement changes in the processing of these parts. *Bedient Organ, NE:* The Bedient Organ is a small company located in Lincoln, Nebraska that manufactures different types of pipe organs. This company uses NNF facilities and expertise to test various types of alloys and its composition as this is crucial for the manufacturing of high-quality pipe organs. The company uses XRF, EDX and XPS instruments in NNF for various analysis. **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 has supported more than 70 regional institutions in more than 7 states in the Midwest region over the past several years 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. **Facility User Survey**: The NNF conducts facility user surveys every year among the users of the facility. The response from the most recent survey in 2024 indicated 93% were either satisfied or very satisfied with the quality of data and the quality of service received.

<u>Education and Outreach Activities</u>

The main goals of NNF's education and outreach programs and communications are to increase awareness of nanoscience and Quantum to students, teachers, businesses and the general public and to increase the number of students entering nanoscience fields.

NNF-SPONSORED EVENTS: National Nanotechnology Day Celebrations in October included a couple of different events: 1) NNF submitted images by graduate and postdoc students to the national NNCI 2024 "**Plenty of Beauty at the Bottom"** image contest. 2) NNF recognized Nano Days in Nebraska by providing Tables in Jorgensen Hall (our Physics building the NNF is attached to) to students and Faculty alike to visit and learn about Nanotechnology in our building, but also in everyday life. **Junior/Senior High Tours** We continued in person tours exclusively this year. Estimated number of participants in 2024-25 tours were 250-300. We continually try to suggest this activity at educational events to increase this number in the future. **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. March 2024 through October of 2025, ~200 junior high students from 10 schools throughout Nebraska received nano lessons using hands-on materials provided for the lesson. **Family Science Night:** We continued our presence with the collaboration between us and the Southeast Community College system for Family Science Night. We set up a table with demonstrations and activities for children and their family to experience the wonders of Nano and Quantum Physics. 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 2nd time this year. It attracted 1200 people from around the state of Nebraska and Iowa. We set up multiple tables and presented activities and lesson pertaining to “Nature in Nano.” We also had attendees construct LED candles in celebration of “Smokey the Bears’” 50th birthday. The attendees were mostly families with younger children, and surprisingly a large amount of “Home Schoolers”. **Morrill Hall Astronomy Night:** This was our 3rd-time for this event. 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 topic used in Astronomy. This included Nanocomposites, Spectral identification, etc. There was a total of ~350 attendees this year at the event. This event also attracted a large group of families that home school.

WORKFORCE DEVELOPMENT: Nanotech Lab Course for Student Users: This one-credit-hour per semester course provided graduate students with an introductory, but yet comprehensive, view into the large variety of instruments available at the NNF. The purpose of this course was to help student’s master experimental skills in their own research area and to broaden their horizon in experimental nanotechnology methods, complementary to that area. **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. This was accomplished through different methods including tours of the NNF Central Facilities, microfluidic devices design, fabrication, and experimentation workshops, in-classroom nano-engineering modules and demonstrations, and other information and activities stressing the importance of nanomaterials and their applications. **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 All 3 presented his research at the NNCI REU Convocation in Lincoln, Nebraska this year. We were honored to have over 100 students and sponsors at this year’s REU convocation, and from feedback from the participants the convocation was a great success. **High School Intern Program:** NNF hosted 21 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. Following their summer internship, students did presentations of their research work for all in attendance and presented with the REU students on campus at the Grad Studies poster sessions at the beginning of August. **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

HS Interns (left) and REUs (right)

(NATS), the state AAPT meeting and Astronomy Day, the 4H Tech Changemakers (TCM) conference, and the National NSTA conference in Denver. We presented at three of these conferences, doing a Nano/Quantum activities. The virtual conference was the South Dakota State Science teachers meeting where we presented on Zoom to a group of teachers with the collaboration of Professor Larry Browning of SDSU Physics Dept. Attendance was ~350-400 for all sessions. **Research Experience for Teachers**: Three teachers were selected to participate in NNF's 2024 Summer RET Program scheduled from June 3 - Aug 6. Teachers worked in nanoscale science and engineering labs to gain hands-on experiences in the techniques and tools used within NNF facilities, with follow-up support during the school semesters. Work will be highlighted by attending the National Science Teachers Association (NSTA) Conference in March where they will present their poster at the NNCI booth. Participants include one high school science teacher (grades 9-12), one Middle school Science teacher, and one community college faculty (SCC) within commuting distance from NNF. This RET Program is in partnership with three other RET sites throughout the US (Georgia Tech, Minnesota, and Northwestern) and provides teachers an opportunity to network with scientists and teachers across the country and design curricular materials to use in their classrooms. **Nanoscience Summer Institute for Middle School Teachers in Partnership with Stanford:** Last summer nine teachers participated in the NanoSIMST four-day virtual workshop at the end of June. This summer we have 7 teachers signed up. The goals of the workshop were to: 1) excite teachers about nanoscience, 2) equip middle school teachers with content knowledge and empower them with pedagogy to teach their students; and 3) effectively teach thousands of students about nanoscience. Teachers from across NE will learn about quantum, nanoscience and engineering through lectures, hands-on activities (materials sent in advance), facility video tours, and guest speakers. They will also develop their own lesson plans to bring back to their classrooms. Sessions on the social and ethical implications of quantum/nanotechnology, a remote access session through RAIN, and a career panel featuring reps from different local companies will also be part of the curriculum. **Traveling Nanoscience Exhibits:** Our two 400-sq.-ft. hands-on exhibits are still active and making their rounds in museums in the Midwest. During this reports time span the Nano exhibit was viewed at the Elkhorn Valley Museum in Norfolk, Nebraska. Our second traveling exhibit, the Sun, Earth, Universe Exhibit, was hosted by the Washington Pavilion Museum in Sioux Falls, SD. These 2 exhibits over the past 8 years have had well over 300,000 visitors. **Nano/STEM Kits:** 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. Kits can be adapted for different ages, contain reusable hands-on activities, and include digital files, training videos, scripted lesson plans, and national science standards about nanoscience topics. **Training Modules:** 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 video tutorials 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. Also, K-12 teachers benefited from some of these videos as part of our online nanoscience teaching modules.

Nano Exhibit

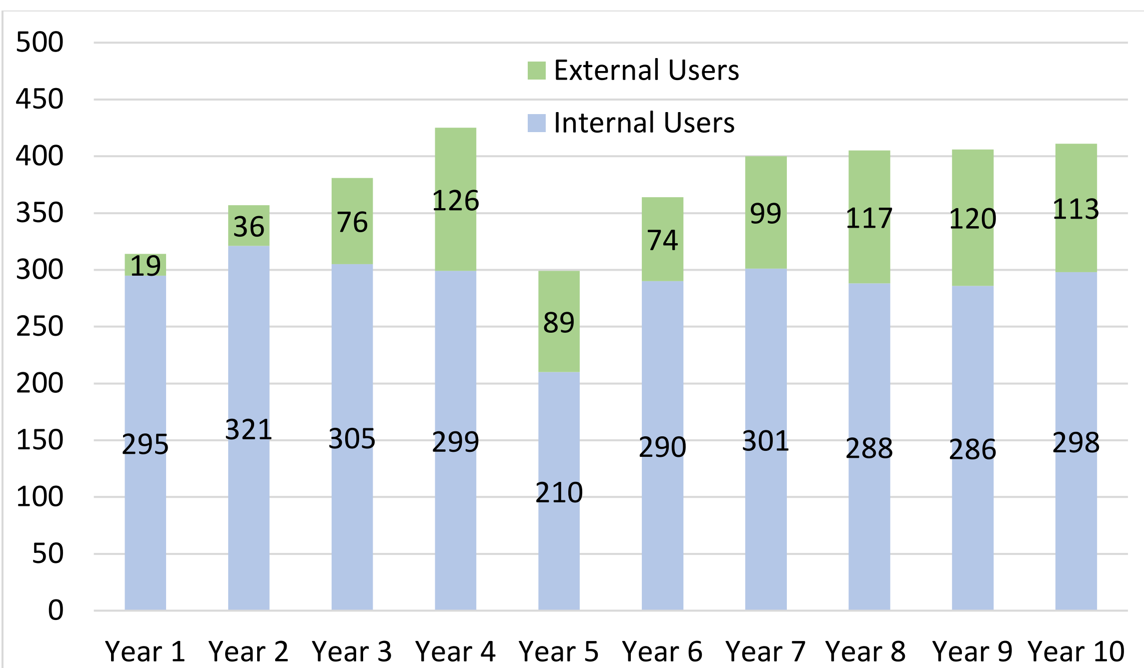
ASSESSMENT ACTIVITIES: The Nebraska Nanoscale Facility (NNF) evaluated efforts to promote nanoscience by surveying participants at the completion of the After-School programs for Discover Engineering Days participants. Students in our 2024 Discover Engineering outreach events were assessed and 100% of 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. NNF is a member of the NNCI Evaluation Working Group which continues to provide information and advice on how to 1) define and follow an evaluation plan, 2) include consideration for the population involved and measurement methodology, 3) assess and analyze data, and 4) apply the results to planned and future activities and share lessons learned with others.The NNF will continue to promote broadening participation in nanoscale science and engineering through a variety of REU and workforce development programs, strategic partnerships, and resources. Quality assessment practices will be an integral part of the learning processes and activities.

Innovation and Entrepreneurship Activities

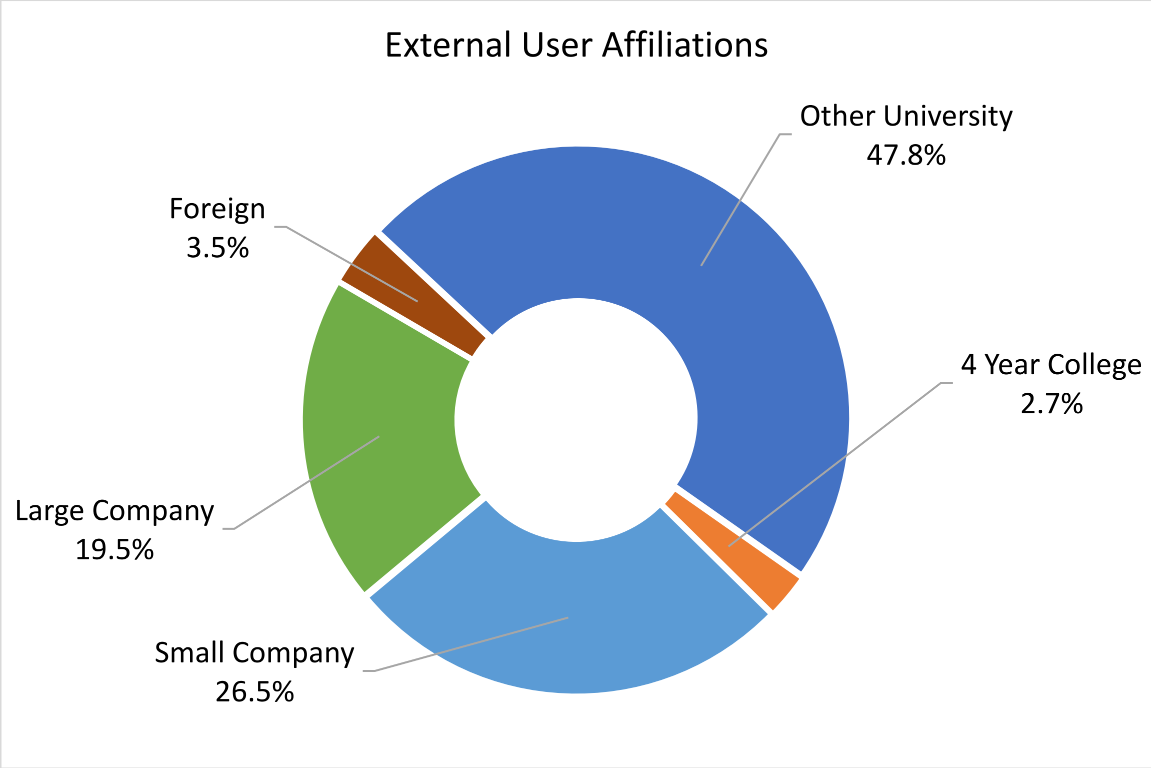
Entrepreneurship success by NNF faculty user Prof. Ravi Saraf: Vajra Instruments, INC., a small startup and recipient of several federal government grants including SBIR, was founded by UNL faculty and NNF User, Prof. Ravi Saraf. Vajra Instruments, Inc. is focused on an inexpensive screening tool for pancreatic cancer. Recent research indicates that less than 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.

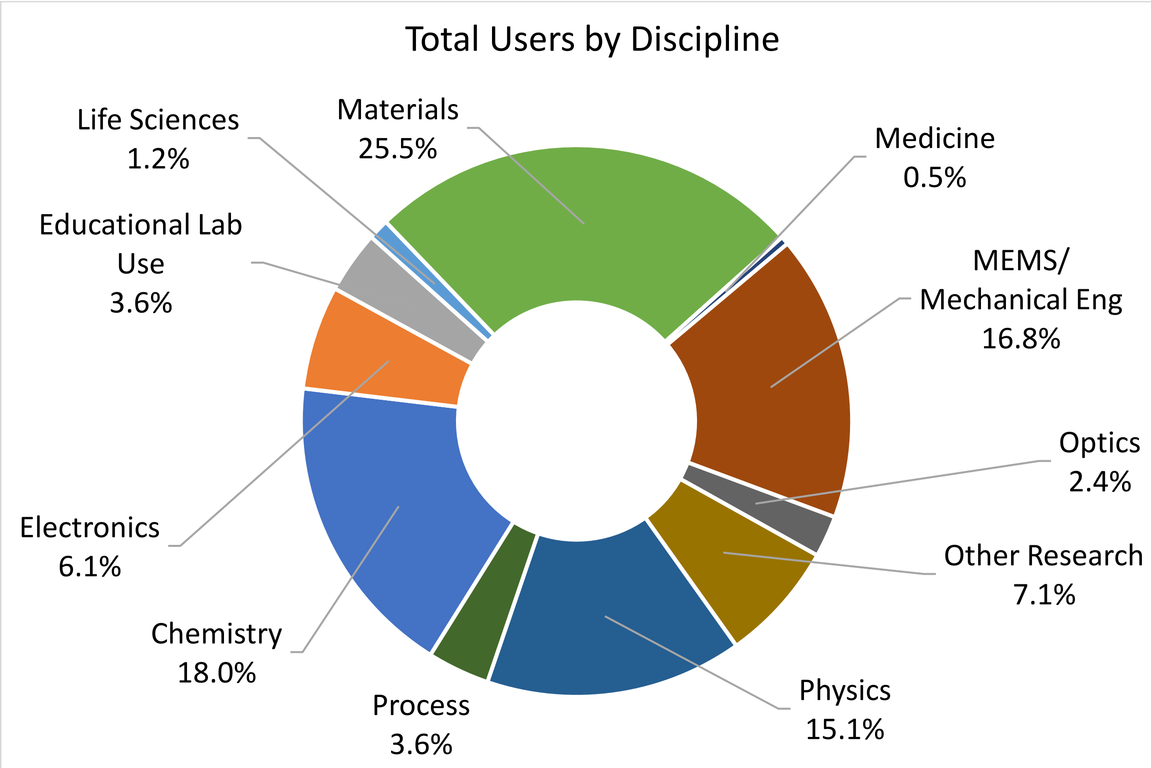
NNF Site Statistics

Yearly User Data Comparison					
	Year 6	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Total Cumulative Users	364	400	405	406	411
Internal Cumulative Users	290	301	288	286	298
External Cumulative Users	74 (20%)	99 (25%)	117 (29%)	120 (30%)	113 (27%)
Total Hours	23,422	27,262	23,297	18,833	18,627
Internal Hours	20,382	23,388	19,779	15,462	14,770
External Hours	3,040 (13%)	3,874 (14%)	3,518 (15%)	3,371 (18%)	3,857 (21%)
Average Monthly Users	120	134	128	129	109
Average External Monthly Users	15 (12%)	17 (13%)	18 (14%)	18 (14%)	16 (15%)
New Users Trained	215	278	211	245	201
New External Users Trained	16 (7%)	26 (9%)	14 (7%)	5 (2%)	6 (3%)
Hours/User (Internal)	70	78	69	54	50
Hours/User (External)	41	39	30	28	34



NNF Year 10 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 paid 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 Cameca 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 17 Ph.D.s) who support the lab community's research endeavors.

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

On September 1, 2025, SNF and SNSF merged into a single shared user facility, now called nano@stanford, under the Dean of Research combining two world-class teams and infrastructure into the largest shared facility on campus and one of the largest in the country. The merger will enhance the researcher experience - streamlining administrative processes, and improving equipment availability, and data infrastructure, as well as increasing space for workforce development and training. Staff supported the merger by participating in six working groups focused on administrative processes, website integration, lab management systems, education and training, quality principles, and staff. This approach accelerated progress and helped integrate staff across the two organizations.

During year 10, nano@stanford added ***thirteen new capabilities***:

- Zeiss Gemini 560 Field Emission Scanning Electron Microscope
- Park FX-40 Atomic Force Microscope
- CHA Solutions II Evaporator
- KLA SPTS OMEGA Deep Silicon Etcher
- 3 Oxford Instruments PlasmaPro 100s: (1) ALE, (2) PECVD, + (3) Cobra ICP-RIE
- SemiTorr Group Entegris GateKeeper GPU Gas Purifier (N2)
- Aixtron AIX-CCS Heater for Aixtron AIX-CCS MOCVD system
- Micromanipulator Company P200L Semi-Automatic Probe Station
- Agilent/Keysight B1500A Semiconductor Device Analyzer

- Bruker TriboLab CMP
- Beckman Coulter Optima XE-100 Ultracentrifuge

Construction progress on SNSF's DeepLab expansion project.

SNSF is making rapid progress on its expansion, which will add 10,000 sq ft of facility space and new characterization capabilities, supported by a major investment from the Vice Provost and Dean of Research: $30M for construction and approximately $20M for new instrumentation. Construction is nearing completion, with a grand opening planned for spring 2026. A 20% expansion of SNF is also underway, with a targeted completion in mid-2026. This expansion will support both Stanford's participation in the Pacific Northwest AI Hardware Hub of Microelectronics Commons, a new collaboration with TSMC in new materials for advanced electronics research, and future programs

In year 10, nano@stanford hired five new staff members including Olivia Abramson (Accountant 1, SNF), Eli Weiss (Process Engineering Manager-MOCVD, SNF), Paul Hart (TEM Associate, SNSF), Doc Daugherty (Direct-Write Lithography Engineer, SNSF), and Lukas Michalek (SPM Support Scientist, SNSF). In the second half of the year, the facilities underwent university-mandated layoffs and staff transitions, resulting in the departure of 4 team members.

<u>User Base</u>

The nano@stanford marketing efforts underwent significant growth since hiring a new Program Communicator in year 8. We have 4100 YouTube subscribers, 2522 newsletter subscribers, 203 Instagram followers, and 415 LinkedIn members (34K post views in year 10). Our interns also host their own Instagram to share about the intern experience with 441 followers.

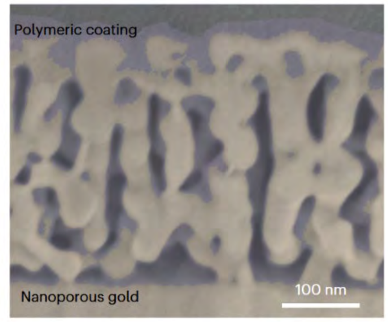
To augment the user experience, we send weekly update emails to the lab community to keep them informed of news, events, and opportunities. We also continue to support the nano@stanford Lab Member Collaborative (nano-LMC, a user advisory group), which strives to provide a direct line of communication between users and nano@stanford leadership and to create a supportive community. In year 10, the nano-LMC's initiatives included supporting the SNF/SNSF merger by hosting listening sessions and gathering user feedback, societal and ethical implications (SEI), and cleanroom hygiene best practices. To increase program awareness and build community, the group also organized Trivia Night, happy hours, and SEI lunch n' learns.

In year 10, nano@stanford served ***1474 users, the highest number of cumulative annual users*** for the duration of the award (versus 1449 in year 9). The user base includes 215 users from 113 small companies, which exemplifies the strong entrepreneurial ecosystem in the area.

<u>Research Highlights and Impact</u>

During 2024, we captured 156 published journal articles from internal users, 38 articles from external users, and 46 conference presentations. The following are two research highlights from internal and external users.

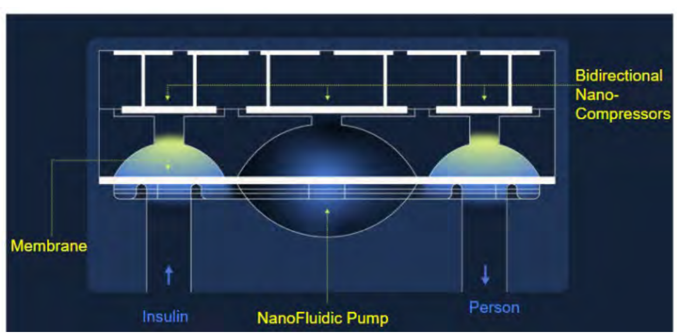
Sensors that continuously measure blood analytes could revolutionize health monitoring by enabling real-time tracking of disease progression, drug levels, and metabolic or physiological activity in both clinical and everyday settings. Research by **Stanford Professor H. Tom Soh's group**, developed a novel biochemical sensor, SENSBIT (Stable Electrochemical Nanostructured Sensor for Blood In situ Tracking), designed to overcome the challenges of biofouling and signal drift that previously limited continuous in vivo sensing in blood. Utilizing a biomimetic multicomponent design inspired by intestinal mucosa, SENSBIT featured a 3D nanoporous gold structure, a protective polymer coating (hyperbranched PEG), and electrochemically modified aptamer switches, enabling sensitive detection of small target molecules, such as the antibiotic kanamycin, while shielding the sensor from interferents.



Cross-section SEM image of a SENSIBIT sensor.

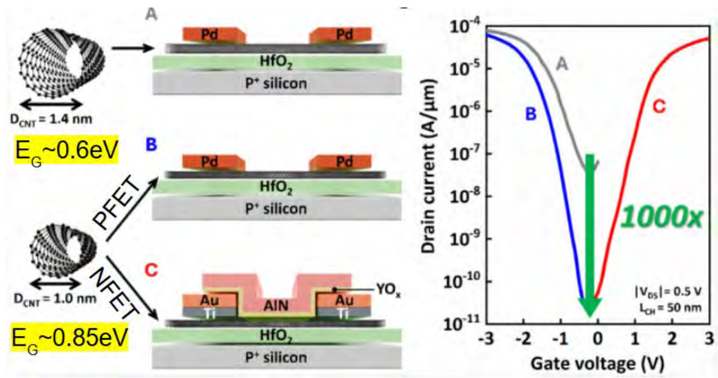
In vitro, SENSBIT maintained over 70% of its baseline signal and consistent sensitivity after 1 month of continuous exposure to undiluted human serum. The sensor also exhibited minimal fouling after incubation in human blood and chicken plasma. SENSBIT retained over 60% baseline signal stability after 7 days in the femoral veins of free-moving rats, far exceeding previously demonstrated in vivo durations. This stable performance allowed for correction-free, real-time tracking of kanamycin pharmacokinetics in the bloodstream for up to 4 days. SENSBIT provides a robust and generalizable foundation for implantable sensors for long-term health monitoring of small-molecule analytes. The research was published in *Nature Biomedical Imaging.*

As an example of external industry research**, Torramics Inc.** is using the facilities to develop a disposable, 3-day, miniaturized insulin patch to revolutionize diabetes management. The patch leverages the company's recently patented nanoPump and nanoCompressor technology. This nano gas pump system is capable of generating gas flow, compression, and rarefaction by thermal diffusion. The nanoPump operates across a wide pressure range (mtorr to several atm), achieves pumping speeds of up to several L/min, provides output pressures of up to 15 PSI, and has very low power consumption (<20 mW when pumping). The pump does not have any moving parts, but instead uses steep temperature gradients created by a series of PNP, NPN, PP, NN thermoelectric segments to drive the gas flow through nanometer-sized channels based on the Knudsen phenomenon. The effective integration of the thermoelectric segments enabled the reduction of the pump's size, complexity, and manufacturing costs compared to traditional mechanical solutions. The most recent patent related to this work is *US 2025/0035099 A1*.



Miniaturized insulin patch enabled by Torramic's patented nanoPump technology.

External research by **TSMC** made a significant breakthrough for next-generation electronics using carbon nanotube field-effect transistors (CNTFETs). By leveraging carbon nanotubes as channel materials, CNTFETs offer ultra-scaled device dimensions, but their widespread adoption has been hindered by two persistent challenges: excessive off-state leakage (particularly at $V_{DS} > 0.5$ V) and the difficulty of forming low-resistance electrical contacts at ever-smaller scales. The team addressed the off-state leakage issue by increasing the CNT energy bandgap (E_G) to 0.85 eV, which reduced the minimum leakage current by three orders of magnitude. Using these large-bandgap CNTs, they successfully fabricated both N-type (NFETs) and P-type (PFETs) transistors with symmetric, high performance. Notably, this work represents the first known demonstration of NFETs based on large-bandgap CNTs, enabled through titanium contacts and YOx/AlN solid-state doping. The results showed strong promise to meet the 2034 IRDS roadmap goals, supported by contact-resistance (R_C) measurements of single-CNT N/PFETs with contact lengths ranging from 18 to 200 nm. The study was published in *NanoLetters.*



PFET and NFET device schematics and leakage current performance for devices with different energy bandgaps.

<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 durable skills, the lab benefits from extra staff and user support. The interns stock supplies, run process monitors, perform equipment maintenance, give lab tours, and collaborate on lab support projects. These projects are distinct from an REU because the activities are not research-based but directly benefit the facilities. For example, the interns developed a camera monitoring system for furnaces so users can check furnace-run status from outside the cleanroom. Professional development highlights from year 10 included (1) 9 interns attended the 2025 TechConnect Conference including the NNCI pitch competition, thanks to support from MNTEC, and (2) 10 interns presented posters at the nano@stanford Open House.

Interns collaborating on photolithography

In year 10, we ***trained 20 students*** from 8 local community colleges. Out of the 43 interns since 2018, 26 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, 2 were hired as full-time staff at nano@stanford, and 3 are pursuing advanced degrees at Stanford, Columbia, and MIT.

150 Miwok Middle School students visited with their teacher, a NanoSIMST alumna.

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 10, ***49 teachers were trained*** nationwide with 11 NNCI sites participating by either running an in-person program or sponsoring virtual teachers from their areas. Eleven of those teachers and 1 teacher facilitator were supported by the Microelectronics Commons NW-AI-Hub. From historic NanoSIMST implementation data, we estimate the 49 teachers will impact 3200 students with nanoscience lessons this year, and that ***over 15K students have been impacted since 2017 from the 246 NanoSIMST alumni***. For the 3rd consecutive year, we hosted a field trip for ~150 eighth graders from Sacramento' s Miwok Middle School, where a NanoSIMST alumna teaches.

Other E&O activities (e.g., tours, demos, workshops, curriculum support, etc.) reached ~6100 participants in year 10 (Oct 2024 - Sept 2025). This included 12 Stanford classes which used the facilities to supplement classroom content with experiential learning for ~275 students. One E&O highlight was the 2nd nano@stanford Open House, which impacted ~400 participants and featured research posters and talks, instrument vendors, facility tours and demos, industry meet and greets, and a career discussion panel. We continue to create content for our edX courses, reaching ~13,000 learners from 141 countries since 2019.

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

In year 10, 3 Stanford graduate students and 2 postdocs participated in the NNCI's Science Outside of the Lab (SOtL) program. nano@stanford staff continue to serve as guides and proponents for a SEI Student Working Group, composed of alumni from SOtL and SEI-interested lab members. The group continues to organize quarterly SEI Lunch n' Learns, featuring topics like data reproducibility and the impact of AI on the research community.

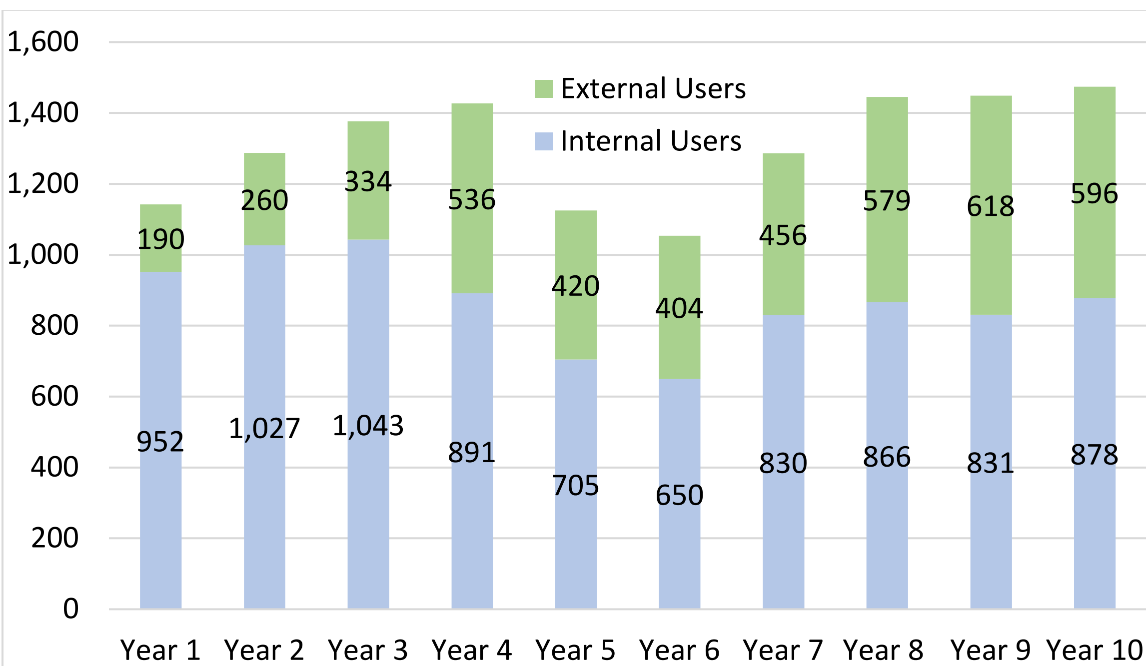
<u>Innovation and Entrepreneurship Activities</u>

Nine nano@stanford interns cheered on the NTEC finalists at TechConnect 2025.

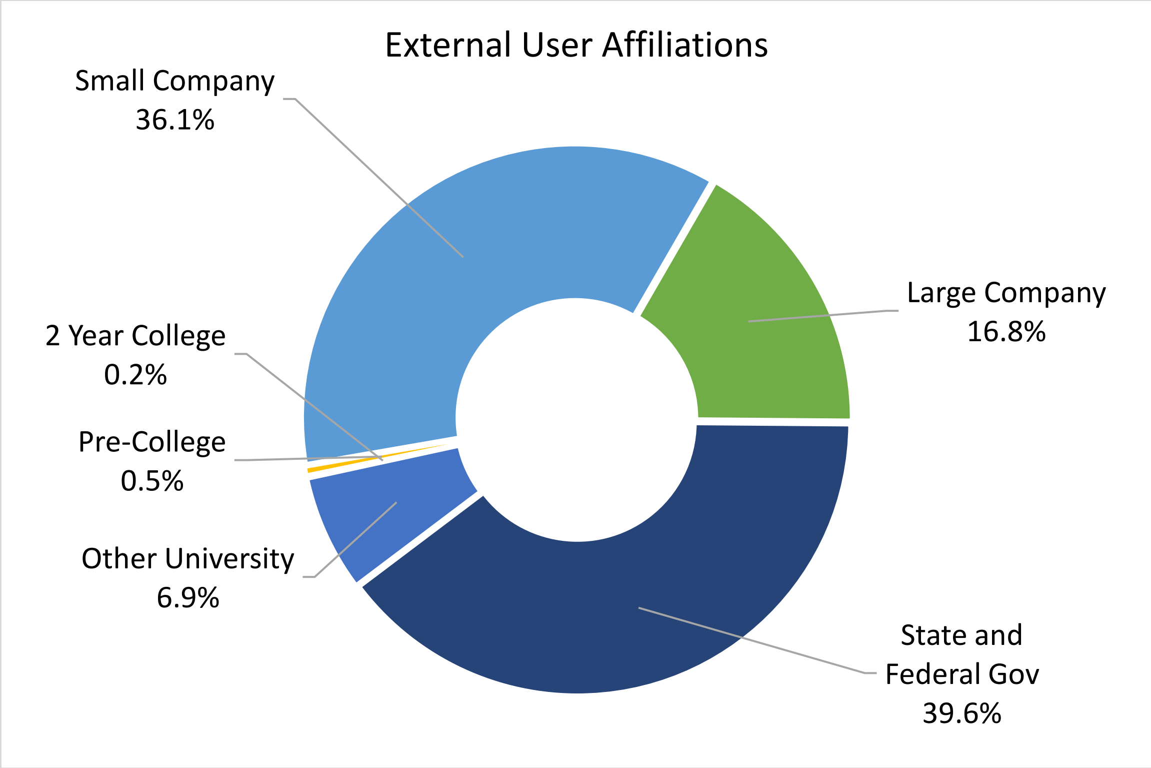
Four nano@stanford teams participated in the NNCI's 2025 NTEC programs. Two nano@stanford teams were accepted into the spring program for projects about MEMS Microfluidics Molds and AI-driven Raman-based detection of metabolic liver disorders. Neither team was selected for the final pitch competition at TechConnect, but nano@stanford interns attended the session to cheer on the finalists. Two additional nano@stanford teams have been selected to participate in the fall program.

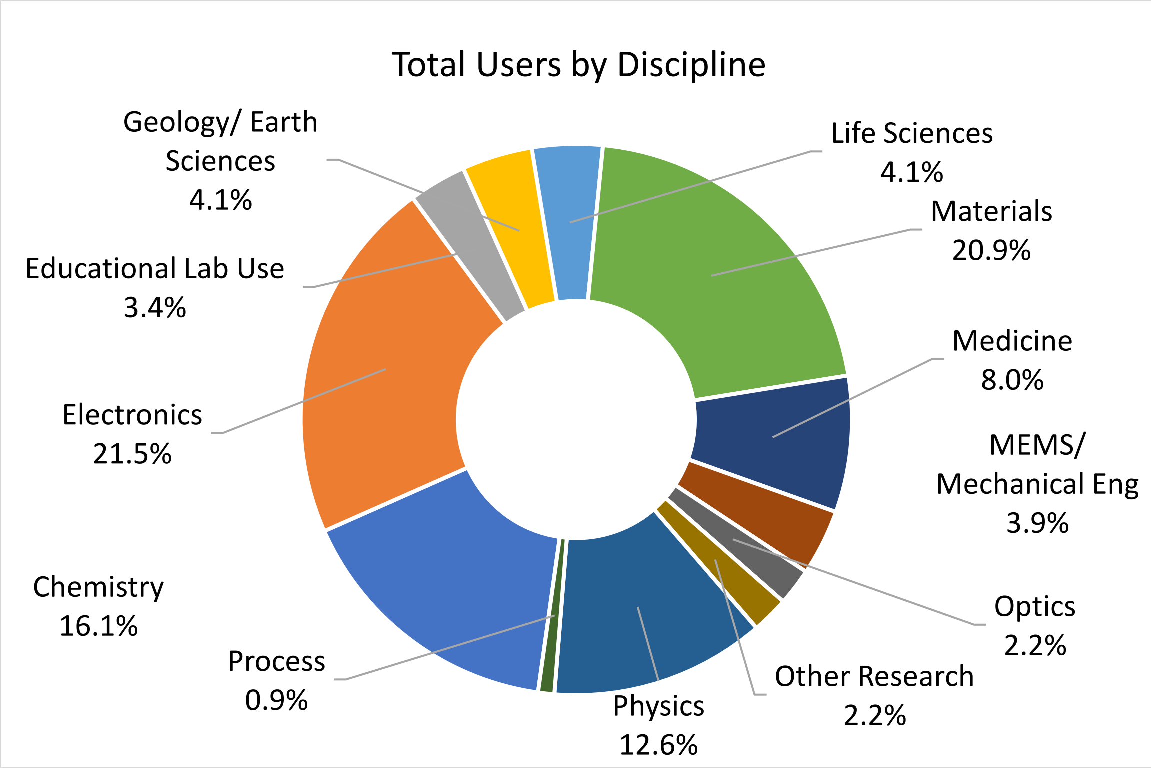
nano@stanford Site Statistics

Yearly User Data Comparison					
	Year 6	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Total Cumulative Users	1,054	1,286	1,445	1,449	1,474
Internal Cumulative Users	650	830	866	831	878
External Cumulative Users	404 (38%)	456 (35%)	579 (40%)	618 (43%)	596 (40%)
Total Hours	104,536	108,702	109,649	122,538	138,280
Internal Hours	63,013	69,230	66,599	66,365	83,595
External Hours	41,523 (40%)	39,472 (36%)	43,050 (39%)	56,173 (46%)	54,684 (40%)
Avg. Monthly Users	470	548	589	600	644
Avg. External Monthly Users	162 (34%)	176 (32%)	198 (34%)	247 (41%)	256 (40%)
New Users Trained	491	581	579	572	457
New External Users Trained	186 (38%)	197 (34%)	212 (37%)	175 (31%)	178 (39%)
Hours/User (Internal)	97	83	77	80	95
Hours/User (External)	103	87	74	91	92



nano@stanford Year 10 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.

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

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 the College of Engineering is 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)
- Angstrom Engineering electron beam evaporator
- IntlVac NanoQuest II IBE
- SPTS Synapse Dielectric Etcher
- Raith Voyager electron beam lithography
- FEI Verios 5 SEM with EDS detector
- SUSS ACS200 Coater/Developer Track
- SUSS MABA8 contact aligner
- SUSS SB8GEN2 Universal Bonder
- AJA evaporator/sputter system with load lock oxidation for quantum materials

Molecular Analysis Facility (UW)

- Thermo Fisher Helios 5UX Dualbeam Focused Ion Beam
- Kratos Axis Supra+ XPS
- Gatan Pecs 2 - Broadbeam Ion Mill
- Buehler SimpliVac -Vacuum epoxy impregnator

ATAMI (OSU)

- The Jen-Hsun & Lori Huang Collaborative Innovation Complex ($200M, 150,000 ft^2) will include new nanofabrication facilities, lab space, and the fastest supercomputer on the West Coast. Construction is scheduled to be completed in 2026.

MaSC, APSCL, OPIC (OSU)

- Two Signatone High Precision Manual Probe Stations
- Coherent 205F KrF laser
- Thermionics PLD system
- Neocera PLD system
- Schrader thermal evaporator

Staff Updates

Maria Huffman, director of the WNF cleanroom since 2019, returned to Lund University to lead the Swedish Chips Competence Center (SCCC). Darick Baker, previously the WNF Engineering and Business Development manager, has been appointed the acting director. 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 10, NNI facilities have seen a slight increase in total users, where internal users have increased around 5 percent while external users from small businesses have dropped by a similar degree. Other user categories (external academic, large companies, government, foreign) have held steady. External users still 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.

<u>Research Highlights and Impact</u>

NNI is honored to have UW Professor 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 a team at Oregon State University for this year's research highlight. In this paper (doi.org/10.1002/cssc.202400332), co-PIs Líney Árnadóttir, Zhenxing Feng and their colleagues study high-efficiency and low-cost catalysts for the oxygen evolution reaction (OER), which is critical for electrochemical water splitting to generate hydrogen. Among the emerging OER catalysts, transition metal dichalcogenides have exhibited superior activity compared to commercial standards such as RuO_2, but inferior stability due to uncontrolled restructuring with OER. In this study, bimetallic sulfide catalysts are created by adapting the atomic ratio of Ni and Co in $Co_xNi_{1-x}S_y$ electrocatalysts to investigate the intricate restructuring processes. Surface-sensitive X-ray photoelectron spectroscopy and bulk-sensitive X-ray absorption spectroscopy confirmed the favorable restructuring of transition metal sulfide material following OER processes. These results indicate that a small amount of Ni substitution can reshape the Co local electronic structure, which regulates the restructuring process to optimize the balance between OER activity and stability. This work represents a significant advancement in the development of efficient and noble metal-free OER electrocatalysts through a doping-regulated restructuring approach.

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.
- The WNF is receiving 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.
- The WNF has also received additional funding from Micron to continue offering short courses to URM and Community College students.
- Before her departure, Maria Huffman was a member of the Washington State Commerce Department working group that coordinates a comprehensive, statewide approach to securing current and future grant opportunities enabled by the CHIPS and Science Act.

<u>Education and Outreach Activities</u>

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 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.

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 the NW AI HUB, 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), Oregon State University TRiO, and Bellevue College Veterans Program students, focusing on semiconductor fabrication.

- Co-investigators Liney Arnadottir and Zhenxing Feng (OSU) received a $200k grant from Intel to design lab modules and course materials on semiconductor technology.

- WNF hosted 11 students from Japan for a one-week nanofabrication workshop through the UPWARDS for the Future program–a partnership between Micron, Tokyo Electron and the NSF.

- The WNF offered IEEE certifications to students completing microfabrication short courses by coordinating with the CA DREAMS HUB and the NW-AI HUB, along with the University of California at Santa Barbara, The University of Southern California, and Stanford University.Student assistant programs at the Washington Nanofabrication Facility (WNF) and Materials Analysis Facility (MAF), employ undergraduates and offer hands-on lab experience.

- Partnerships with programs like the Engineering Dean's Scholars, SESEY 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 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 have exceeded 85%, surpassing historical averages for similar populations.

Teacher Training

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 UW ECE 331 (Devices and Circuits I), ECE/MSE 486 (Fundamentals of Integrated Circuit Technology), ECE/ME/MSE 504 (Introduction to MEMS), ECE 527 (Nanofabrication Techniques), and OSU BioE 445 (Surface Analysis), 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 the 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 2014 NTEC Showcase included a team from NNI on a "Durable double perovskite ($SrCoIrO_3$) electrocatalyst for acidic media water electrolyzer", which won the network-wide competition. The most recent NTEC Showcase took place on December 4 and a team from NNI was again selected as one of the finalists.

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 10 we were able to fund a total of 14 seed grants, which were further supplemented with resources from the UW Institute for Nano-engineered Systems and the College of Engineering.

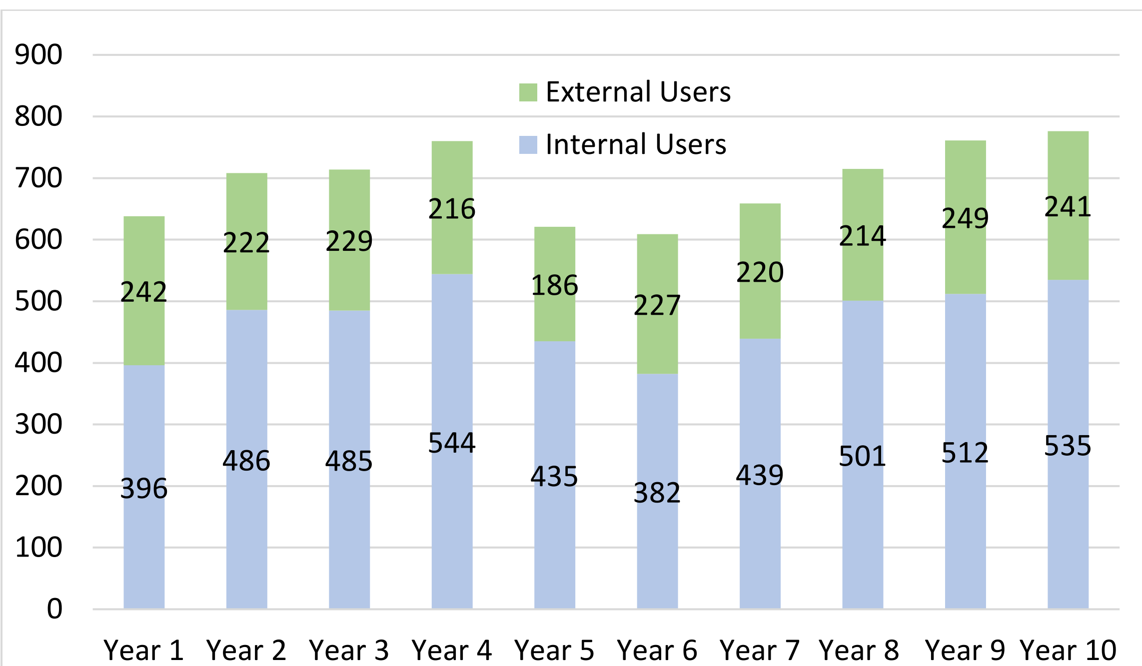
Regional Technology and Innovation Hubs (Tech Hubs)

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

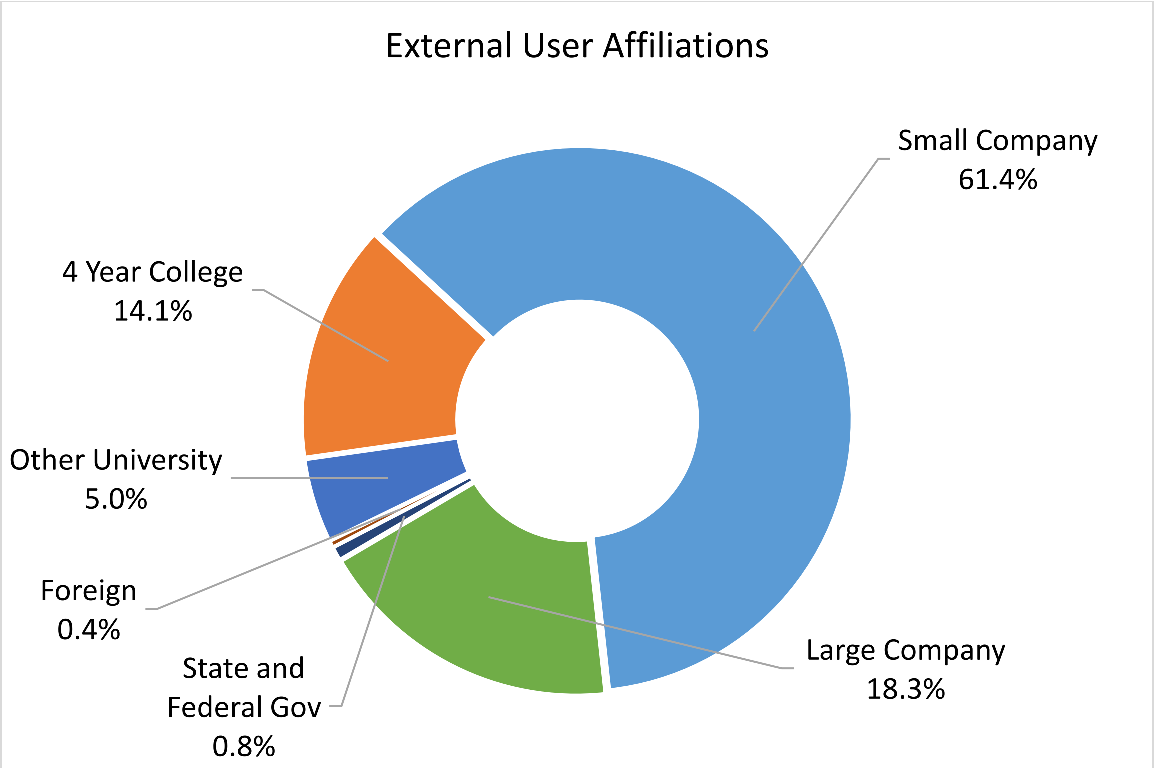
University. At OSU, the NSF named Frontiers of Advanced Semiconductor Technology (FAST), a finalist to receive up to $160 million federal investment over the next decade. FAST is one of 15 finalists in the Regional Innovation Engine, which will focus on advanced semiconductor technology and work force development. Additionally, 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.

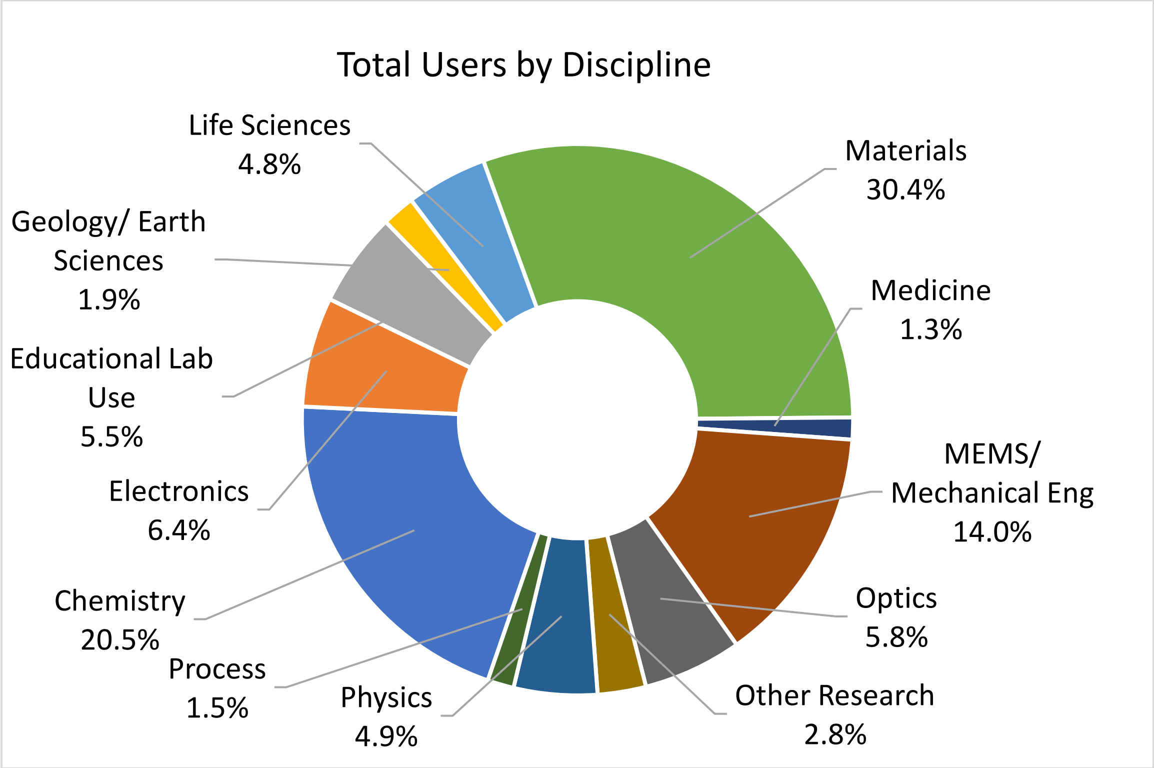
NNI Site Statistics

Yearly User Data Comparison					
	Year 6	Year 7	Year 8	Year 9	Year 10
Total Cumulative Users	609	659	715	761	776
Internal Cumulative Users	382	439	501	512	535
External Cumulative Users	227 (37%)	220 (33%)	214 (30%)	249 (33%)	241 (31%)
Total Hours	72,122	60,027	52,784	51,854	45,819
Internal Hours	26,740	29,379	26,864	25,441	21,555
External Hours	45,382 (63%)	30,648 (51%)	25,920 (49%)	26,413 (51%)	24,264 (53%)
Average Monthly Users	252	265	282	321	335
Average External Monthly Users	88 (35%)	85 (32%)	87 (31%)	113 (35%)	118 (35%)
New Users Trained	115	186	170	153	120
New External Users Trained	31 (27%)	56 (30%)	45 (26%)	16 (10%)	17 (14%)
Hours/User (Internal)	70	67	54	50	40
Hours/User (External)	200	139	121	106	101



NNI Year 10 User Distribution





12.11. Research Triangle Nanotechnology Network (RTNN)

Facility, Tools, and Staff Updates

Tools: In Year 10, 43 new instruments valued at >$20 million were acquired or ordered, including a JEOL JBX-8100FS Electron Beam Lithography System, a Class One Solstice LT Au plating tool/hood, a Thermo Scientific Scios 2 HiVac FIB/SEM, an Oxford Instruments PlasmaPro Cobra 100 High-Power ICP for SiC Via Etch, an RF Electronics Test Station with multiple components, a scia Systems Mill 200 Chemically Assisted Ion Beam Etch (CAIBE) tool, a Thermo Scientific Nexsa X-ray Photoelectron Spectroscopy (XPS) tool, a Nu Horizon Isotope Ratio Mass Spectrometer with Elemental Analyzer, a Thermo Scientific Spectra Ultra TEM with a Protochips Poseidon AX in-situ electrochemical TEM holder.

Techniques: NNF at NC State has a considerable amount of new nanofabrication techniques now available as a result of some of the new tools listed in the prior section, particularly in wide-bandgap semiconductor materials and packaging. CHANL at UNC has developed a process to now offer nanoimprint lithography service to users.


New RTNN staff/personnel, from left to right: Rosa Grigoyan (SMIF Engineer), Ray Unocic (AIF Associate Director), and Zhennan Huang (SMIF Engineer).

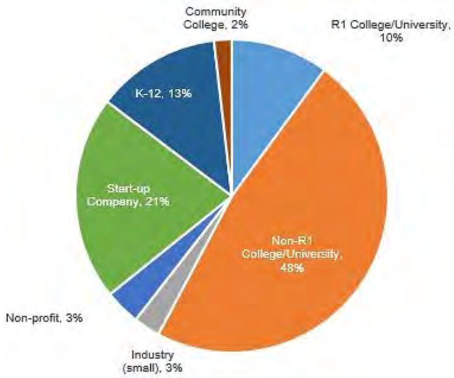
Staff: NNF, SMIF, and AIF all expanded their technical staff this year to strengthen user support and stand up new capabilities. NNF hired two engineers: Geza Dezsi, who is leading the launch and management of the new electronics packaging lab, and Colin Catella, who is responsible for maintenance, troubleshooting, and repair of NNF's extensive equipment suite. NNF also added a part-time equipment technician, Scott McDiarmid, a semi-retired industry veteran with decades of semiconductor experience. SMIF hired two new engineers as well: Zhennan Huang, who manages the new S/TEM and FIB instruments and provides user training and support, and Rosa Grigoryan, who manages the Mass Spec lab and supports users on its instrumentation. Finally, AIF appointed a new faculty Associate Director, Ray Unocic, who brings deep expertise in electron microscopy and user facility experience from ORNL's CNMS. Three of these new team members are shown in the photos above.

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.

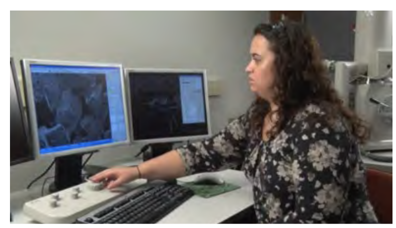
Satisfaction: RTNN continually assesses its facility users and programs. The RTNN Assessment team is associated with PCOST (Public Communication of Science and Technology) at NC State. Unique surveys are used for collecting demographic and user satisfaction data from various RTNN programs. Surveys are 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 10 (6.36 ± 1.15 on a 7-point Likert scale where 7=very satisfied, n=343). This level of satisfaction was consistent with responses from previous RTNN years (Year 9: 6.30 ± 1.01, n=272). 99.7% of users (n=343) 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, 112 projects have been awarded (Year 10: 8 projects). The figure below shows the affiliations of the program participants. Most participants are from non-R1 colleges/universities (48%), start-ups (21%), while K-12 students/classrooms make up about 13%. 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 that completely used their time in the program, >40% subsequently continued to use facilities spending >$350,500 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=112).

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. The photo at right shows a representative screenshot of a laboratory video. Since the course launch, over 354,000 (Y10: >25,500) people have visited the course website, more than 73,000 enrolled (>5,800 in Year 10), >47,000 engaged with a part of the course (>4,000 in Year 10), and >15,000 completed all course components (>1,600 in Year 10). 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: "*This course was well delivered and engaging. Not only did it cover the theory of the main fabrication and characterization processes, but it also provided detailed lab demonstrations of the processes. It really felt like a hands-on experience.*" 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 30, 2024 – March 18, 2025. We received 391 completed surveys. (Note: Only students who completed the course receive 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. >94% of respondents noted that they were likely or very likely to recommend the course to others. 73% 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 Environmental Scanning Electron Microscopy (E-SEM).

Workshops, short courses, symposia: In Year 10, the RTNN held >15 short courses or workshops (mostly in-person or with hybrid virtual components) with over >170 participants. Instrument-focused short courses introduce tools and techniques to provide a foundation for subsequent training on a specific tool (photo 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, a new 'Introduction to Rheology' workshop delivered December 2024 drew over 75 attendees from the Research Triangle area and featured tutorial lectures, hands-on demonstrations, and company sponsorship from TA Instruments and Anton Paar.

Focused Ion Beam Short Course participants, including hands-on instrument use by participants.

On June 10, 2025, the RTNN and the Research Community for Nanotechnology Convergence hosted the Soft Matter Infrastructure Symposium (SMIS), which brought together over 60 participants with needs and expertise in soft matter characterization to facilitate building a national network of open-access shared instrumentation facilities for characterization and fabrication of soft materials and recorded collective thoughts and insights on topics including University-Industry Engagement, Unmet Needs in User Research Services, Best Practices and Management, and Emerging/Needed Capabilities.

Students from across NC present and discuss their work in a poster session at Carolina Science Symposium 2024.

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 November 2024 (Year 10), this in-person event drew over 70 participants, some of which are pictured above.

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.

<u>Research Highlights and Impact</u>

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 >254 publications in 2024 by our users (176 of which cited the NNCI award number). 44 of these publications were authored by external users (32 cited the NNCI award). Work performed in the facilities led to >126 patents filed and >51 patents awarded in 2024.

Education and Outreach Activities

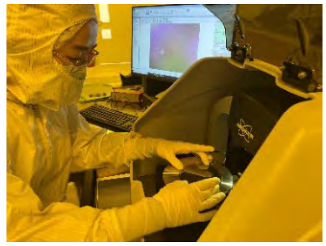
The RTNN's educational and outreach activities are central to building its user base; The table below summarizes key programs and Year 10 participation. In response to growing workforce needs in high-technology fields such as semiconductors and microelectronics, RTNN began distinguishing between traditional "outreach" and "early workforce development" in Year 9. Early workforce development programs extend beyond one-time exposure and include multi-session learning or training modules. One such program continuing in Year 10 is Engineering for US All (e4usa), which engages rural students in a year-long, project-based engineering course hosted within an RTNN nanotechnology facility.

RTNN Year 10 Education & Outreach Events	
	Participants
Kickstarter Program	8
Engaged learners in Coursera course on nanotechnology	>4,000
Public Events (e.g., Booths at Museums, NC Science Olympiad)	>280 interactions (>8,000 attendees)
Remote outreach events (e.g., SEM demonstrations in classrooms)	>140
RTNN Facility Visits (e.g., Outreach events hosted on campus, Tours)	>4,000
Technical Events (e.g., short courses, workshops)	>170
Symposia/Conferences	130
Total	>8,660

In-Person Programs: Year 10 maintained strong momentum for in-person outreach programs and events. One program to highlight is Girl Scouts STEM Day @ Duke. Developed through long-standing partnerships with youth organizations, this program expands RTNN's K–12 reach beyond the Research Triangle and into rural communities. In collaboration with Triangle Women in STEM, Duke's Pratt School of Engineering and Trinity College of Arts and Sciences, Credit Suisse, and IBM, the event hosts Girl Scouts and their families for hands-on SEM activities alongside parent sessions focused on supporting STEM pathways. A complementary virtual option, "Girl Scouts STEM Power Hour", extends participation nationwide, including rural communities and members of two North Carolina Native American tribes. The most recent in-person event in May 2025 engaged 442 participants and volunteers.

Education and Experiential Learning: RTNN staff expertise and facilities significantly enhance coursework across the network, including Class-Based Explorations, Advanced Physics Laboratory Experiences, and topical courses such as Wide Bandgap Semiconductor Device Fabrication/Technology and Biological Electron Microscopy. These resources provide hands-on access that extends beyond standard classroom instruction.

RTNN also maintains strong connections with local community colleges within the Triangle ecosystem. Dr. Phil Barletta, NNF Director of Operations, continues to engage Central Carolina




RTNN CC Interns Angelina Yang (left) and Aramenta Owens (right) have both transferred to NC State and continue working in facilities after their CC internship.

Community College's Laser and Photonics Program through cleanroom tours and demonstrations at NC State, as well as participation in student advisory days. In May 2025, RTNN facilitated the construction of a vacuum training system for CCCC classroom use, supporting workforce training needs such as leak-detection instruction for technicians and operators at Wolfspeed. In Year 10, the third cohort completed RTNN's Community College Internship Program, which places community college students alongside core facility staff to build technical skills and prepare them for transfer to research universities. This year's interns—Jason Nguyen (Durham Technical Community College) and Aramenta Owens (Wake Technical Community College)—were both admitted to NC State. A previous intern, Angelina Yang, has also transferred to NC State and continues to work in research groups utilizing RTNN facilities. These outcomes underscore the program's effectiveness in engaging students in research and supporting academic transitions.

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 and a Research Experience for Teachers program that hosted 10 teachers in Year 10. Additionally, eleven REU students from the Summer 2024 cohort attended the NNCI REU Convocation at the KY MultiScale in Louisville, KY.

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

In Year 10, the Social and Ethical Implications of Nanotechnology (SEIN) team led all assessment design, data collection, and analysis for RTNN, managed IRB approvals, maintained RTNN's online visibility, and continued its social science research efforts. SEIN contributed to the NNCI Research Community for Nanotechnology Convergence, where David Berube served as the sole social scientist; the group published its findings in Environment Systems & Decisions in October 2024. SEIN also advanced its long-term 'deep assessment' research by preparing to analyze 10 years of RTNN longitudinal data, building on earlier findings published in the Journal of Nanoparticle Research. This expanded analysis will refine research questions and hypotheses, with a new publication targeted for 2026.

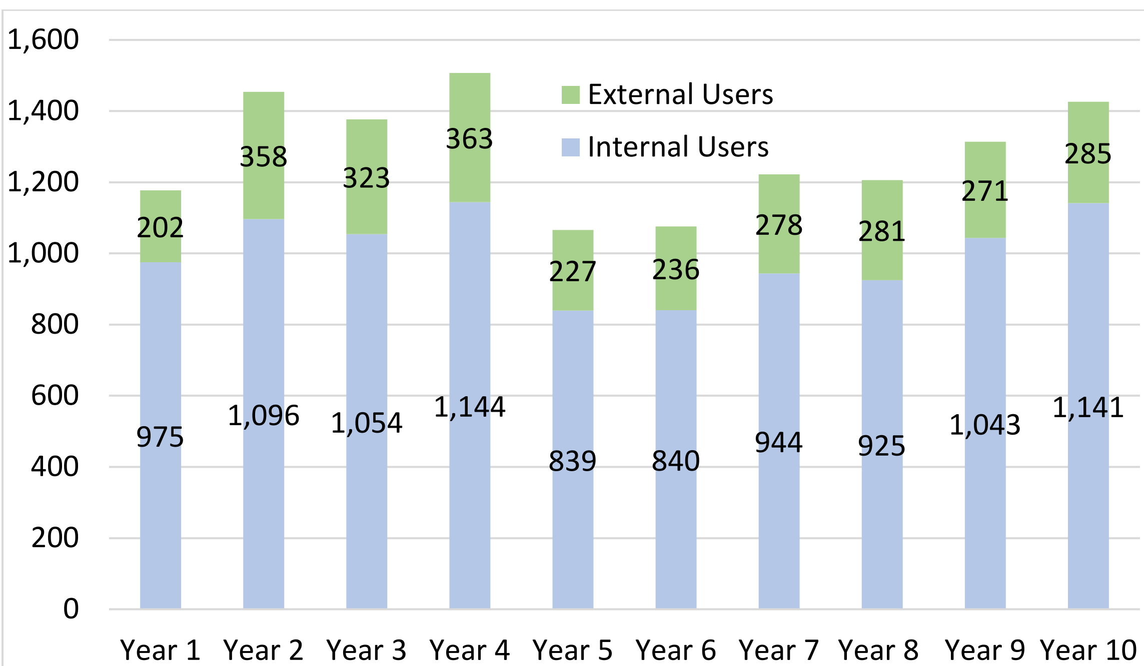
<u>Innovation and Entrepreneurship Activities</u>

The RTNN serves a critical role in innovation and entrepreneurship through facilities, expertise, and programs. The majority (63%) of companies in Year 10 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 21% 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 student teams in the 2025 NNCI Nanotechnology Entrepreneurship Challenge (NTEC) lead by NanoEarth: Nanolipids (led by Liubov Palchak, a graduate student) and Micelles (led by Hallie Hutsell, a graduate student).

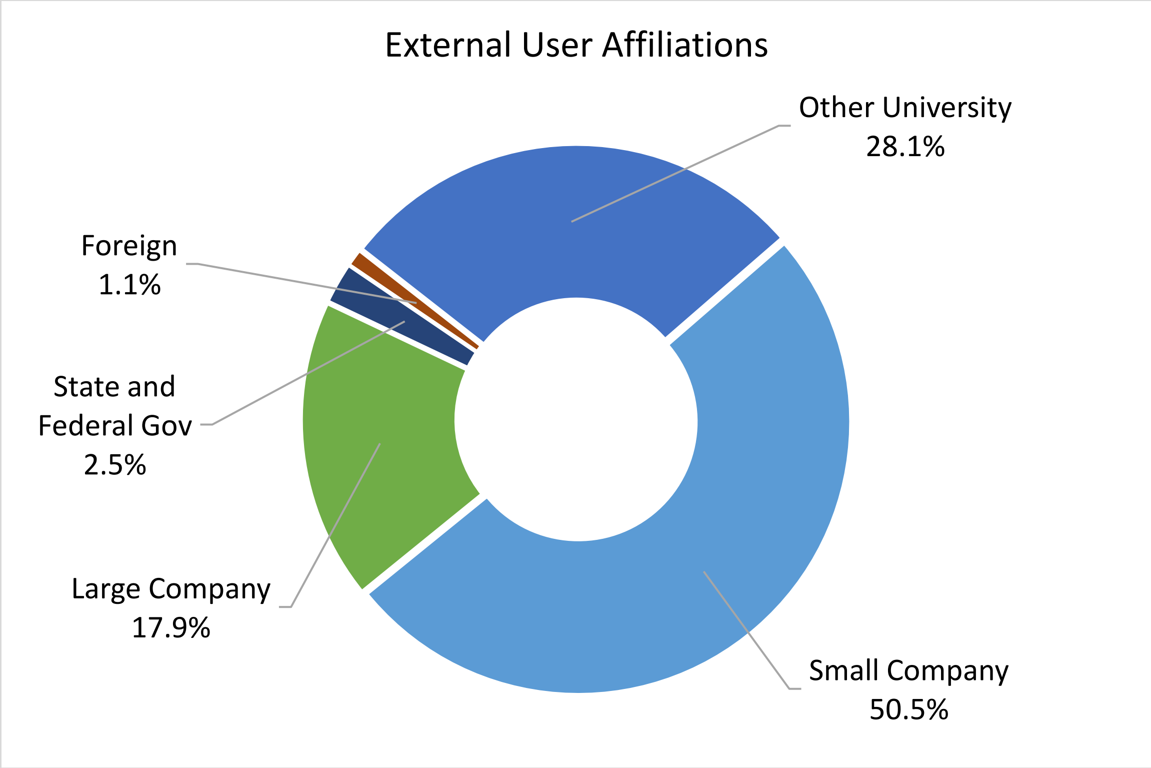
Many start-up companies spin out of RTNN universities and continue to use our facilities in their operation, with notable ongoing success stories including: Qatch Technologies, Smart Material Solutions, Adroit Materials, Cell Microsystems, Third Floor Materials, Voxel Innovations, IonQ, InSomaBio, Isolere Bio, Tyrata, and many more. Codetta Bioscience is a spin-out that has raised >$17M in the past 3 years in Series A funding (among other sources). These companies alone have received >$75 million altogether in SBIR/STTR and other funding. In August 2024, Lindy Biosciences, a Research Triangle company that relies on SMIF's soft materials lab, announced a licensing and collaboration agreement with Novartis for multi-target drug delivery innovation, receiving a $20M upfront payment and eligibility for up to $934M in milestone payments and tiered single-digit royalties on net sales.

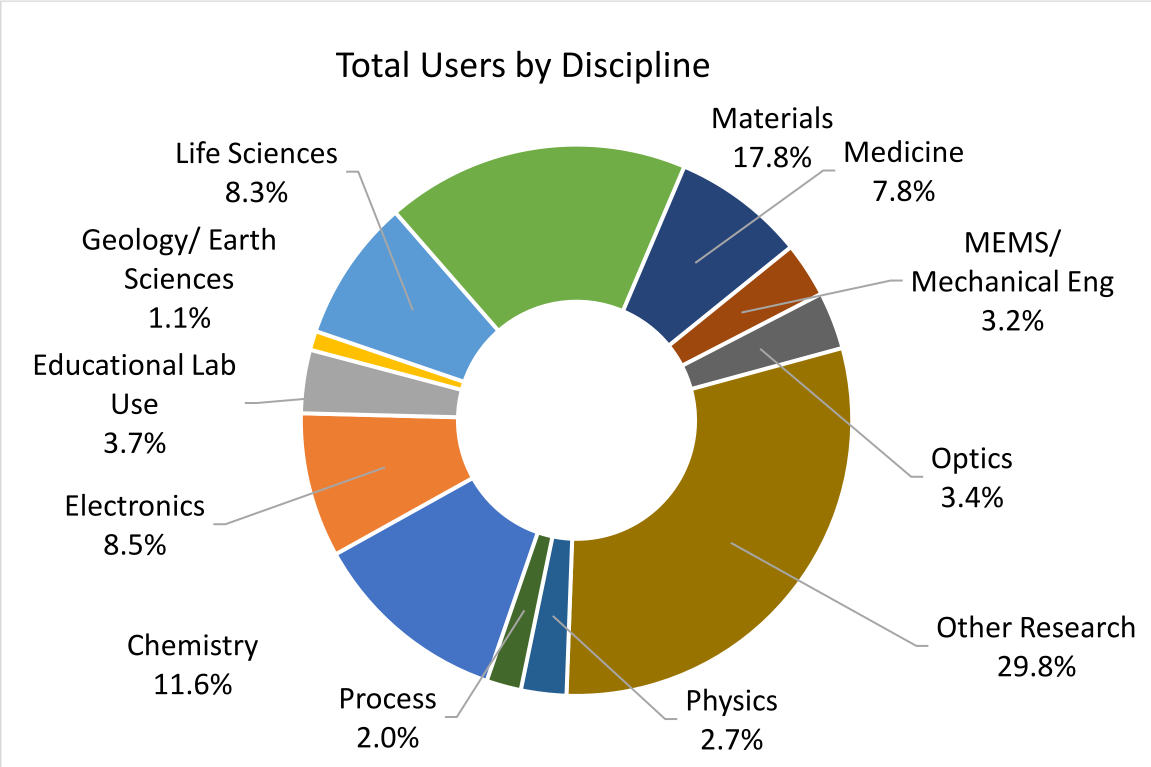
RTNN Site Statistics

Yearly User Data Comparison					
	Year 6	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Total Cumulative Users	1,076	1,222	1,206	1,314	1,426
Internal Cumulative Users	840	944	925	1,043	1,141
External Cumulative Users	236 (22%)	278 (23%)	281 (23%)	271 (21%)	285 (20%)
Total Hours	53,491	51,211	50,150	58,905	69,949
Internal Hours	43,209	40,837	40,958	49,963	59,639
External Hours	10,282 (19%)	10,374 (20%)	9,192 (18%)	8,943 (15%)	10,310 (15%)
Average Monthly Users	352	396	397	450	491
Average External Monthly Users	67 (19%)	78 (20%)	80 (20%)	76 (17%)	78 (16%)
New Users Trained	435	492	449	564	556
New External Users Trained	74 (17%)	60 (12%)	75 (17%)	75 (13%)	93 (17%)
Hours/User (Internal)	51	43	44	48	52
Hours/User (External)	44	37	33	33	36



RTNN Year 10 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.

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.

SDNI has been working with an industrial partner (PDF Solutions) to **apply AI/ML to analyze the processing data and optimize the operation of the tools**. We also help establish the **first GMP (Good Manufacturing Practices) facility for FDA approved medical devices within a university environment.**

Tools: In 2025 SDNI invested more than $2,000,000 in acquiring new equipment for its Nano3 facility. A state-of-the-art PHI Genesis XPS (X-ray Photoelectron Spectroscopy) surface analysis system was acquired and installed. This system, with its advanced capabilities, such as depth profiling with Argon ions and clusters of Argon ions, Aluminum and Chromium dual monochromated X-ray sources, Ultraviolet Photoelectron Spectroscopy capability, Angle Dependent XPS, scanning Auger capability, and its hot/cold stage of a temperature range from -100°C to 500°C, will greatly expand SDNI's ability in surface analysis, which is on high demand for academic and industrial research.

The plasma dry etching and Atomic Layer Etching (ALE) equipment (investment greater than $750,000) has been delivered and installed in SDNI's Nano3 facility and made available to our users. As the state-of-the-art plasma dry etching and ALE system, the system has many innovative features, including deep silicon etching with a fast-switching Bosch process, achieving a high silicon etching rate of >8μm/min and excellent selectivity to photoresist (PR) and SiO2 mask materials, cryo Si etching process for ultra-smooth sidewall silicon etching, with sidewall scallop size <5nm (RMS), wide substrate temperature range (-150°C to 400°C) with rapid heating/cooling.

SDNI added a new Atomic Layer Deposition (ALD) system, which can accommodate 8" wafers. This new equipment has been delivered and installed in 2025. The new ALD is integrated with a glovebox system. The integration of two systems provides our users a unique research tool for batteries, solar cells, and applications that require performance of the ALD process without water or oxygen.

SDNI acquired an advanced Keyence laser 3D surface profiler to strengthen our capabilities in metrology, especially for samples with deep trenches, large steps, or large size with a wide field of view. SDNI also added a new precision polisher as part of its efforts in expanding its back-end processing capabilities. The high precision lapping machine, with a 15" super flat lapping plate, can accommodate 8” wafers.

Staff Update: SDNI continued to hire talented personnel as staff members and invest resources for their professional development. In 2025, SDNI hired a senior process engineer to strengthen the process development and service team, and an equipment engineer to strengthen Nano3’s equipment support team. On the other hand, SDNI has experienced a few staff turnover, including the departure of SDNI’s safety coordinator and an equipment engineer.

To save cost, SDNI has investigated opportunities of hiring post-doctoral researchers to train and mentor student interns, develop and characterize new materials and processes such as 2D materials, produce services requested by users, and help workforce development. As a result, one postdoc and one visiting scholar have joined SDNI.

Student assistant positions in SDNI have achieved the highest level of 25 students, showing that SDNI continues to be an attractive workplace for students of diverse background. These student assistants receive thorough trainings in nanofabrication and semiconductor process from SDNI staff. A Lab Assistant Excellence Award was created by SDNI to recognize students who have made excellent contributions to the facilities.

User Base

In the last 12 months, SDNI facilities have had more than 58,000 hours of facility usage by 771 active users, of which 577 users were from 120 UCSD research groups, and 194 users were from 75 companies and 18 non-UCSD academic institutes. Around 25% of the total users are industrial users from large and small companies. In addition, 27% of the average monthly users have been using our remote services. Last year, more than 170 new users were trained by SDNI facility staff. The work that used SDNI facilities has resulted in 124 publications in peer-reviewed journals and conference proceedings and 7 patents.

SDNI facilities have continued to be valuable and accessible resources for local and national business. As an example, SDNI’s Electron Beam Lithography (EBL) service has been a very popular, reputable and reliable resource to users from across the nation. In the past 12 months, SDNI’s EBL service alone has generated a revenue of greater than $500,000. Among the industrial users 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. SDNI has demonstrated its value to the academic and industrial communities and produced enormous economic and scientific impacts in driving research, technology development, and training new generation of researchers.

SDNI facilities have also been a major training hub for workforce development. By leading and participating in different training programs designed to train students, technicians, and veterans, SDNI facilities committed tool time and more than 400 hours of staff time to the trainees to help them acquire the knowledge and hands-on experience in nanofabrication.

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 124 peer-reviewed scientific publications and 7 patents 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.

SDNI supported research on **all-optical biological voltage sensing via quantum statistics**. The work studies exciton-to-trion conversion in Angstrom-thick semiconductors to experimentally demonstrate label-free, dual-polarity, all-optical detection of electrical activity in cardiomyocyte cultures with ultrahigh temporal resolution. It is shown that the monolayer MoS2 enables completely bias-free tetherless operation due to its substantial trion density originating from intrinsic sulfur vacancies introduced during chemical vapor deposition. This line of thinking at the intersection of biology and quantum science could lead to the discovery of quantum materials for detection of biological electrical activity. The work was published in Nature Photonics in 2025 (https://doi.org/10.1038/s41566-025-01637-w)

SDNI also plays a crucial role in the **Integration of chemical and physical inputs for monitoring metabolites and cardiac signals in diabetes**. The work demonstrates continuous monitoring of both physical and biochemical parameters with multi-functional wearable devices, signifying a breakthrough in wearable devices for healthcare. Researchers create a hybrid flexible wristband sensing platform that integrates a microneedle array for multiplexed biomarker sensing and an ultrasonic array for blood pressure, arterial stiffness and heart-rate monitoring. The device represents a key breakthrough in addressing the limitations of today's wearable devices for healthcare. The work was published in Nature Biomedical Engineering, 2025 (https://doi.org/10.1038/s41551-025-01439-z)

SDNI facility and its staff contribute significantly to **Convergence and Translational Research on surface molecular engineering to enable sulfide solid electrolytes in humid ambient air**. Sulfide solid-state electrolytes (SSEs) are promising candidates to realize all solid-state batteries due to their superior ionic conductivity and excellent ductility. However, their hypersensitivity to moisture requires processing environments that are not compatible with today's lithium-ion battery manufacturing infrastructure. The research presents a reversible surface modification strategy that enables the processability of sulfide SSEs (e. g., Li6PS5Cl) under humid ambient air. The technology based on surface molecular interactions represents a major step forward towards cost-competitive and energy-efficient sulfide SSE manufacturing for all solid-state batteries.

SDNI has also contributed significantly to the CHIP 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, electromagnetic warfare, and AI hardware. 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 GMP facility in medical devices within a university environment.**

Education and Outreach Activities

SDNI's education and outreach efforts in 2024-2025 include visits, tours, and presentations to 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.

Nanostructure visualization is an effective means to introduce STEM subjects to K-12 and community college students. In 2024-2025, 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 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's Summer Institute for Middle and High School Teachers is a week-long program that aims to introduce nanotechnologies to the teachers so that they can teach nanotechnologies in their science classes. Since each teacher typically teaches 100 to 150 students every year, the outreach over the years can be substantial. The Summer Institute introduce teachers to the realm of nanoscience and nanotechnology and its multiple applications. At the conclusion of the summer session, teachers develop instruction plans to integrate nanotechnology to their NGSS-aligned science curricula. SDNI provides continued supports to these teachers during the school year after the training. Since 2021, SDNI has trained 95 teachers with its Summer Institute, including the 24 teachers attending the 2025 Summer Institute.

Research Experience for Undergraduates (REU). We are the host of the 2025 NNCI REU Convocation. Our REU students attended the convocation together with over 70 REU students from other NNCI sites. They also presented their research results at the 2025 UC San Diego Summer Research Conference together with other summer research students on campus, an opportunity to widen their experience, make new friends, and extend their network.

Hands-on Kit for Nanophotonic Education. Silicon photonics is evolving into a key technology to support high performance computing for AI data centers. There is 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 because of the high cost and great difficulties in packaging the photonic chips and the expensive test equipment needed for characterization. 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 prepackaged 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. Thus, the IPEK education tool allows groups who would otherwise be inaccessible to integrated photonics training to have direct hands-on experiences with advanced Si photonics.

SDNI has delivered dozens of IPEKs to numerous technical schools, universities, and industry. Current development work is focused on expanding and improving the curriculum and demo programs. More production runs are scheduled to provide more prototypes to interested institutions. Additionally, grant applications are submitted to expand the program. To increase productivity and reduce cost, we are working on a semi-automated photonic packaging station to help reduce the cost of production.

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

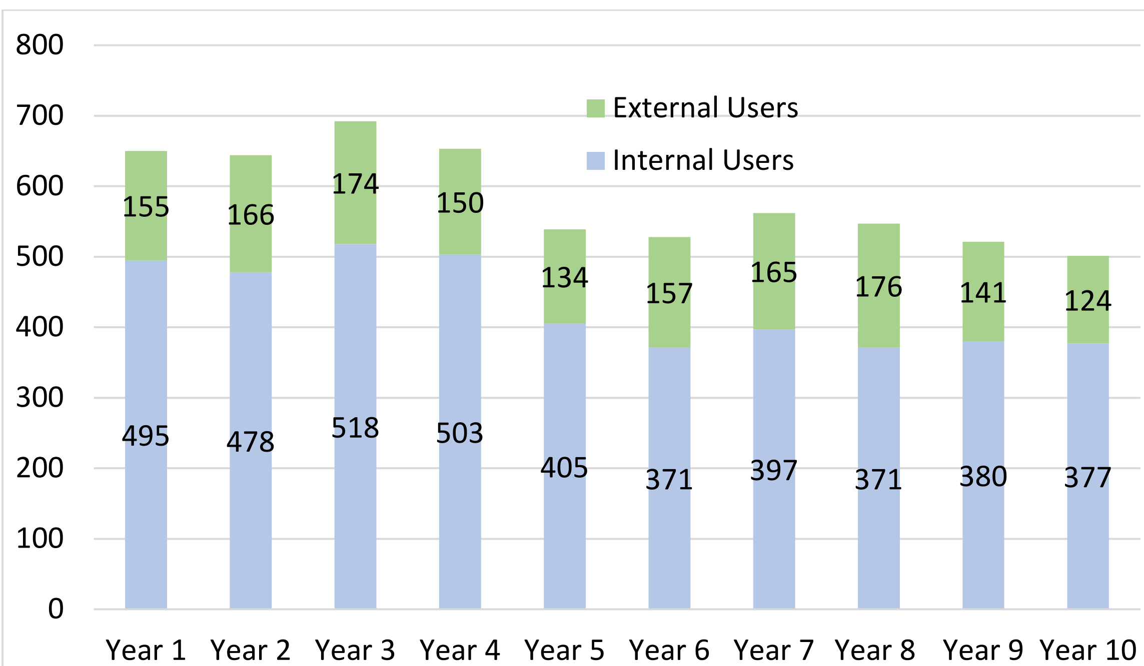
Microelectronics and Nanomanufacturing for Veterans Consortium. In this past year, SDNI has provided 192 hours of nanofabrication and characterization instructions and hands-on training to each of 24 veterans admitted to the program. The goal of the program is to train veterans with nanofabrication and semiconductor processing and characterization technologies to prepare the veterans for their post military careers and to address the workforce shortage problem in US semiconductor industry.

Collaboration with community college on an NSF Advanced Technological Education (ATE) grant to train technicians for the semiconductor industry. SDNI has partnered with community colleges to develop a nanotechnology collaborative education program. The program enables community colleges to provide a technician-oriented program for students aiming to enter the marketplace after graduation from the community college. The program also provides a general education program for students aiming to transfer to UC San Diego for college and advanced degrees. SDNI intends to partner with other community colleges in California to maximize its impact on workforce development.

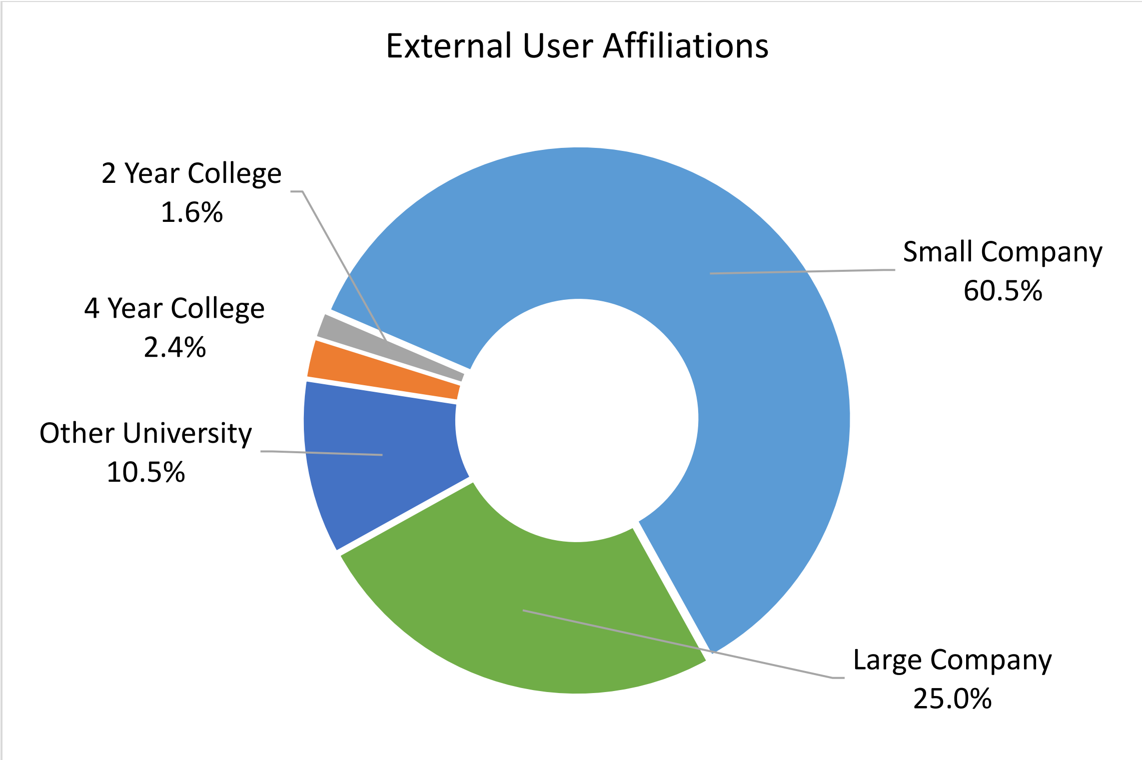
Education/Training Courses. We have offered training courses and short courses in areas that have industry and user demands, including courses for cleanroom device fabrication, vacuum systems, microfluidic devices, and electron microscopy. We have collaborated with the UCSD MRSEC to produce a training course on electron microscopy and run a series of workshops to teach trainees the principle and operation of scanning electron microscopy (SEM) and transmission electron microscopy (TEM).

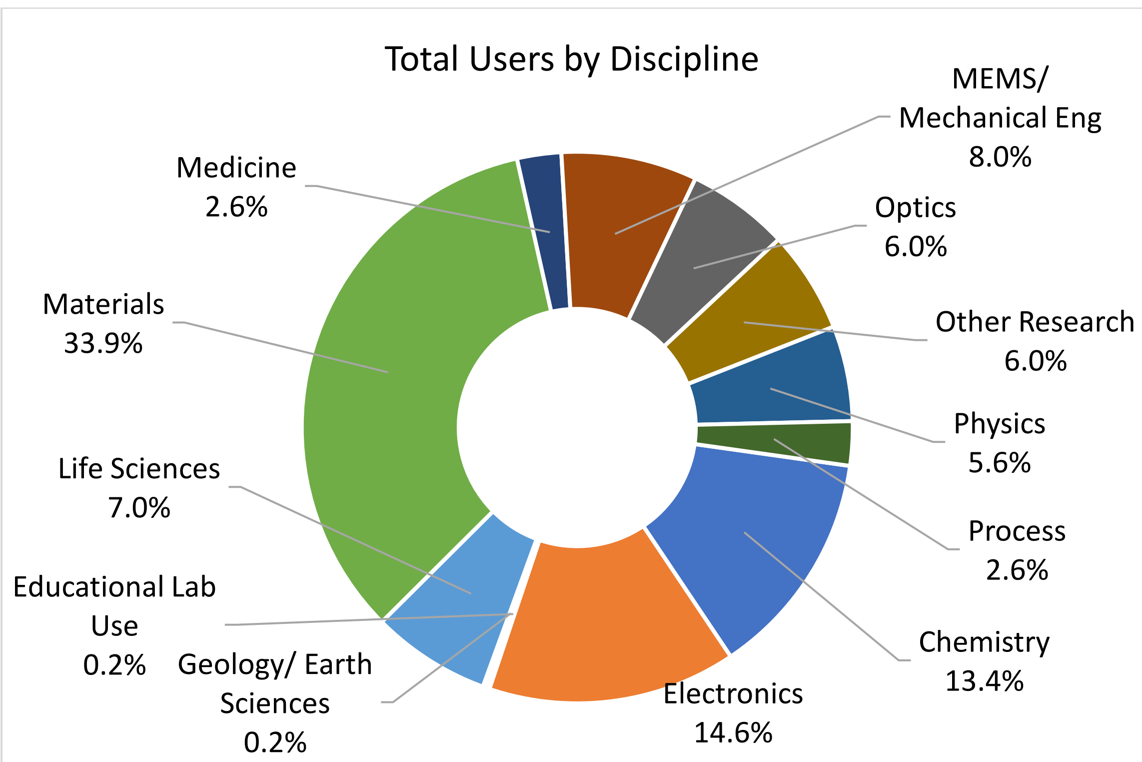
SDNI Site Statistics

Yearly User Data Comparison					
	Year 6	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Total Cumulative Users	528	562	547	521	501
Internal Cumulative Users	371	397	371	380	377
External Cumulative Users	157 (30%)	165 (29%)	176 (32%)	141 (27%)	124 (25%)
Total Hours	61,111	65,051	58,521	58,240	58,329
Internal Hours	44,969	45,279	38,781	43,498	47,597
External Hours	16,142 (26%)	19,773 (30%)	19,740 (34%)	14,742 (25%)	10,791 (18%)
Average Monthly Users	234	260	248	238	230
Average External Monthly Users	53 (23%)	63 (24%)	68 (28%)	55 (23%)	45 (20%)
New Users Trained	152	152	152	152	152
New External Users Trained	18 (12%)	18 (12%)	18 (12%)	18 (12%)	18 (12(
Hours/User (Internal)	121	114	105	114	126
Hours/User (External)	103	120	112	105	87



SDNI Year 10 User Distribution





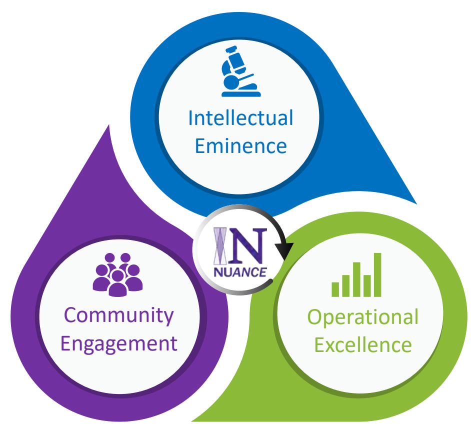
12.13. Soft and Hybrid Nanotechnology Experimental (SHyNE) Resource

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*, NUFAB, IMSERC, NUCAPT, JB Cohen XRD, PLD, CRN *[formerly SQI]*), and the University of Chicago (PNF).

Facility, Tools, and Staff Updates

SHyNE facilities are actively engaged in acquiring and upgrading key equipment within the facilities through a combination of internal and external funding mechanisms. More than 22 new instruments and tool upgrades valued at over $10M were installed in Year 10. **NUFAB**: JEOL 4700 Ga+ FIB/SEM/EDS; ULVAC Oxide Etch system; LPKF Protolaser R4; 3D printer microArch; UPS for cleanroom; **NU*ANCE***: Thermo/FEI Helios 5 Hydra cryo-enabled Plasma FIB; Thermo-FEI Ga+ FIB/SEM; Bruker NanoIR AFM; Tera-Fab Maskless Photolithography System; Hitachi IM4000-II ion mill; Oxford EBSD system; PIE plasma cleaner; Double-tilt cryo-holder; Cryo Industries Cryogenic Stage for TERS-AFM system; Malvern Ellipsometer Upgrade; **IMSERC**: CW X-Band Benchtop EPR Spectrometer; **NUCAPT**: MBraun dual glove-box system;. **CRN**: CEM Multipep 2 parallel peptide synthesizer, Waters Prep 150 2555 HPLC; **PNF**: KLA Model Zeta-20 Optical Profilometer, Woollam RC2 Ellipsometer, V&N Vacuum Evaporator.

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 10: **NUFAB**: Nathan Dvorak, Research Associate; **NU*ANCE***: Dr. Chris Sharpe, Cryogenic Electron Microscopy; Dr. Yu Wen, EPIC-FIB Research Associate; Liam Foley, Program Assistant; **CRN**: Joe Grzybek, Core Technician; **IMSERC**: Dharmeshkumar S Parmar, Mass Spec Director, Research Assistant; **PNF**: Joseph Chamberlain, Associate Process & Equipment Engineer.



SHyNE mission: Following NUANCE as lead facility, each member strives to achieve the highest intellectual achievements, to meaningfully engage with community stakeholders, and to operate with integrity and efficiency.

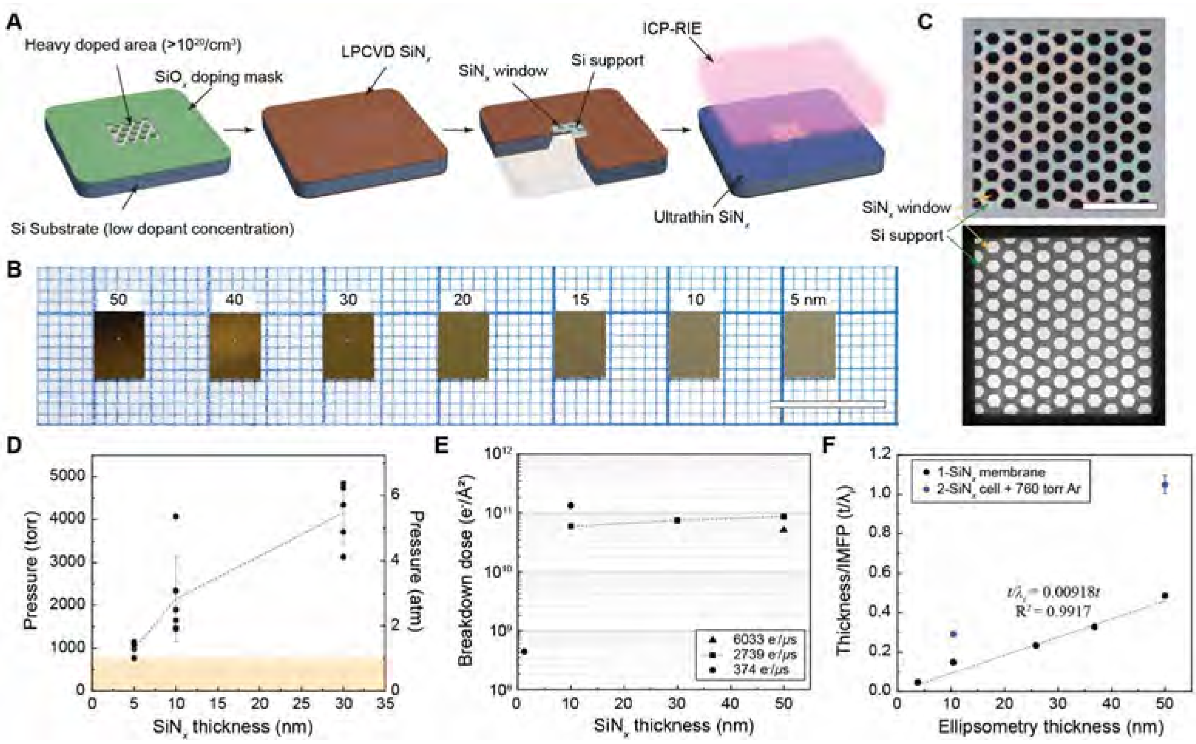
User Base

SHyNE facilities in Year 10 served 1,962 unique users who logged over 233,000 hours of instrument time generating $8.4M 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 reached pre-pandemic activity, and Year 10 shows continued growth. External users in Year 10 accounted for 16% of total users and 15% of total revenue. UChicago's PNF, which began operations in Year 1, had 41 external users in Year 10.

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 maintaining an active social media presence. In Year 10, SHyNE continued managing a SEED (SHyNE External Experiment Development) funding program to recruit new external users by providing start-up grants to support $2,500 in facility usage. Two SEED grants were extended for faculty Mathew and Sharma from University of Illinois at Chicago, federally designated as MSI, AANAPISI, and HSI. Beyond the award period, SHyNE will continue recruiting new external academic, industry, and government users through an active engagement campaign.

Research Highlights and Impact

Ultrathin silicon nitride microchip for in situ/operando microscopy with high spatial resolution and spectral visibility. Utilization of in-situ/operando methods with broad beams and localized probes have accelerated our understanding of fluid-surface interactions in recent decades. The

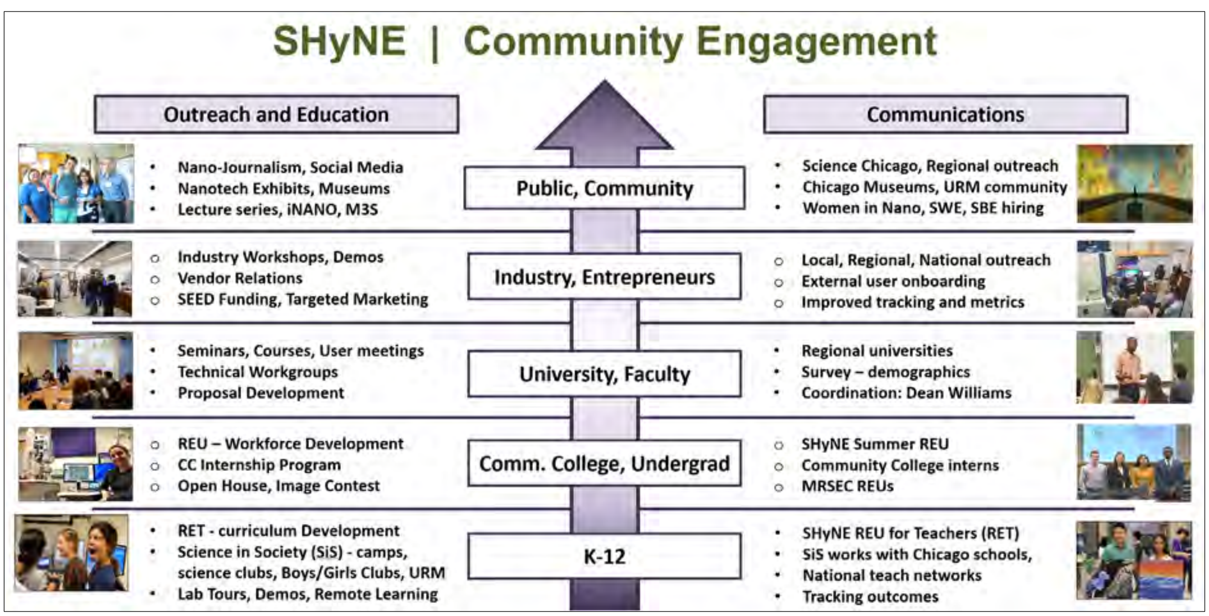


"Fabrication and physical characterizations of the ultrathin SiNx membrane with back-supporting structure." (A) Fabrication process of the UT SiNx membranes. (B) Digital photograph of fabricated membrane chips with thickness ranging from 50 nm to 5 nm. The scale bar is 10 mm. (C) Optical micrograph (top) and the bright field TEM image of the UT microchip with honeycomb patterns. The scale bar is 100 µm. (D) Pressure-resistance of the SiNx membrane with different thickness. Dashed line indicates the averaged pressure tolerance and orange-colored box indicates the general operation pressure. (E) Breakdown electron dose of SiNx membrane under a focused illumination in STEM mode. (F) Correlation of membrane thickness and inelastic mean free path (IMFP: t/λi) of SiNx membrane measured with TEM-EELS. The black dots indicate the t/λi of single membrane and blue dots indicate the t/λi of assembled closed cells with 760 Torr Ar gas. Kunmo Koo et al., Science Advances 10, eadj6417(2024). DOI:10.1126/sciadv. adj6417.

closed-cell microchip based on silicon nitride are widely used as "nanoscale reactors" inside the high vacuum electron microscopes. However, the field has been stalled by high background scattering from encapsulation (typically ~100 nm) that severely limits the figures-of-merit for in-situ performance. This adverse effect is particularly notorious for gas cells as the sealing membranes dominate the overall scattering, thereby blurring any meaningful signals and limiting the resolution. By adopting the back-supporting strategy, researchers from Dravid group successfully reduce the thickness of encapsulating membrane down to ~10 nm, while maintaining structural resiliency. The systematic gas cell work demonstrates advantages in figures-of-merit for hitherto the highest spatial resolution and spectral visibility. Furthermore, this strategy can be broadly adopted into other types of microchips thus having broader impact beyond the in-situ/operando fields.

<u>Education and Outreach Activities</u>

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 10 we assisted with 22 courses, hosted 30+ workshops, lectures, and seminars, and provided tours for K-12, academic, international, government, and industry participants. SHyNE sponsored 4 REU students in a unique, facilities oriented REU program that exposed undergraduates to advanced instrumentation as a key component of their projects. Over 30 workshops and demos were held, including a 2-day Bruker workshop with demos on AFM-IR with live demos on the Dimension IconIR, a collaborative SEM workshop with Oxford Instruments and Hitachi, and a Rigaku and JEOL 2-day Seminar with demos and a poster competition in collaboration with SHyNE's IMSERC facility. 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



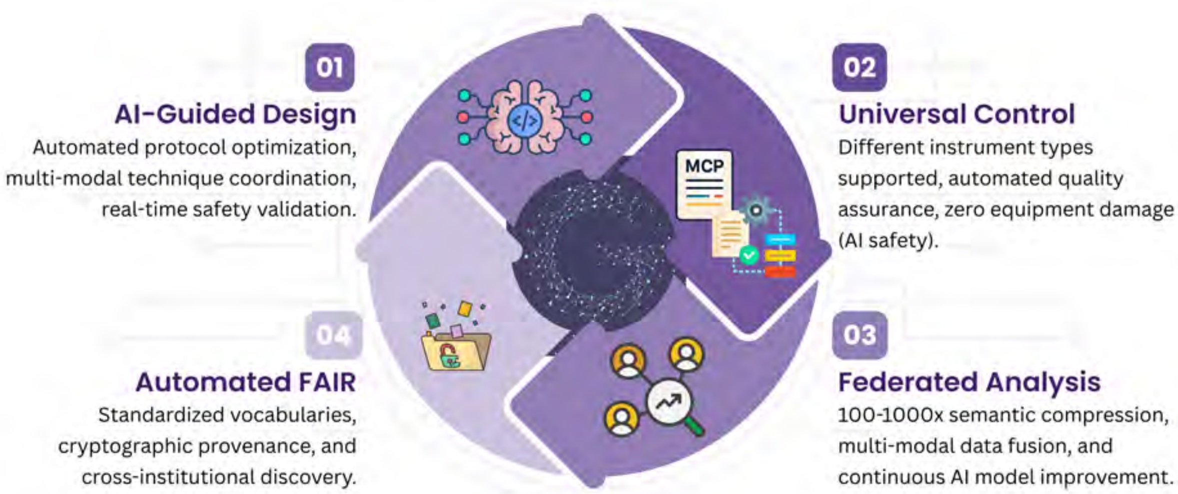
Schematic of comprehensive SHyNE approach to community engagement across all layers of community.

opportunities for underserved youth. Other K-12 outreach included participation in Oakton Community College's *Futures Unlimited Day* for local middle-school and high school students, Northwestern's *All Scout Nano Day* program and an in-person tour and demo for the Northwestern University Research Program for Hich Schooler's (NURPH) SHyNE also hosted the Midwest Microscopy & Microanalysis Society Spring meeting and the 5th 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 media content producer, responsible for creating educational video 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 is working with Oakton Community College to establish an internship program for their Nanotechnology Certificate students.

<u>Computation Activities</u>

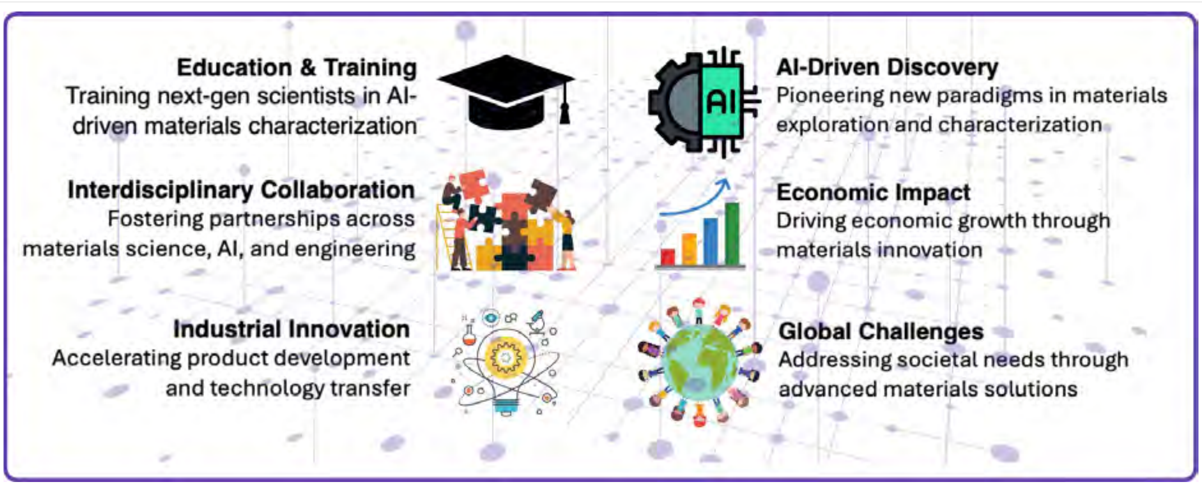
SHyNE is leveraging AI-driven solutions to automated discovery and predictive maintenance. The acquisition of high-speed direct electron detectors at SHyNE facilities has introduced the need to improve the network infrastructure to accommodate the massive amount of data produced. Recognizing this challenge, SHyNE has implemented a LIMS pilot program integrates with pre-



SHyNE's GENESIS four-thrust integration architecture. A central federated network coordinates (01) AI-Guided Design for automated protocol optimization, (02) Universal Control for vendor-agnostic operation with AI safety validation, (03) Federated Analysis for 100-1000× semantic compression and privacy-preserving computation, and (04) Automated FAIR for cryptographic provenance and cross-institutional discovery. Feedback loops ensure distributed analyses refine design recommendations, FAIR automation generates training data, and semantic discovery supports rapid replication and growing network effects.

existing systems to optimize and modernize lab workflows, enhancing security, integrity, and provenance of generated data. 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. In this vein, NU*ANCE* is developing programs to advance foundational cyberinfrastructure through four coordinated thrusts that interlock into a self-improving, AI-native data system: (1) AI-Guided Design develops multimodal models that encode experimental logic, expert heuristics, and provenance-aware learning to make advanced workflows accessible to non-specialists; (2) Universal Control enables vendor-agnostic remote operation via Model Context Protocol (MCP)–based orchestration and AI-safety verification, delivering secure nationwide "experiment anywhere" access; (3) Federated Analysis provides distributed, privacy-preserving pipelines with semantic compression, high-speed similarity search, and cross-facility compute optimization for petabyte-scale materials and biomolecular data; and (4) Automated FAIR Curation embeds continuous metadata capture, cryptographic provenance, and rapid DOI minting directly into instrumentation workflows so that datasets are FAIR-compliant and publication-ready by design. This Category II project also lays groundwork for future Category I–level scaling by piloting an end-to-end acquisition-to-publication lifecycle in which each user session seeds automated, encrypted, and compliant data lineage culminating in cloud-discoverable, DOI-minted datasets aligned with emerging federal expectations for scientific data, security, and open access.

Predictive Maintenance is a program that allows facility managers to detect equipment/facility problems before the failure occurs and prescribe remedies. Characterization, analysis, and fabrication systems employ many sensors and monitor their readings in real-time. 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. This system evaluates the equipment's condition, predicts future trends, toward maintenance recommendations, and can be



SHyNE leverages AI-enhanced research and academic excellence to enhance regional and national economic development.

monitored remotely, with push notifications to designated facility managers. In summary, SHyNE 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.

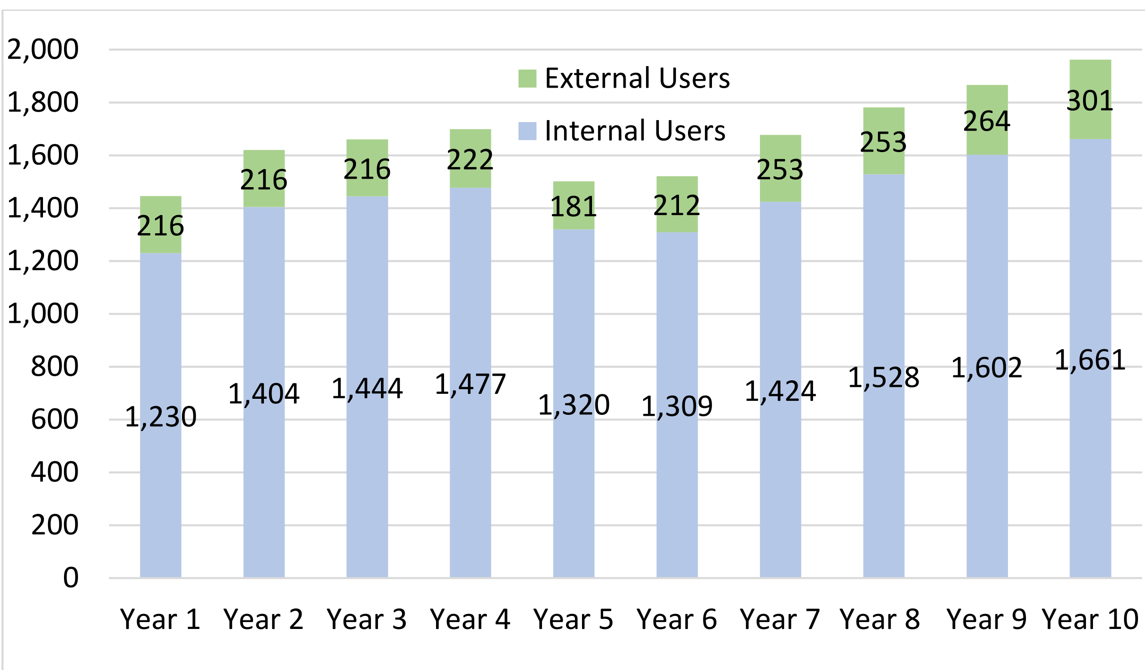
We expect that in the coming years, the latest data analysis tools and techniques will gain a greater foothold into facility environment and revolutionize this environment in ways that leave it better positioned to address major scientific challenges.

Innovation and Entrepreneurship Activities

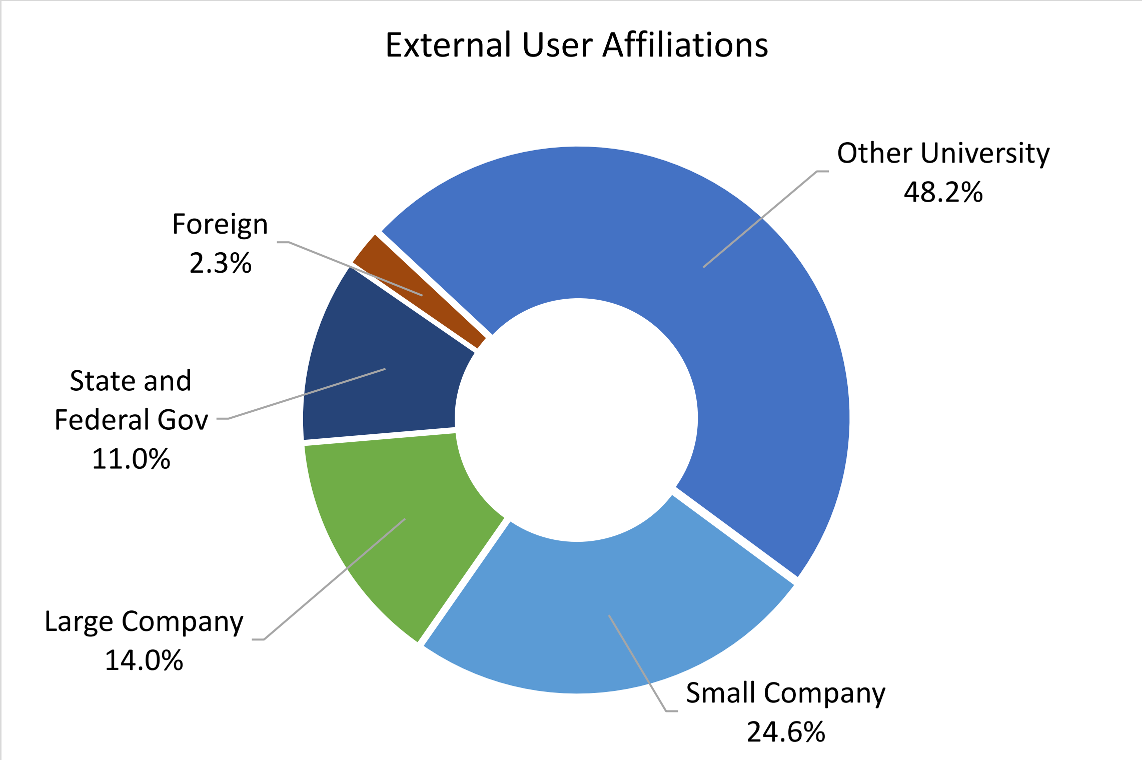
A number of the industrial users are based on technology and entrepreneurs who developed their key technology using SHyNE facilities. SHyNE member facilities partner with UChicago’s Polsky Center for Entrepreneurship and Northwestern’s Corporate Liaison Network, INVOHub, and InQbation Lab to support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

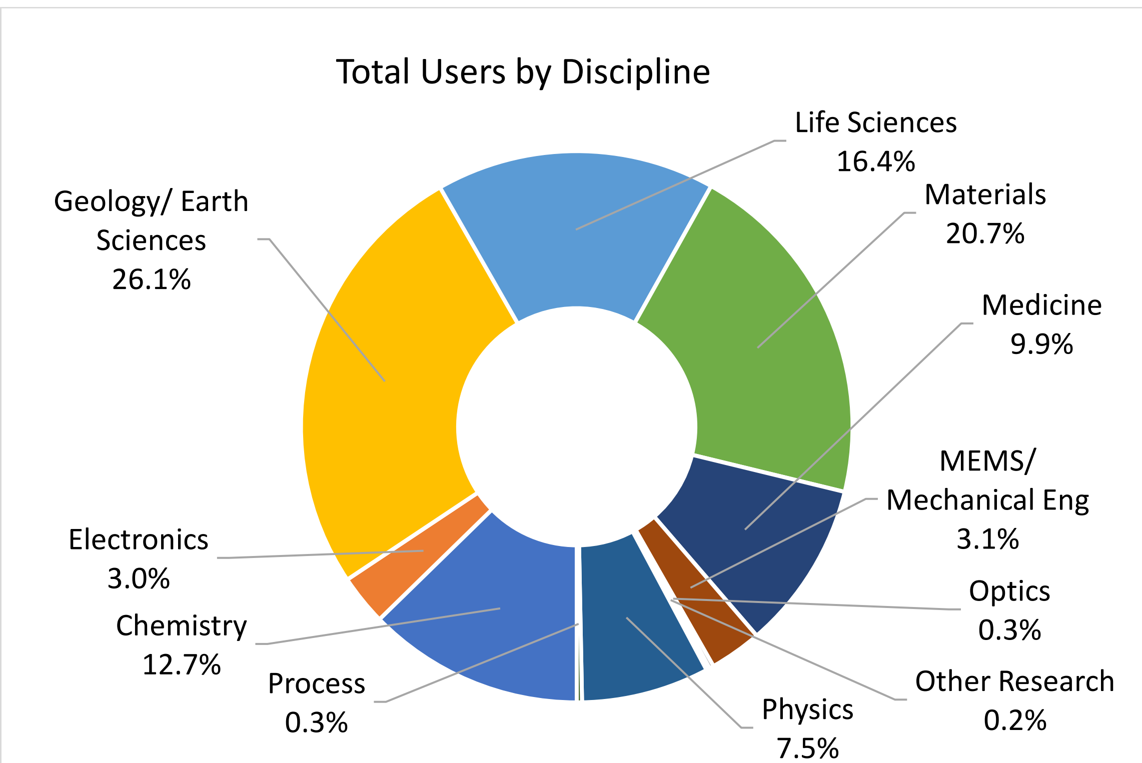
SHyNE Site Statistics

Yearly User Data Comparison					
	Year 6	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Total Cumulative Users	1,521	1,677	1,781	1,866	1,962
Internal Cumulative Users	1,309	1,424	1,528	1,602	1,661
External Cumulative Users	212 (14%)	253 (15%)	253 (14%)	264 (14%)	301 (15%)
Total Hours	159,720	179,802	200,070	225,932	233,236
Internal Hours	150,425	167,794	185,264	212,423	218,510
External Hours	9,294 (6%)	12,008 (7%)	14,806 (7%)	13,509 (6%)	14,726 (6%)
Avg. Monthly Users	693	759	815	858	909
Avg. External Monthly Users	54 (8%)	61 (8%)	72 (9%)	77 (9%)	82 (9%)
New Users Trained	597	649	653	698	685
New External Users Trained	121 (20%)	137 (21%)	132 (20%)	124 (18%)	168 (25%)
Hours/User (Internal)	115	118	121	133	132
Hours/User (External)	44	47	58	51	49



SHyNE Year 10 User Distribution





12.14. Southeastern Nanotechnology Infrastructure Corridor (SENIC)

Facility, Tools, and Staff Updates

SENIC continues to facilitate the "3 universities, 2 locations, 1 site" mindset and partnership between the Georgia Tech Institute for Matter and Systems (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 as well as societal and ethical implications programs targeting the SE, and (5) assist the NNCI network in becoming more than the sum of its parts.

To improve operational efficiency and align with evolving research priorities, the IMS Lab Operations Team was restructured into five specialized functional groups: Fabrication Support, Building Infrastructure, Specialty Labs, Equipment Support, and Shared User Management System (SUMS). Each group is responsible for managing its respective operations, including process development, tool performance, facility support, and day-to-day responsibilities. This new structure promotes team accountability, enables targeted performance assessments, and empowers each group to drive strategic improvements. The reorganization is designed to enhance coordination, streamline workflow, and elevate the level of support provided across Georgia Tech's shared user facilities. In addition, to support facility expansion and increased tool usage, the IMS cleanroom added three new professional staff positions in Year 10: Lab and Facility Coordinator, Process Equipment Engineer I, and Research Equipment Specialist I.

The Materials Characterization Facility (MCF) at Georgia Tech made strides in deepening its staff expertise and broadening its range of analysis techniques. On the staff side, this past year MCF research scientist Weston Straka took on the role of leading the mechanical testing core facility while a search for a lead for the near-surface analysis suite of instruments resulted in the hiring of Josh Davies who joined the MCF in July 2025. In addition to those new researchers, the MCF selected Zac Enderson to be the new lead for the scanning probe and surface-science systems with a special focus on broadening the impact of the Low-Temperature Scanning Probe Microscope (LT-SPM).

As in previous years, JSNN has continued to maintain a strong Facility and Technical Support team with user program manager, facility and lab managers for different core labs, including for the Micro and Nanofabrication (cleanroom) core, Biology 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 2024-2025 JSNN recruited 13 paid Core Facility Assistants, experienced JSNN graduate students who report to and assist the lab managers primarily in user training, consultation, and support services.

Georgia Tech launched a major infrastructure improvement initiative, beginning with the conversion of the former Marcus building technical staff office into a new 1,800 sq. ft. 3D integration cleanroom laboratory. As part of this effort, three dry abatement systems have been procured to replace legacy burnbox units, a transition expected to significantly reduce energy and water consumption and generate long-term cost savings. Upgrades also include CMOS and MEMS chemical wet benches, now capable of handling substrates up to 8 inches, and the replacement of unsupported gas cabinets with ten new units to enhance safety and operational efficiency. Additional facility improvements, including the installation of a plating waste collection system and an upgraded acid waste neutralization system are underway, with continued focus on enhancing lab infrastructure and safety protocols.

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, 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:

Georgia Tech IMS Facilities

- Disco DAS8930 Planar
- Suss Lab Spin6
- Suss Lab Spin8
- SPTS ICP Dielectric Etcher
- Markforged Mark II 3D Printer
- Suss AltaSpray Spray Coater
- WOP Waveguide Laser System
- Fusei Menix Vacuum Laminator
- KLA Plating Bath Analysis System
- CathodoLuminescence (CL) Detector on Zeiss Ultra60 SEM
- High-resolution Detector (Gatan Metro Camera) on Thermo/FEI Tecnai TEM
- Collision Cell Module for Thermo Neoma ICP-MS
- New ZnSe Window added to Createc LowTemp-Scanning Probe Microscope (LT-SPM
- New and Upgraded Accumulators for Hi-Bay Mechanical Testing Facility

JSNN Facilities

- Zeiss Elyra 7 Super-Resolution Microscope
- Rigaku Miniflex XRD
- TA Instruments HR20 Rheometer/DMA
- Malvern Panalytical Zetasizer Advance Ultra
- Malvern Panalytical NanoSight Pro
- Linkam Cryostage for the Witec Confocal Raman
- UV-Vis-NIR Spectrometer
- Agilent Cytation 5
- Leica CPD300 Critical Point Dryer
- NS CNC Elara Mini CNC Mill
- 532nm Laser Upgrade for Horiba XPlora Confocal Raman
- Laser/Detector Upgrade for Beckman Flow Cytometer
- Laurell Spin Coater for new EBL
- Film-Sense Benchtop Ellipsometer

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.

Recently, Georgia Tech IMS has begun conducting customer discovery interviews with recent external facility users. External User Outreach Manager Dr. Billyde Brown has developed a template with interview questions probing the user experience including challenges, successes, and recommendations for improved services. This customer discovery study may also be extended to potential or anticipated future user communities as well.

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 10, new Catalyst awards were made to researchers from Morrow High School, Berry College, Auburn University of Montgomery, Duke University, and NC State University. Since the start of the program in 2019, 49 projects have been awarded, most of them to HBCUs, PUIs, and high schools. The Catalyst award to Berry College (a primarily undergraduate institution) was used for a journal publication and the student involved received a Goldwater Scholarship (photo at left). More details can be found in a Georgia Tech news story (May 27, 2025).

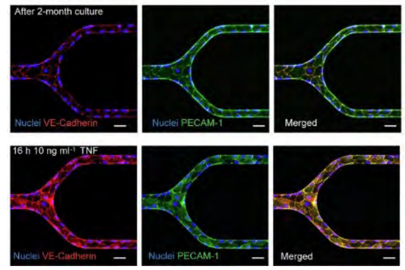
As stated in our renewal proposal, SENIC expanded its relationship with the Center for Nanophase Material Science (CNMS) at Oak Ridge National Lab (ORNL). In particular, we have developed a pathway for joint user/project support, where a SENIC user can obtain expedited access to ONRL resources not available in SENIC facilities. After a period of inactivity, SENIC has revived the Southeastern Nano Facility Network (SENFN) which now convenes as a regularly scheduled monthly virtual meeting.

During NNCI Year 10 (Oct. 2024 - Sept. 2025), SENIC facilities served 1,508 individual users, including 357 external users (72% growth since Year 5) representing 87 companies, 46 colleges/universities, and 12 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 176 users obtained services remotely, and some users were served both on-site and remote. Monthly users averaged 655 (a 76% increase compared to Year 5), and on average 50 new users/month were trained (595 total during the reporting period).

Research Highlights and Impact

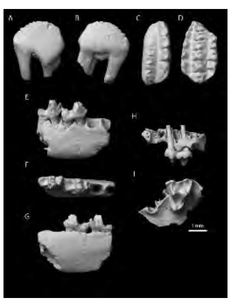
Notable new academic users of the SENIC facilities this past year come from Davidson College, Johnson C. Smith University, Penn State University, and University of Oregon, while new industry users include AkzoNobel, Falcon Engineers, Quoherent, Recognition Analytics, Salvus, and Wolf Biotechnology, to name a few. Some example research highlights include:

Clot on a Chip



Research from Emory University, Children's Healthcare of Atlanta, Georgia Tech, and University of Washington may revolutionize how clinicians understand and treat blood clots associated with life-threatening conditions such as sepsis, sickle cell disease, heart attack and stroke. In a study published in Nature, researchers have discovered the potential to provide life-saving medications to patients using a new thromboinflammation-on-a-chip model that can sustain the clots for several months in a more accurate, human-like manner, leveraging 3D microvessels on a chip. This novel model allows the thrombi to exist in human blood and veins for months and resolve as they would naturally in a real patient. Researchers are then able to track the blood clot and measure the effectiveness of various treatment options. This research was supported by the National Institutes of Health and published in *Nature*.

Paleocene Mammal Fauna from the Great Divide Basin



Researchers from University of Kansas, Grand Rapids Community College, Arizona State University, and UNC-Greensboro compared a new Paleocene mammal fauna from the Great Divide Basin in southern Wyoming with fossil assemblages of similar age elsewhere in Wyoming. Unexpected faunal associations likely reflect changing climates and associated taxon-specific range shifts across a latitudinal gradient in the Rocky Mountain Interior. The apparently asynchronous first and last appearances of certain taxa across this latitudinal gradient highlight the utility of immigrant clades over endemic taxa in biostratigraphy. The micro-CT used in this work was funded by an MRI grant from the National Science Foundation and the research was published in *Journal of Vertebrate Paleontology*.

Wearable Brain-Computer Interface

Georgia Tech and collaborators in South Korea developed a microstructure brain sensor that is placed into the tiny spaces between hair follicles and slightly under the skin of the scalp. The sensor offers high-fidelity signals and makes the continuous use of brain-computer interfaces (BCI) possible. Other, more invasive signal capture methods such as brain implants are possible, but this research created sensors that are both easily placed and reliably manufactured. This research was supported by the National Science Foundation, the IMS WISH Center, and grants from the Republic of South Korea, and was published in *PNAS*.

Scholarly impact can be measured indirectly with more than 630 publications, presentations, and patents benefiting from SENIC facilities in CY 2024. Using a Google Scholar search, 210 of these 2024 publications (and more than 1,400 publications 2015-2024) acknowledged the SENIC NSF award number.

SENIC facilities supported multiple lab courses from Fall 2024 to Summer 2025. GT teaching cleanroom and Materials Characterization Facility supported 11 courses from 6 academic schools in the College of Engineering and College of Science. JSNN facilities supported an additional 11 courses for graduate students in Nanoscience and Nanoengineering. These courses had more than 500 students enrolled. Over the academic year from Fall 2024 to Summer 2025, nearly 400 degrees were awarded to current/former SENIC users at GT and JSNN including 110 Bachelors, 153 Masters, 123 Doctorates.

SENIC's impact is multiplied by the centers and other large multi-PI, multi-institution programs that are enabled by the supported core facilities, and this past year was particularly productive. Through the 3D Systems Packaging Research Center (3D PRC), IMS helped secure nationally competitive microelectronics awards in FY25 including the **National Advanced Packaging Manufacturing Program (NAPMP) Glass-Core Packaging Substrate & Materials** program and DARPA's **Next-Generation Microelectronics Manufacturing (NGMM)** effort. Work has started for the **KIAT-Georgia Tech Semiconductor Electronics Center (K-GTSEC)**, a center managed by IMS's Wearable Intelligent Systems and Healthcare Center (WISH Center). The **Georgia Tech-Advanced Battery Center (GT-ABC)** secured $3.8M in federally-directed spending to help build a new prototyping and research facility. With support from the State of North Carolina as part of Engineering NC's Future Capital Improvement Fund, NC A&T completed the establishment of the **Interdisciplinary Bioengineering Core (IBEC)** at JSNN and NC A&T (M-ERIC 183) campus. UNCG in collaboration with JSNN launched two institutes: The **Battery Research, Innovation, and next-Gen Energy Harvesting Technologies (BRIGHT)** Institute and the **Institute for the Convergence of Optimized Methods for Military Advances and National Defense (iCOMMAND)**.

While economic impact can be difficult to quantify, select examples from Year 10 indicate that SENIC-supported companies are achieving success:

- **Andson Biotech** launched DynaCHIP X1 at the American Society for Mass Spectrometry 2025 conference. The company is focused on revolutionizing mass spectrometry workflows for biopharma, particularly in the realm of cell and gene therapy analytics. The company also received $5 million in seed funding from Biotools Innovator in 2025.
- **OXOS Medical** received FDA 510(k) clearance for its MC2 Portable X-ray System, and it is now available for sale.
- **Syensqo** is expanding its presence in Georgia, including a new EV material facility in Augusta and investments in workforce development, creating approximately 100 new full-time, highly skilled, local manufacturing jobs.
- **JTEC Energy** received recognition as one of TIME's "America's Top GreenTech Companies" 2025 list. The company also won the "Energy Production Innovation Award" from CleanTech Breakthrough.
- **Lux Semiconductors** secured $2.9 million in seed funding in March 2025. The company has received over $6 million in non-dilutive funding from sources including the U.S. Air Force, Space Force, Department of Energy, and National Science Foundation.

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. During NNCI Year 10 through our programs, we reached more than 14,000 individuals from young children to adults.

JSNN hosted 26 Semi-BELLS Interns who are working with faculty and graduate students on semiconductor and microelectronics projects that utilize JSNN's facility. The internship is part of the Commercial Leap Ahead for Wide Bandgap Semiconductors (CLAWS) hub which is part of the Department of Defense sponsored Microelectronics Commons. 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 44 undergraduate students. 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 and JSNN also hosted twelve REU students in 2025. In addition to internships, SENIC also provided opportunities for high school students and undergraduates to work in the facilities as student assistants.

IMS is also a participant in the Microelectronics and Nanomanufacturing Partnership for Veterans. This NSF funded program is based out of Penn State and began in 2022. The purpose of this program is to bring education and training opportunities in nanomanufacturing and microelectronics to military service members and veterans. Veterans are recruited from local community colleges. IMS's partner in this program is Georgia Piedmont Technical College. Students who successfully complete this program will earn a Microelectronics and Nanomanufacturing Certificate of completion from the Center for Nanotechnology Education and Utilization (CNEU) at Penn State. They will also be prepared to take the three nanotechnology stackable certification exams administered by the international standards organization ASTM International. The 12-week program consists of live-streamed lectures from CNEU, paired with a hands-on experience in the IMS cleanroom. The hands-on laboratory sessions consisted of cleanroom safety training, wafer processing in cleanroom, material characterization, microelectronic device characterization, and device fabrication. IMS Has hosted three cohorts, training 12 veterans during the reporting period.

Each academic year, JSNN hosts a weekly seminar, and IMS hosted a bimonthly seminar called Systems Matter Seminar Series. In October 2024, JSNN hosted the 5th annual NanoImpacts Conference, with the theme: Semiconductor Materials, Devices, and the CHIPS Act. NanoImpacts brought together leaders from government, academia, and industry to explore the future of semiconductor research, development, and manufacturing in the United States. The event offered attendees an in-depth look at the evolving semiconductor ecosystem.

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 and was renewed for 2025. Under the renewal, we hosted a cohort of 4 teachers from the metro Atlanta area in 2025. 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 (February 2026) to share their results and experience with the broader teaching community. The summer 2025 Nanotechnology Summer Institute for Middle School Teachers (NanoSIMST) program was held in-person at JSNN with a cohort of 23 teachers from North Carolina. Teachers participated in a week of instruction that introduced them to nanotechnology and learned about classroom lessons that meet North Carolina state standards. The teachers also participated in cleanroom and lab tours, used the portable SEM, and participated in a careers panel.

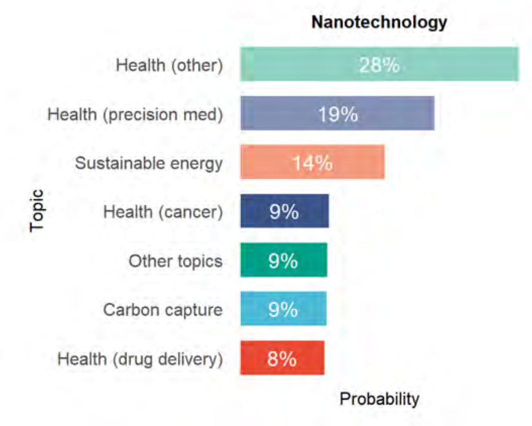
The JSNN's summer internship research experience reached 11th and 12th grade students in their region, enrolled at several different local schools and school districts. These students spent at least one day/week for a semester working in partnership with a graduate student on research projects. During the summer of 2024, JSNN hosted 13 Draelos High School Scholars and an additional 13 high school interns.

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. Over 600 kids have participated in the virtual program. In June 2025, Georgia Tech hosted 60+ 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 "Soft Lithography for Microfluidics". IMS also held one-day workshops covering topics such as x-ray characterization, laser micromachining, XPS and elemental analysis.

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 10, Prof. Diana Hicks and graduate student Sergio Pelaez completed the examination of societal orientation of nanotechnology inventions, identifying statements promising societal or commercial benefits from an innovation in patent text. The research investigated whether the societal promises made in patent documents actually align with what the technology can deliver. The study examined over 65,000 U.S. patents in nanotechnology filed between 2005 and 2023, analyzing whether value-laden statements in these patents correspond to the technologies' real potential for social impact. Patents often contain narrative statements beyond technical descriptions — promises about solving societal problems, improving health outcomes, or addressing environmental challenges. We wanted to know: Are these statements genuine reflections of the technology's potential or are they merely persuasive marketing language designed to make patents appear more valuable?

The findings reveal a significant positive relationship between public value statements and socially oriented technologies. Patents containing promises about societal benefits were indeed more likely to be classified as addressing social challenges based on their underlying technology. Conversely, patents emphasizing only commercial benefits showed a negative association with social orientation. Most intriguingly, patents containing both public and private value statements — those promising both societal benefits and commercial advantages — showed the strongest positive relationship with social orientation. This suggests that technologies addressing both social needs and market demands may be best positioned for real-world impact.



Nanotechnology patents focused heavily on environmental applications and health benefits, particularly cancer treatment (Figure: Topic Model of Value Statements). University-affiliated patents demonstrated higher rates of public value statements compared to corporate patents, likely reflecting academic institutions' social missions and funding requirements for broader societal impact.

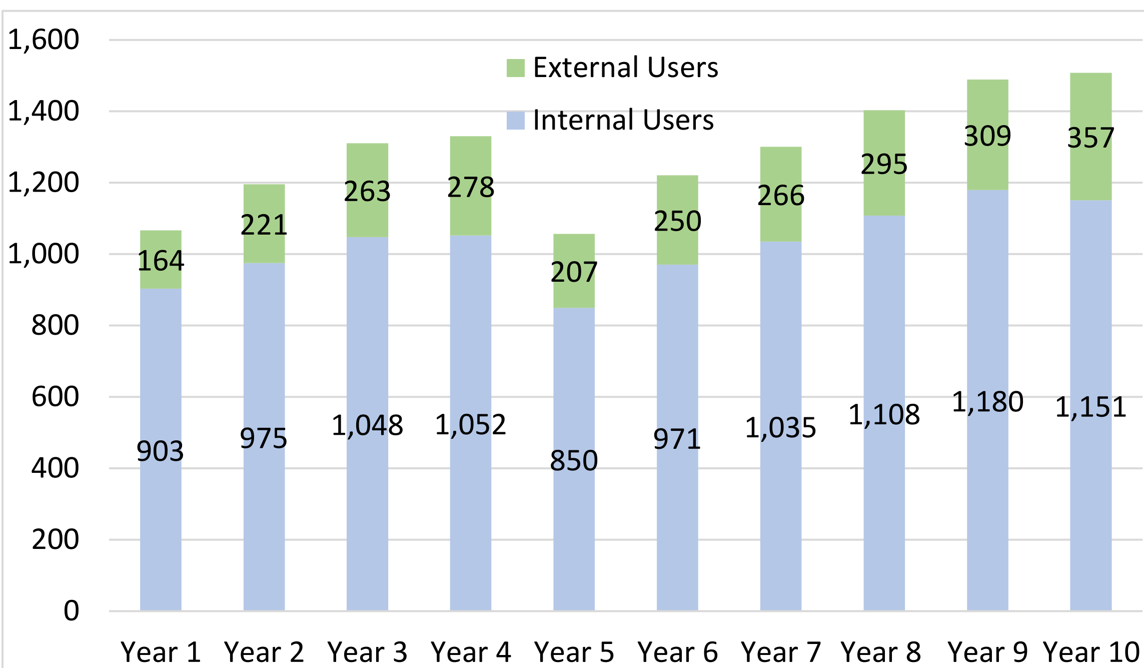
These findings challenge the notion that value-based statements in patents are merely "ethics-washing" or rhetorical devices. Instead, they suggest that when inventors articulate societal promises, these often reflect genuine technological potential for social impact. This has important implications for how we understand innovation, technology governance, and the role of patents in shaping technological development.

Innovation and Entrepreneurship Activities

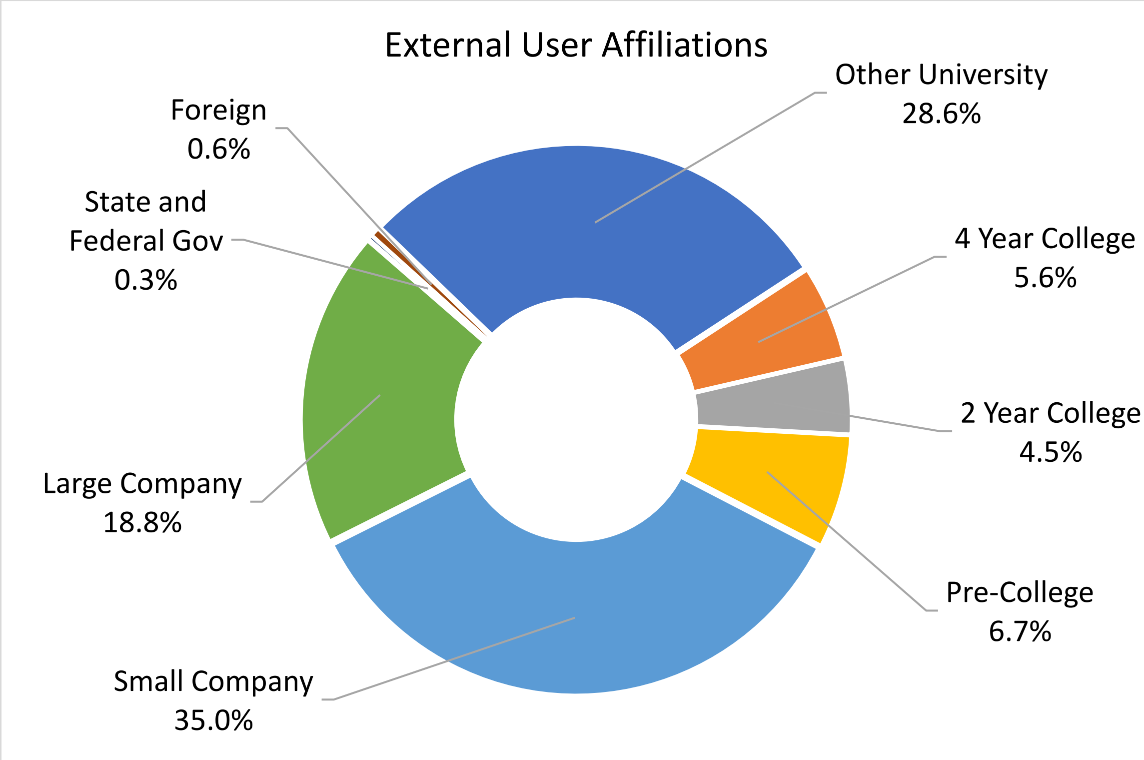
In 2025, nine project teams from SENIC (all from JSNN) participated in the fourth NNCI NTEC. The top 4 teams from the NTEC Showcase, including a SENIC team led by Gregory Roberts (Mentor: Shyam Aravamudhan), had an opportunity to pitch live at a special “Future Innovators” session at TechConnect in Austin, TX, June 9-11, 2025. Greg Roberts also won the “Forged by Fire Award” during the showcase and Kumari-Ebrahimi (SENIC, Mentor: Kristen Dellinger) secured Honorable Mention.

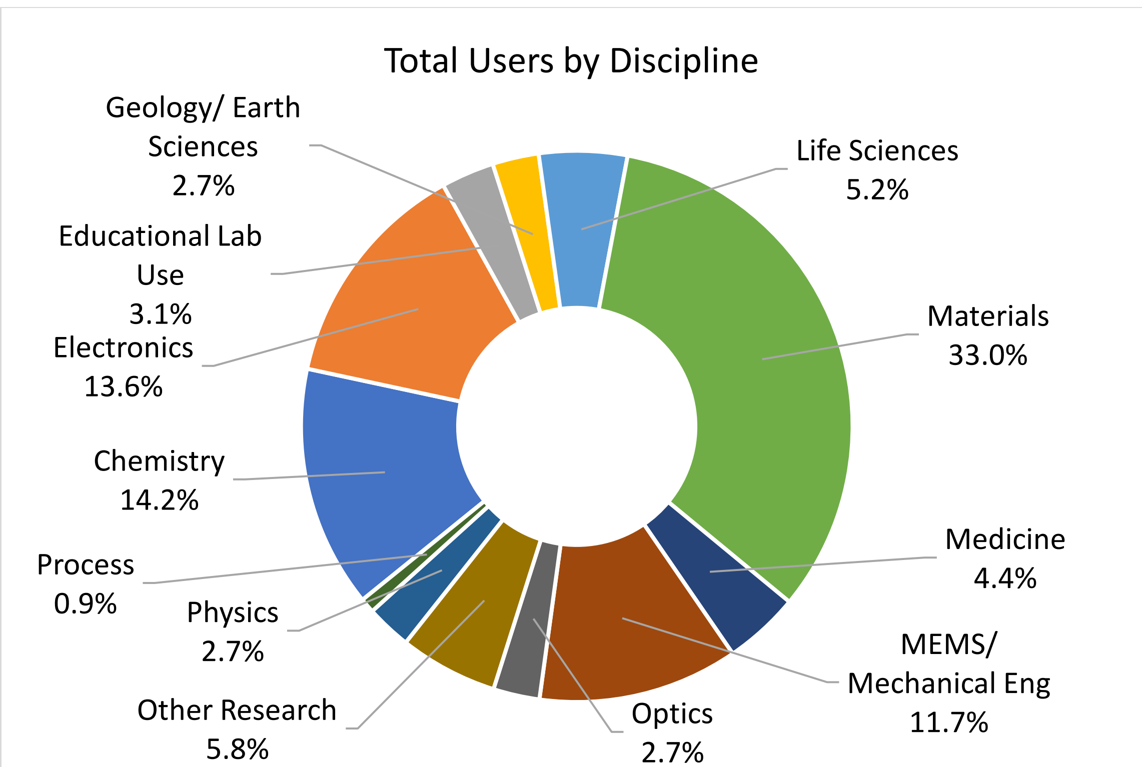
SENIC Site Statistics

Yearly User Data Comparison					
	Year 6	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Total Cumulative Users	1,221	1,301	1,403	1,489	1,508
Internal Cumulative Users	971	1,035	1,108	1,180	1,151
External Cumulative Users	250 (20%)	266 (20%)	295 (21%)	309 (21%)	357 (24%)
Total Hours	92,998	109,049	127,584	136,945	152,462
Internal Hours	80,751	96,276	112,755	118,809	131,917
External Hours	12,247 (13%)	12,773 (12%)	14,829 (12%)	18,136 (13%)	20,545 (13%)
Avg. Monthly Users	499	563	603	656	655
Avg. External Monthly Users	75 (15%)	73 (13%)	83 (14%)	87 (13%)	98 (15%)
New Users Trained	453	505	571	589	595
New External Users Trained	80 (18%)	124 (25%)	142 (25%)	180 (31%)	221 (37%)
Hours/User (Internal)	83	93	102	101	115
Hours/User (External)	49	48	50	59	58



SENIC Year 10 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 users' 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 member 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.

Roberto Panepucci 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.

<u>User Base</u>

In Year 10, TNF hosted over 1100 unique users, and 50,000 total laboratory usage hours. Average laboratory hours and user fee revenue has increased from Year 9. As in Year 10, 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, Electronics, or Chemistry disciplines.

TNF had 9% average outside users at the end of the tenth year, and it has been around 23% during the first 6 years. The percentage drop is mainly due to an increase in the 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. The external user percentage share of total laboratory hours dropped in recent years because of the pandemic. This year, the cleanroom was shut down for extended periods due to a major upgrade, leading to a drop in usage by external users.

<u>Research Highlights and Impact</u>

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)

Leo Mathew and Rajesh Rao, Applied Novel Devices (AND)

Previously, AND 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. They 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 $V\pi L$ 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 confirm 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 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

Societal and Ethical Implications Activities

Dr. Lee Ann Kahlor, a science communication expert at the University of Texas at Austin, has led the Social and Ethical Implications (SEI) team for the National Nanotechnology Coordinated Infrastructure (NNCI) at Texas Nanofabrication Facility (TNF) for the past decade. The purpose of SEI at NNCI-TNF is to train and mentor junior communication scholars to research societal and ethical topics related to nanotechnology, train TNF employees on SEI as part of the employee onboarding procedures, and present and publish research focused on SEI and communication. Each year, a new doctoral student is funded and trained.

She officially launched the SEI at the NNCI-TNF website as part of our SEI outreach efforts in 2020 (https://sites.utexas.edu/nnci-sei/). This site provides introductory information about NNCI, TNF, and SEI, including the training module developed during previous funding cycles. It also features a variety of local and online educational resources related to nanoethics (e.g., SEI education videos) designed for both scientific and professional audiences. The website continues to serve as a centralized hub for SEI-related projects, resources, and updates for NNCI-TNF. The website remains regularly maintained and updated.

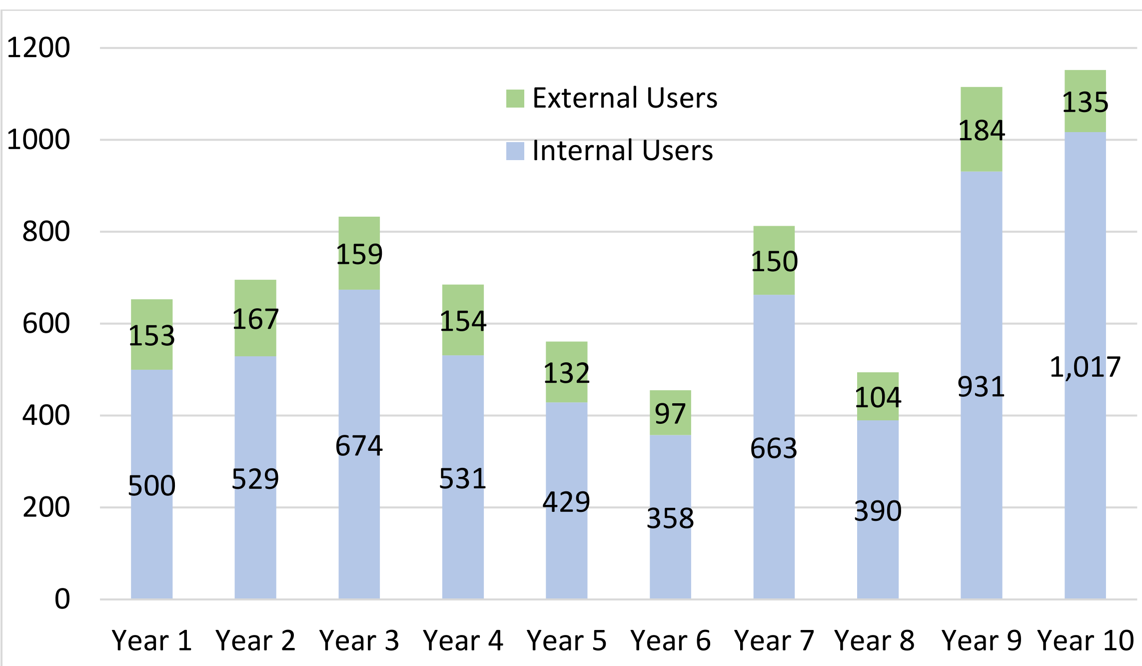
Computation Activities

Professor Frank Register directs computational projects and tool development, which are chosen based on the needs of the experimentalists in TNF. Various projects were completed.

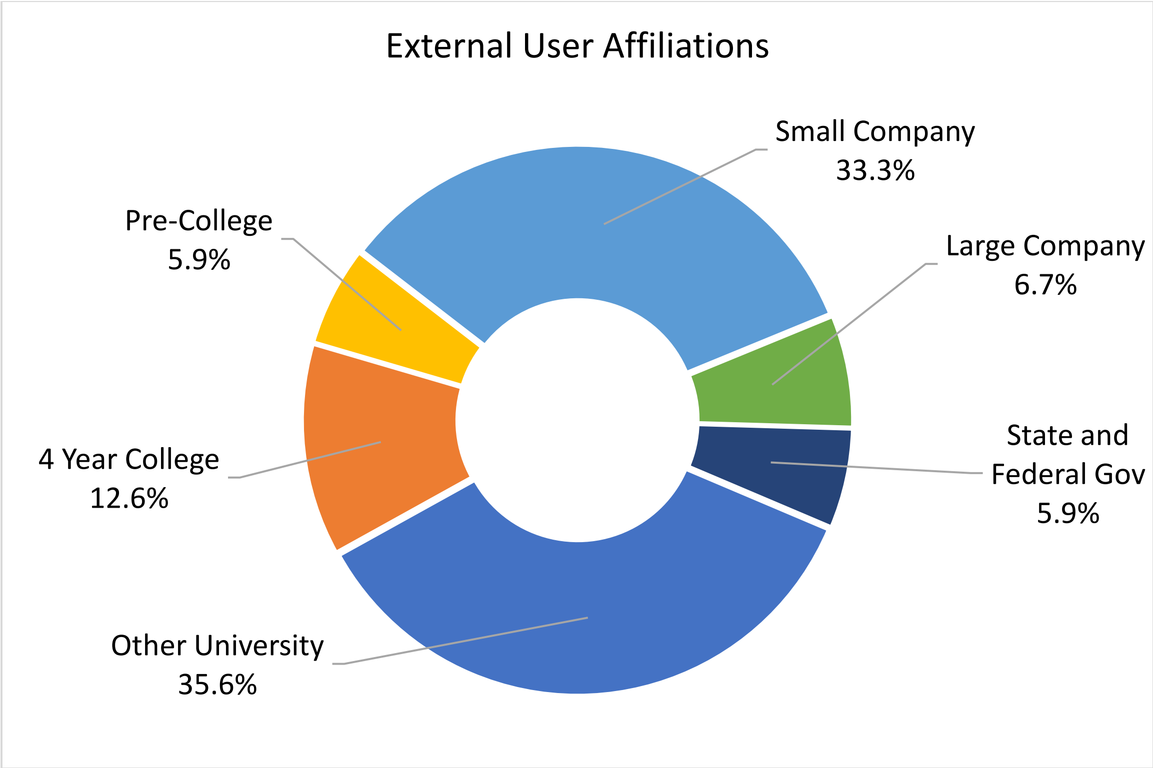
- Engineering Si-Qubit MOSFET: Quantum-Electrostatic Integration at Cryogenic Temperatures
- Analytical Modeling of Short-Channel Effects in BEOL-Compatible Thin-Film Transistors
- Multi-Domain Dynamics and Ultimate Scalability of CMOS-Compatible FeFETs
- Impact of Multi-Domain Microscopic Interactions on Magnetic Tunnel Junction’s Static and Transient Characteristics
- Impact of Multi-Domain on Ferroelectric Tunnel Junction Design Metrics
- 2-D Analytical Modeling of the Magnetic Tunnel Junctions Including Multidomain Effects: Predictive Insights and Design Optimization
- Dynamics of Domains and Its Impact on Gate Tunneling in CMOS-Compatible FeFETs

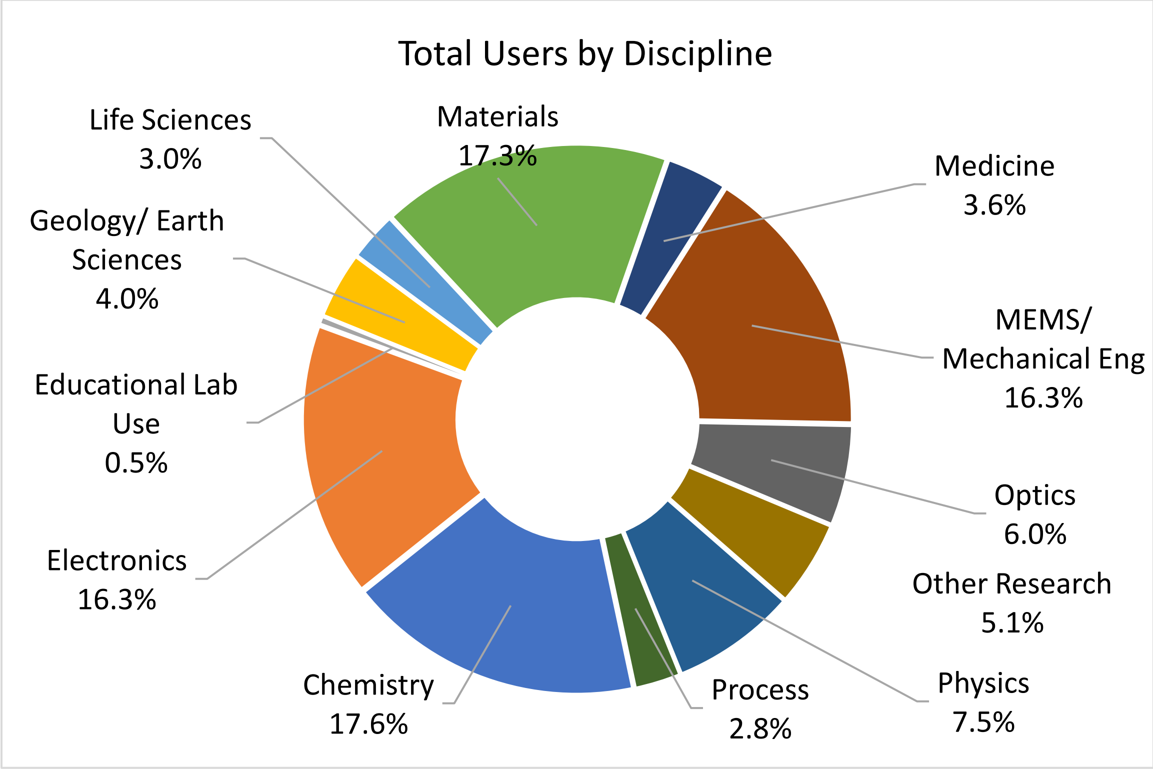
TNF Site Statistics

Yearly User Data Comparison					
	Year 6	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Total Cumulative Users	455	813	494	1,115	1,152
Internal Cumulative Users	358	663	390	931	1,017
External Cumulative Users	97 (21%)	150 (18%)	104 (21%)	184 (17%)	135 (12%)
Total Hours	53,901	65,193	41,445	50,922	51,756
Internal Hours	41,159	51,438	30,537	38,102	40,607
External Hours	12,742 (24%)	13,755 (21%)	10,908 (26%)	12,820 (25%)	11,150 (22%)
Average Monthly Users	246	337	245	352	431
Average External Monthly Users	53 (22%)	66 (20%)	51 (21%)	68 (19%)	61 (14%)
New Users Trained	38	54	12	67	78
New External Users Trained	10 (26%)	18 (33%)	5 (42%)	9 (13%)	7 (9%)
Hours/User (Internal)	115	78	78	41	40
Hours/User (External)	131	92	105	70	83



TNF Year 10 User Distribution





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

Facility, Tools, and Staff Updates

Facility & Tools: A new JEOL JSM-IT800 (SHL) high-resolution field emission gun was acquired and installed at the NCFL to replace the 20+ year old Zeiss LEO. The JSM-IT800 SHL features the Super Hybrid Lens (SHL) configuration and includes multiple detectors for versatile imaging, such as Everhart Thornley detector, Scintillator backscattered electron detector, and inlens detector. The instrument combines confocal Raman Imaging and Scanning Electron (RISE) Microscopy. A JEOL IB-19520CCP Cooling Cross Section Polisher was acquired for cutting away thin materials and leaving a smooth surface so that materials can be viewed in cross-section using an SEM, a FIB/SEM, microprobe, or other suitable imaging tool. Due to high demand for EBSD on our Helios 5 UC FIB/SEM, a duplicate EBSD accessory was purchased for the Quanta ESEM. This acquisition allows the NCFL to have two SEMs with integrated EBSD/EDS detectors from the same manufacturer. TEM capabilities were upgraded through the acquisition of a new twin jet polisher and a 4D STEM module for the NEOARM.

Staff: The facility hired one new Instrumentation Laboratory Manager, Dr. Inno Shuro, who will join the team on November 24, 2025. Dr. Shuro is a versatile materials characterization specialist with expertise in electron microscopy including SEM, TEM, FIB, EBSD, EDS, and EBL. Previously, Dr. Shuro served as a Materials Characterization Specialist at the University of North Carolina, Chapel Hill. Dr. Shuro's hiring is critical as long-time NCFL lab manager, Stephen McCartney, retired in Fall 2025 and transitioned into a part-time role.

As NSF funding is exhausted during the no cost extension period, NanoEarth will support the transition of our staff to new roles either within our facilities, the university, or at other institutions. Instrumentation Specialist Dr. Weinan Leng's role is now fully supported by the facility. Assistant Director Tonya Pruitt has transitioned to a new program led by a NanoEarth coPI. Outreach and Communications Coordinator Sylvianne Velasquez has left the university.

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.

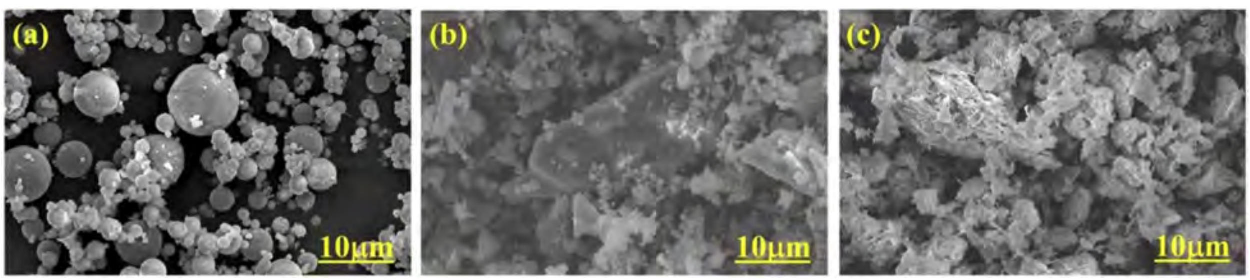
Research Highlights and Impact

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

Academic Highlight – Chiang Mai University, Thailand (Kedsarin Pimraksa, PI)

Manickam, C., Chuwongwittaya, A., Jaideekard, M., Thala, M., Kumprom, C., Setthaya, N., Juengsuwattananon, K., Wattanachai, P., Murayama, M., Chindaprasirt, P., Siyasukh, A., & Pimraksa, K. (2024). **Geopolymer/zeolite-P materials prepared from high-CaO fly ash, biomass ash, and metakaolin using geopolymerization with a hydrothermal process for environmental clean-up**. *Construction and Building Materials*, 456, 139255. https://doi.org/10.1016/j.conbuildmat.2024.139255 [abstract and publication's Fig. 3 are below]

[Publication Abstract] – "This study aims to synthesize geopolymer/zeolite-P (GP-ZP) materials as a building material for environmental clean-up. High-CaO fly ash (FA), biomass ash (BMA), and metakaolin (MK) are designed as starting materials to generate geopolymeric and zeolitic materials simultaneously through geopolymerization and zeolitization using hydrothermal treatment at only 100°C. This study explores that CaO can be quarantined in the geopolymeric structure using SiO2/Al2O3 molar ratios of 6.0 and 8.0 while at lower SiO2/Al2O3 molar ratios, CaO tends to precipitate various calcium compounds. Various SiO2/Al2O3, Na2O/Al2O3, CaO/Al2O3, and CaO/SiO2 molar ratios are investigated using different ratios of FA and BMA mixes to explore the geopolymeric binding characteristics and evaluate the types of zeolites formed. Unmilled and milled MK are also used to partly replace FA to improve the development of porous zeolite-P materials in geopolymeric matrix. Furthermore, the differences in the material characteristics obtained from the powdered and bulk materials are compared in terms of the mineralogical composition, surface morphology, specific surface area, and cation exchange capacity. The mechanical properties of the materials are also investigated to understand the relationship between the phase development and binding properties. Hydrothermal treatment improves the mechanical properties when the FA and BMA system is used with an SiO2/Al2O3 ratio of 8.0, or when the FA, BMA, and MK system is used with an SiO2/Al2O3 ratio of 6.0, showing the better development of geopolymeric gel composited with zeolite-P. The environmental clean-up capability is determined using powdered and bulk material dosages of 1.0 g and 10.0 g, respectively, to remove nearly 100 % of 20 mg/L methyl orange dye."

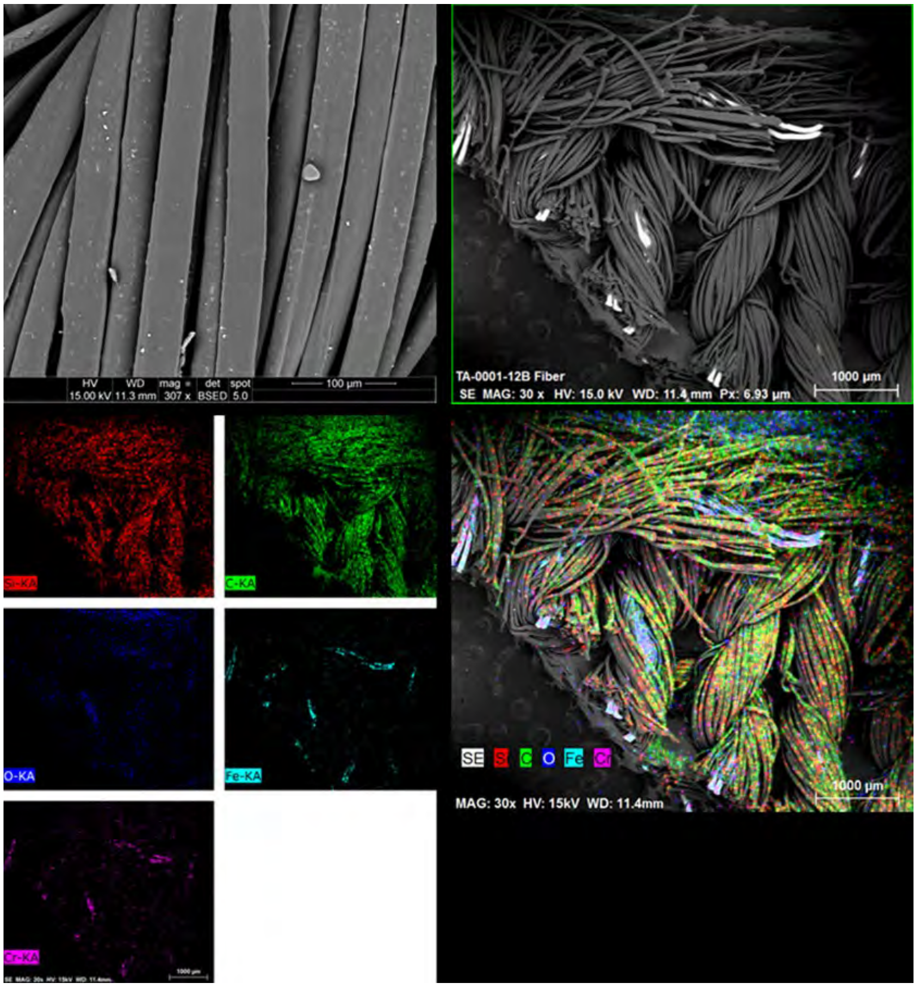


Scanning electron microscopy photomicrographs showing the microstructures of (a) fly ash, (b) biomass ash, and (c) metakaolin. [Fig. 3 in the publication listed above].

Industry Highlight – The Graphene Council, Ltd., Manchester, UK (Terrance Barkan, PI)

Hill, W. C., Barkan, T., Amos, T., Leng, W., & Hull, M. (2024). **Investigation of commercial cut-resistant gloves claiming graphene additive content**. *Graphene and 2D Materials*, 9, 87-99. https://doi.org/10.1007/s41127-023-00070-6 [abstract and publication's Fig 1. are below]

[Publication Abstract] – "Five commercially available cut-resistant gloves were sourced from four different worldwide manufacturers which were advertised to contain graphene. A method was developed to assess the fibers composing each glove, including dissolution of the constituent fibers using sulfuric acid or liquid paraffin at elevated temperature, to extract and analyze particle additives. Scanning electron microscopy with energy-dispersive X-ray spectroscopy was applied to fibers and extracted particles for morphological and elemental analysis; Raman spectroscopy was applied to discern the composition of carbonaceous materials for the ultimate purpose of identifying any graphenic additives. Only one of the five tested products contained conclusive evidence of material in the graphene family, as graphene oxide was clearly presented as advertised. Two of the products, which were sourced from the same manufacturer, exhibited evidence most suggestive of graphite or amorphous carbon rather than graphene. The remaining two products exhibited signatures of amorphous carbon without evidence of graphitic or graphenic material. The four products that did not conclusively present evidence of advertised graphene also contained prolific alternative cut-resistant additives such as steel wire, glass fiber, or a silicon-based particle that elemental analysis suggests may be silicon carbide. Methods and techniques for the evaluation of products claiming graphene content are demonstrated for the purposes of improving market integrity and consumer confidence in product claims."



Glove A and Glove B fibers presented similarly (Glove B images pictured). Embedded particles (top left) and metallic wire (top right) were suggested by backscatter imaging, appearing brighter in contrast to the polymeric fiber background. Elemental analysis (bottom left and right) indicated embedded particles were silicon-based; while, the wire appeared to be composed of a variety of stainless steel [Fig. 1 in the publication listed above]

<u>Education and Outreach Activities</u>

Not including social media engagement and *Pulse of the Planet* listenership, we interacted with over 2,000 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 final NanoEarth episode, "Small Things, Big Challenges – Inside the World of Nanotech", aired on March 27, 2025, featuring NanoEarth Deputy Director Marc Michel, Ph.D. discussing the environmental implications of nanoscience and nano inventions. 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 third year in a row, NanoEarth partnered with Concord University's Arctic REU program (NSF OPP-1950842). MONT is a co-PI on this REU program. REU participants complete fieldwork at the Aasivissuit - Nipisat UNESCO World Heritage site in Greenland before returning to the country to analyze their samples at various locations including Virginia Tech's NanoEarth. During their REU experience, participants have the opportunity to participate in weekly seminars, meetings, and networking activities with REU participants across the country at the NNCI sites affiliated with the Nano EES-RC (NanoEarth, NCI-SW, MONT, and nano@stanford). The REU participants complete their experience by presenting their research findings at the NNCI REU Convocation at the University of California at San Diego in August 2025.
- 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).

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

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.

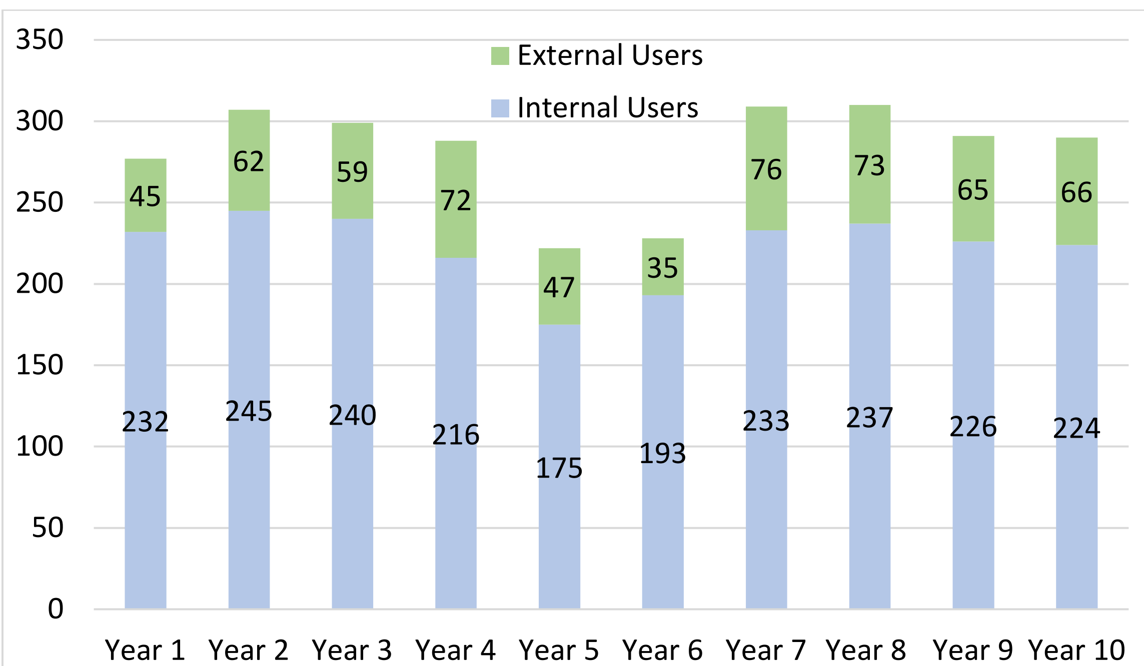
Innovation and Entrepreneurship Activities

NanoEarth continues to operate many of its core innovation and entrepreneurship (I&E) programs including the NanoTechnology Entrepreneurship Challenge (NTEC), the Entrepreneur-in-Residence (EiR) program, and the Research and Entrepreneurship Experience for Undergraduates (REEU). NanoEarth supported ongoing collaborative projects with industry partners but no dedicated industry seminars were hosted this year. Following is a summary of NanoEarth I&E highlights in this reporting period:

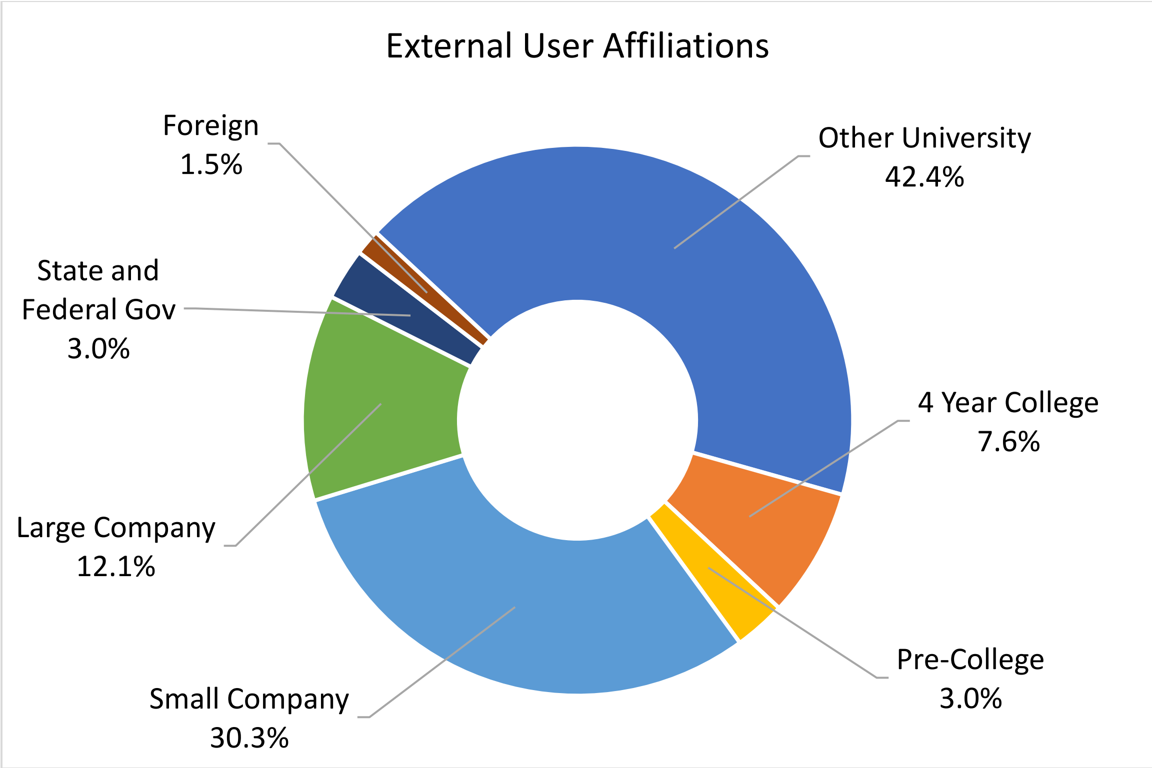
- The NanoEarth Industry Seminar series was concluded.
- M. Hull contributed to the following activities related to NNCI I&E efforts:
    - Invited speaker, 4th European Nanofabrication Research Infrastructure Symposium (ENRIS). May 13-15, 2025, Bologna, Italy. Details available online at https://enris2025.org/.
    - Co-chair, Future Innovators Session – Session at TechConnect World Innovation Conference and Expo. June 9-11, 2025 Austin, TX.
- At the invitation of J. Wetmore (ASU), 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, 2025. Approximately 12 students participated.
- Ongoing industry engagements included ITA International (Blacksburg, VA).
- Through his role as EiR, Dr. Hull continues to mentor faculty and students who are considering start-ups. Through the Spring 2025 NTEC program, Hull contributed to the mentorship of over 30 entrepreneurial students/postdocs via the Nanotechnology Entrepreneurship Challenge (NTEC).
- NanoEarth's Associate Director for Innovation and Entrepreneurship Matthew Hull continues to apply strategies developed at NanoEarth to sustain the NNCI Innovation Ecosystem in his role as AD, I&E for the entire NNCI.
- The Spring 2025 NTEC cohort consisted of 22 teams from 6 separate NNCI sites – NanoEarth, SDNI, SENIC, nano@Stanford, RTNN, and NNI. New to NTEC this year was the addition of the NNCI Innovator's Academy, which consisted of weekly webinars on key topics related to technology translation. These optional webinars allowed teams to explore entrepreneurship topics and opportunities more deeply and were delivered from experts across multiple sites in the NNCI as well as Activate and the NSF. At the end of the 7-week virtual program, the top 4 teams were selected to advance to an in-person pitch challenge at the TechConnect World Innovation Conference & Expo in Austin, TX, June 9-11. A $6,000 supplement from NSF helped support student travel to the event. Anmol L Purohit, Ji Feng, and Almond Lau from the Northwest Nanotechnology Infrastructure (NNI) at the University of Washington achieved first place for "Synthesis of Metal Organic Framework (MOF) particles for removal of short and ultra-short chain PFAS from water". Igor Novosselov served as the team mentor. As the top team, they received $4,500 in support from the NNCI and a $1,000 award from Jones-Dilworth, Inc.

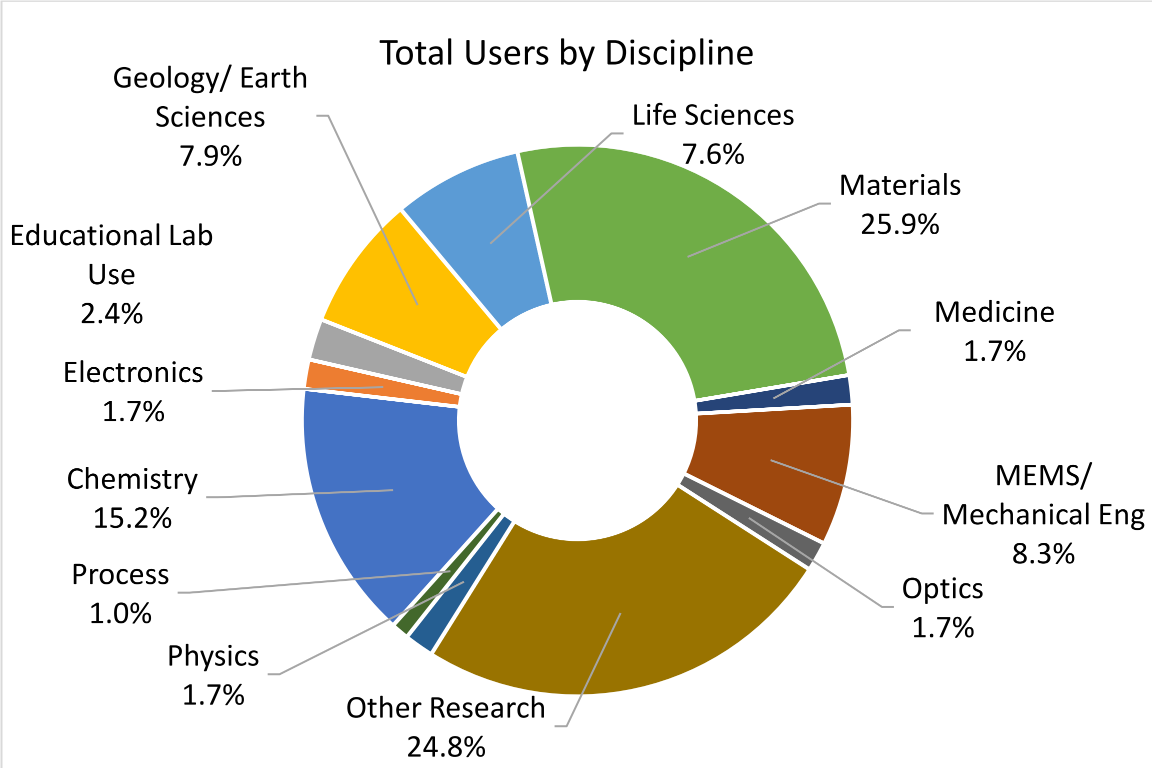
NanoEarth Site Statistics

Yearly User Data Comparison					
	Year 6	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Total Cumulative Users	228	309	310	291	290
Internal Cumulative Users	193	233	237	226	224
External Cumulative Users	35 (15%)	76 (25%)	73 (24%)	65 (22%)	66 (23%)
Total Hours	11,706	18,736	15,884	16,135	13,509
Internal Hours	9,748	15,882	13,597	14,222	11,906
External Hours	1,958 (17%)	2,854 (15%)	2,286 (14%)	1,913 (12%)	1,603 (12%)
Average Monthly Users	83	100	92	84	88
Average External Monthly Users	13 (16%)	20 (20%)	15 (17%)	13 (16%)	15 (17%)
New Users Trained	72	123	99	93	79
New External Users Trained	3 (4%)	10 (8%)	10 (10%)	5 (5%)	9 (11%)
Hours/User (Internal)	51	68	57	63	53
Hours/User (External)	56	38	31	29	24



NanoEarth Year 10 User Distribution





13. Program Plans for No-Cost Extension

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."

The four Associate Directors of the CO will continue to coordinate activities in Education & Outreach, Societal and Ethical Implications, Computation, and Innovation & Entrepreneurship across the network.

With the conclusion of the NNCI program in August 2025, Subcommittees sunset their activity, however the CO will continue to support Working Groups, Research Communities, and the NNCI website. 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.

A number of specific activities planned for the No-Cost Extension are highlighted below:

- *NNCI Website*: The CO will continue to add new and revise existing content to the nnci.net webpage.
- *REU Convocation*: The 2026 REU Convocation will be hosted by SENIC and held at Georgia Tech in August 2026 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”.
- *Staff Exchange Program*: Originally proposed by the Global & Regional Interactions Subcommittee, the CO will continue to support a staff exchange program. Some use of this mechanism has occurred by request in Years 8-10 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, typically organized by one of the Working Groups.
- *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 and degrees awarded to NNCI users. Some of this data collection may be hampered by the grant termination for KY Multiscale, SHyNE, and TNF.
- *NNCI Impact:* The CO will continue 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):* The CO will continue to explore avenues to better interact and collaborate with the five DOE nanolabs (NSRCs). This work has continued with the creation of an ad-hoc NNCI-NSRC working group in January 2025 and will continue through the end of NNCI (and beyond).
- *NNCI International Relationships:* As described above (Section 10.6), efforts to establish Global NanoLab have begun and these will continue. The next meeting of Global Nanolab, with additional members invited, will be held at the UGIM Conference at Stanford in July 2026.
- *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 prioritize its resources to impact the programs that help the network be more than the sum of its parts.