National Nanotechnology Coordinated Infrastructure

NNCI Coordinating Office Annual Report (Year 6)

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NNCI Coordinating Office Annual Report 2022

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1. NNCI Overview

1.1. Introduction

The National Nanotechnology Coordinated Infrastructure (NNCI) is an NSF-funded network of academic nanofabrication and characterization sites and their partners, formed to advance research in nanoscale science, engineering and technology. The NNCI site awards were the culmination of a competition conducted by NSF, under Program Solicitation NSF 15-519, which was generated as a result of input from the science and engineering community following the completion of the National Nanotechnology Infrastructure Network (NNIN, 2004-2015). Over 50 proposals from potential NNCI sites were submitted, resulting in 16 awards. The NNCI network is funded by the NSF through cooperative agreements with the individual sites, with the initial site awards being made around September 15, 2015 with an initial award period of 5 years. The program was renewed for an additional 5 years in 2020. The Coordinating Office (CO) for the network was awarded to the Georgia Institute of Technology on April 1, 2016 and renewed in 2021. Total NSF funding for the 10 years of the NNCI network is approximately $165 million.

The NNCI sites are located in 16 states and involve 29 universities and other partner organizations (see Figure 1) that provide researchers from academia, small and large companies, and government with access to university user facilities with leading-edge fabrication and characterization tools, instrumentation, and expertise within all disciplines of nanoscale science, engineering and technology.

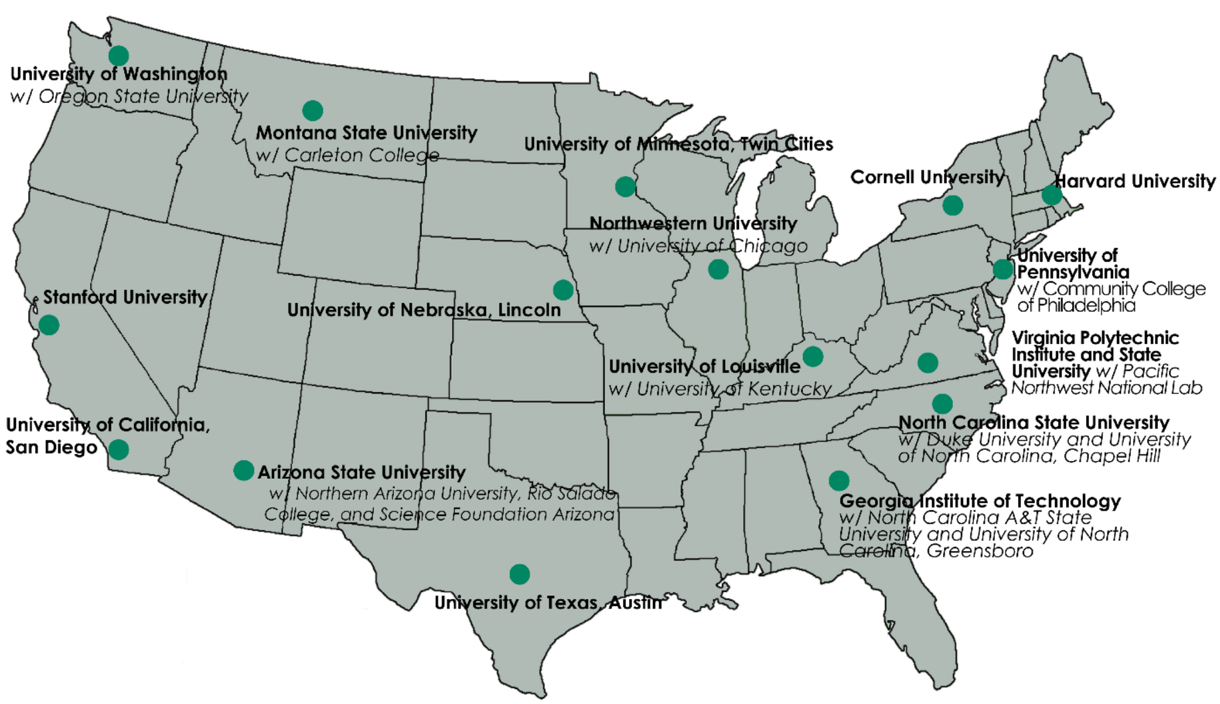


Figure 1: US Map with Locations of the 16 NNCI Sites (Years 6-10)

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

The 16 NNCI sites and their 13 partners (university, college, national lab, and non-profit foundation) provide access to more than 2,200 tools located in 71 distinct facilities. As will be detailed later in this report, these tools have been accessed during Year 6 by more than 11,000 users including nearly 2,800 external users, representing nearly 200 US academic institutions, more than 700 small and large companies, ~40 government and non-profit institutions, as well as ~40 foreign entities. Overall, these users have amassed almost 1 million tool hours. During the 6th year, the network has trained more than 4,400 new users.

This report summarizes the activities and progress for Year 6 of the Georgia Tech Coordinating Office of the NNCI, from April 1, 2021 - March 31, 2022. NNCI sites are funded via separate cooperative agreements between NSF and each site, with reporting of site-specific data and activities corresponding to Year 6 (October 1, 2020 – September 30, 2021).

As indicated above, Year 6 begins the second 5-year period of the NNCI. This report reflects changes to the sites, partners, facilities, and network activities proposed and enacted starting in Year 6. In addition, the previous (Year 5) report 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 rapidly adapted to the new reality, providing a wide variety of online programs to support users and provide education and outreach opportunities, many of which continue during this reporting period. These closures obviously affected the usage of NNCI resources during this reporting period, and return to pre-pandemic operations is still ongoing as noted in the network user statistics in Section 11.

1.2. NNCI Organization

All of the NNCI facilities, most of which have partners and multiple locations, are available for use by students and professionals from around the country and globally. The sites and facilities within NNCI during Year 6 (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. New facility additions in Table 1 are denoted by italics; removal of facilities from NNCI also occurred at MiNIC, NCI-SW, and NanoEarth. Each site operates under its own procedures for user recruitment, user access, training, rates, billing, and other logistical details. However, each has agreed to provide open access, with as minimal a burden as possible, to their state-of-the-art nanofabrication and characterization facilities, their tools, and staff expertise. All sites use the resources provided by NSF to support a variety of education and outreach activities (Section 4.1), and many also offer programs or research in societal and ethical implications (SEI) of nanotechnology (Section 4.2) and simulation and modeling (Section 4.3). With the NNCI renewal, the Coordinating Office has also begun to coordinate network activities that promote and support innovation and entrepreneurship (Section 4.4).

Table 1: NNCI Sites, Locations and Facilities (Year 6, *new facilities in italics*)

NNCI Sites and Locations	NNCI Facilities
Cornell Nanoscale Science and Technology Facility (CNF) Cornell University	Cornell Nanoscale Science and Technology Facility *Cornell High Frequency Test Lab* *Cornell 3D Visualization and Imaging Facility* *Cornell Rapid Prototyping Lab*
Center for Nanoscale Systems (CNS) Harvard University	Center for Nanoscale Systems
Kentucky Multi-Scale Manufacturing and Nano Integration Node (KY Multiscale) University of Louisville University of Kentucky	Micro/Nano Technology Center Center for Nanoscale Science and Engineering Huson Nanotechnology Core Facility Electron Microscopy Center Conn Center for Renewable Energy Research Center for Applied Energy Research Center for Advanced Materials Additive Manufacturing Institute of Science & Technology
Mid-Atlantic Nanotechnology Hub (MANTH) University of Pennsylvania Community College of Philadelphia	Singh Center for Nanotechnology Quattrone Nanofabrication Facility Singh Center for Nanotechnology Nanoscale Characterization Facility Singh Center for Nanotechnology Scanning Probe Facility
Midwest Nanotechnology Infrastructure Corridor (MiNIC) University of Minnesota	Minnesota Nano Center *Characterization Facility*
Montana Nanotechnology Facility (MONT) Montana State University Carleton College	Montana Microfabrication Facility Imaging and Chemical Analysis Laboratory Center for Biofilm Engineering Proteomics, Metabolomics and Mass Spectroscopy Facility *Center for Bioinspired Nanomaterials*
Virginia Tech National Center for Earth and Environmental Nanotechnology Infrastructure (NanoEarth) Virginia Tech Pacific Northwest National Laboratory	Virginia Tech Nanoscale Characterization and Fabrication Laboratory PNNL Environmental Molecular Sciences Laboratory
Nanotechnology Collaborative Infrastructure Southwest (NCI-SW) Arizona State University Northern Arizona University Rio Salado College Science Foundation Arizona	ASU NanoFab Eyring Materials Center *Advanced Electronics and Photonics Core Facility* Nano in Society User Facility Center for the Life Cycle of Nanomaterials *¡MIRA! Center at NAU*

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

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

Through a 2020 update of the NNCI Staff Directory (following the renewal proposals), sites have identified approximately 250 staff that support the NNCI program (Table 2), although some individuals fulfill multiple roles within a site's operations. Many additional technical staff not included in this count are typically supported by NNCI funds while assisting both internal and external facility users. In general, Site Leadership includes Site Directors and Deputy/Associate/Assistant Directors. Some of these individuals also serve as project co-PIs. New User Contacts are those site staff responsible for coordinating access to facilities for external users. Program Managers are identified as those staff who most interact with the Coordinating Office, providing data as requested and communicating information to appropriate site staff. Facility Managers are responsible for the operations of site facilities, often assisted by Technical Staff when identified. Education/Outreach Coordinators handle the K-12 activities and sometimes the university student and professional education as well. SEI and Computation Coordinators are responsible for those aspects of site operations.

Table 2: NNCI Site Staff (2020)

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

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

2. NNCI Coordinating Office

The NNCI Coordinating Office is led by Prof. Oliver Brand (Executive Director, Georgia Tech Institute for Electronics and Nanotechnology (IEN) and Director, SENIC) who serves as **Director**. Dr. David Gottfried (Senior Assistant Director, Georgia Tech IEN and Deputy Director, SENIC) serves as **Deputy Director** and oversees the Coordinating Office day-to-day operations, assisted by a **Program Manager** Amy Duke (Research Administrative Manager, Georgia Tech IEN and Program Manager, SENIC). Four **Associate Directors** manage the network activities in specific areas. Dr. Quinn Spadola (Academic Professional, Georgia Tech IEN and Director of E/O, SENIC) 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 (Program Manager, Virginia Tech ICTAS and Associate Director, NanoEarth) coordinates innovation and entrepreneurship (I&E) programs. This Coordinating Office staff meets monthly by conference call.

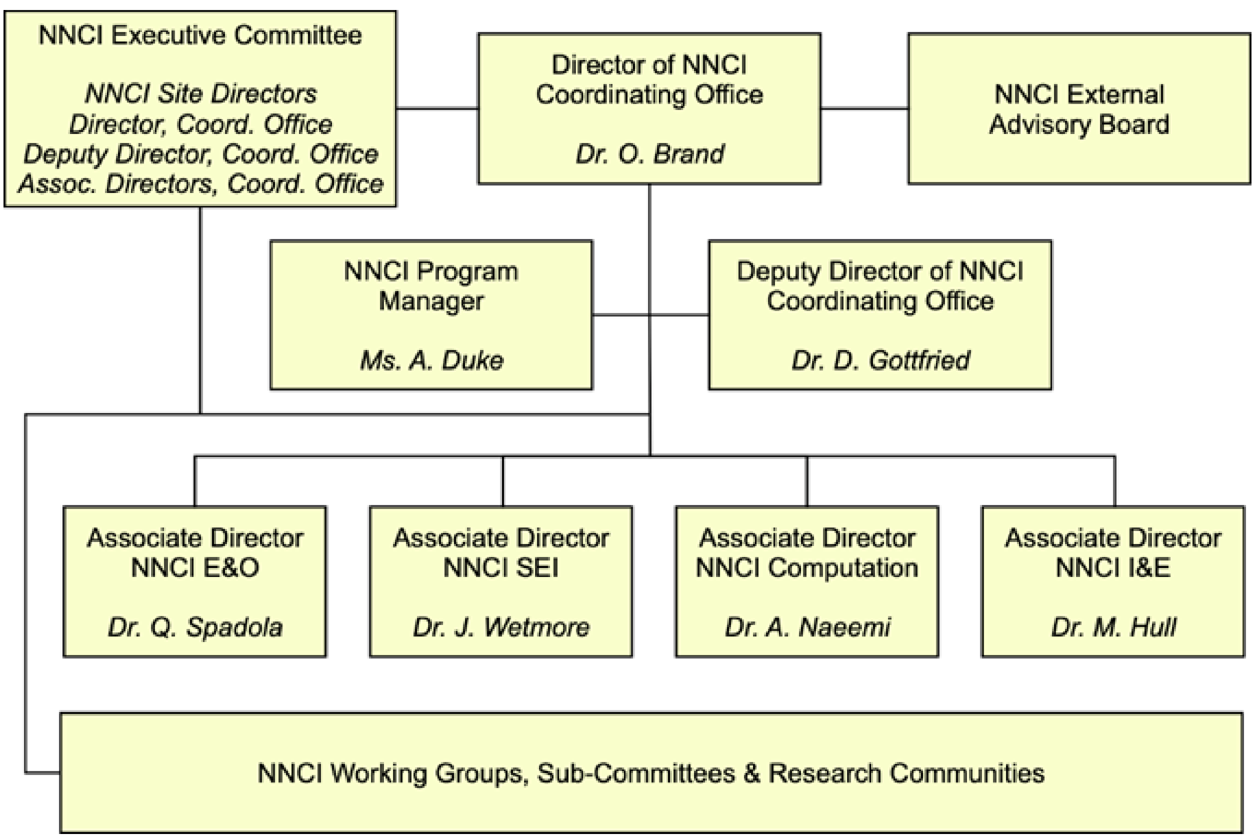


Figure 2: NNCI Coordinating Office Organizational Chart (Years 6-10)

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 began creation of **research communities**, which are organized around key scientific and engineering challenges and represent an opportunity for the NNCI to interact with the broader research ecosystem (see Section 7). Other tasks of the Coordinating Office include:

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

More details on these activities are shared in the sections below, and plans for future activities are provided in Section 13.

3. External Advisory Board

During the first year of the NNCI, the Coordinating Office established an NNCI External Advisory Board. To this end, names for potential advisory board members were solicited from the 16 NNCI sites. The Coordinating Office then assembled the Advisory Board from the solicited list, ensuring a diverse board in terms of gender, ethnicity and disciplinary background. Since its inception, there have been periodic changes in the EAB membership and Table 3 shows the Advisory Board members and their affiliations as of January 2022.

Table 3: NNCI External Advisory Board

Name	Affiliation
Prof. Reggie Farrow	Department of Physics, New Jersey Institute of Technology
Dr. Andrew Greenberg	Associate Director, Institute for Chemical Education, University of Wisconsin
Dr. Elaine Cohen Hubal	Acting Director, Computational Exposure Division, US Environmental Protection Agency
Dr. Angelique Johnson	CEO, MEMStim
Mr. Joe Magno	Executive Director, National Institute for Innovation and Technology
Prof. Richard Osgood	Department of Electrical Engineering & Department of Applied Physics, Columbia University
Dr. Kurt Petersen	Member, Silicon Valley Band of Angels
Dr. Thomas Theis	Director of Innovation, Utopus Insights, Inc.
Prof. Ken Wise	Department of Electrical Engineering and Computer Science, University of Michigan

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

1. What activities can/should NNCI support to achieve the goal of the network surpassing the sum of the parts? This should involve not only research facilities aspects, but also consider support of education/outreach, computational tools, and societal and ethical implications

activities.

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

From the feedback of the Advisory Board at the January 2017 NNCI Conference it became clear that a more detailed "Charter Letter" with input from the NSF on what would constitute a successful network was needed. This document was created during 2017 and communicated to the Advisory Board with a copy provided in the 2017 annual report. The report of the Advisory Board following the most recent NNCI Conference (November 2021) is provided in Appendix 14.1.

4. Associate Director Reports

4.1. Education and Outreach

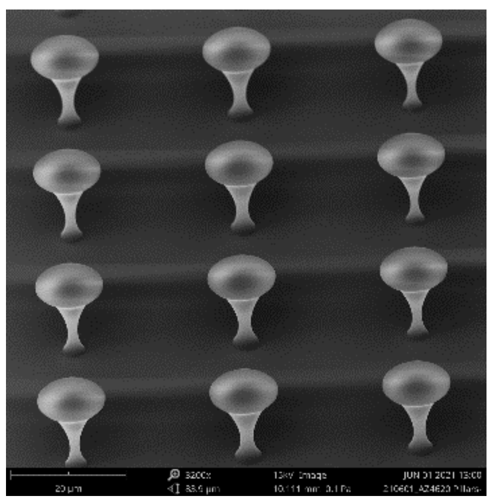
The mission of the NNCI Education and Outreach (E&O) efforts is to offer education and training to address the growing need for a skilled workforce and informed public, provide resources, programs, and materials to enhance knowledge of nanotechnology and its application to real-world issues, and support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

The 16 sites of the NNCI each have separate E&O programs in order to address these goals. Throughout the NNCI Year 6, E&O coordinators reached more than 14,500 people, achieved in personal/virtual interactions through classroom visits, teacher workshops, remote sessions, short courses, seminars, symposia, community events, conference booths, tours, internships, REUs, and RETs. This reach is a significant decrease from the previous year (over 33,000 people) because of the continued effects of the COVID-19 pandemic. That being said, sites quickly pivoted to virtual activities, continued to serve their communities, and some activities returned to in-person format. Of the people reached this past year, 37% are K-12 students, 6% educators (K-12 teachers and community/technical college faculty), 8% general public, and 49% professionals (REUs and other student interns, short course and workshop participants, seminar attendees, etc.). Sites are still struggling to provide outreach to the general public with science days and festivals continuing to be canceled or pivoting to virtual. Outreach to K-12 students was also curtailed compared to last year. While sites are continuing to offer virtual options with many providing materials for hands-on activities, one possible reason for the continued decrease may be that teachers are occupied with transitioning back to in-person classrooms and concentrating on making up lost learning after many students spent the previous year virtual. Programs for educators increased participation to almost 900 teachers and community or technical college faculty, an increase over last year. The number of professionals reached also increased to approximately 8,800 (from ~7,000) as more sites offered webinars, virtual symposia, and other online options. The 14,500 figure also does not include NanoEarth's "Pulse of the Planet" programs, Nebraska Nanoscale Facility's traveling museum exhibit, or the "Nanooze" magazines distributed by the Cornell Nanoscale Science and Technology Facility. "Nanooze" released its latest issue this past year with the theme "How Small Can We Go? (Scale of Tiny Things, Itty-Bitty Transistors and Chips, Nanoscale Weirdness)." Also not included are the number of people enrolled in the online courses offered through RTNN and nano@Stanford; these are discussed in the Technical Content Development working group report (Section 6.12).

In celebration of National Nanotechnology Day, the NNCI again hosted its image contest, *Plenty of Beauty at the Bottom*. Sites submitted images created at one of their facilities during the past two years to three categories, Most Stunning, Most Unique Capability, and Most Whimsical. Public voting took place during the week of National Nanotechnology Day (Oct. 8-15) with sites promoting the contest through their various channels. Over 2,400 votes were cast to determine the winner in each category. In addition to the image contest, individual sites hosted National Nanotechnology Day events with more information provided later in this section.

2021 Most Stunning (NNF)

2021 Most Whimsical (NanoEarth)



2021 Most Unique Capability (RTNN)

In addition to the winning entries shown above, honorable mentions were awarded to entries from NNI (Most Stunning), NCI-SW (Most Whimsical), and SENIC (Most Unique Capability).

To facilitate the sharing of information across the network, coordinators participate in monthly calls and post to the education and outreach listserv. The purpose of the calls is to share information about upcoming events, partnerships, conferences of interest, and for working group leads to update the entire group on relevant information. This is also an opportunity for coordinators to connect over common interests and plan follow-up conversations. Additionally, topic specific teleconferences are organized if multiple sites are interested in learning more from each other. Topics have included launching a multi-site virtual Nano Sumer Institute for Middle School Teachers, best practices for pivoting to virtual programs, and contingency planning for 2021 summer programs. Each year education coordinators are also asked to update a worksheet that lists all the different types of activities offered across the NNCI. Everyone has access to the sheet so if someone wants to learn how to run a specific activity they have never done before, they know which site(s) to contact for information.

Across the network, E&O coordinators make an effort to reach groups historically underrepresented in STEM fields. The transition to virtual and asynchronous instruction has allowed sites to extend their reach beyond their traditional areas, increasing connections to rural communities. As the education coordinator from NNF shared, "In some ways we reached out to more rural and diverse populations because of the virtual teaching (Zoom). We would never have been able to instruct as many students as we did at one time in so many places." Sites also leverage their efforts by working with local organizations (e.g., local Boys and Girls Clubs, 4-H chapters, Society of Women Engineers sections, Girls, Inc., Oakland Promise, local school districts) and national organizations (national 4-H and Hitachi High-Tech America STEM Education) to provide programming. In addition, most sites work closely with other NSF-supported NSE education efforts like NACK's Remote Access Instruments for Nanotechnology (RAIN) and the Micro Nano Technology Education Center (MNT-EC). NCI-SW, SENIC, NNF, nano@Stanford, SDNI, and RTNN all provide remote sessions through RAIN. The PI for MNT-EC, Dr. Jared Ashcroft, gave the August NNCI webinar on his center with an emphasis on how NNCI sites can work with them to provide education to community/technical college students and faculty.

MANTH TA preparing components for the Lab-at-Home microfluidic activity

With outreach to K-12 students, the NNCI is inspiring our future skilled workforce and helping to create an informed citizenry. Many sites participate in summer camps, high school student internship programs, after school programs, career fairs, and both off-site and on-site visits. In response to the pandemic, many sites used the switch to virtual activity as an opportunity to expand outreach. During this past year, in order to further increase the effectiveness of activities with students, many sites provided hands-on materials for students to work with during virtual instruction. The image above shows a teaching assistant preparing materials that were sent to high school students participating in MANTH's Nanotechnology Engineering Summer Academy at Penn course. As the course was virtual, 27 students from across the US were able to participate. NNF was able to provide virtual lessons with hands-on activities to students through 4H, Girls, Inc., and outreach groups on the University of Nebraska's campus. MINIC also worked with their local Girls, Inc. to provide virtual, hands-on activities. TNF contributed to a K-12 Girl's STEM Virtual Day, reaching over 100 6th-8th grade students. CNF provided the materials for five at-home nanoscience kits for students. RTNN participates in the Girl's STEM Power Hour. This new virtual event reached 124 girls and RTNN mailed STEM kits to enable the students to participate in hands-on activities like extracting DNA and observing a variety of insects with the SEM. This event enabled RTNN to engage with more rural participants than a traditional on-campus event, including 17 members of the Lumbee tribe. SENIC's virtual class trips, in which middle and high school teachers invite staff to join their classroom, reached over 1,000 students and helped strengthen connections with school districts across Georgia. CNF, NNF, NanoEarth, and MONT are continuing efforts to work with 4-H at both a local and national level. NanoEarth participated in the annual Virginia 4-H State Congress which was held as a hybrid mix of in-person and online components. NanoEarth hosted an online learning event which was live via Zoom and broadcast to approximately 100 youth per session. The session included a short presentation titled “Intro to Nano & Importance of Sunscreen” and two hands-on activities related to UV light and the value of sun protection. The event also featured “Ask a Scientist” where graduate students entertained questions from the groups as the attendees completed the sunscreen activities. Each of the 4-H classrooms participating received materials so they could follow along at their sites. CNF provided activities for the 4-H National STEM Summit in the fall (more information in Section 6.13).

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. Sites were able to increase their reach to this group from last year, in part thanks to the return to in-person summer activities and increased virtual professional development opportunities. Educator conferences, including the annual National Science Teachers Association Meeting, remained canceled. The Research Experiences for Teachers across the National Nanotechnology Coordinated Infrastructure collaborative proposal, submitted to NSF by SENIC, MINIC, SHyNE, and NNF, was funded last spring. While the first summer of the program had to be canceled due to the pandemic, all four sites were able to welcome high school teachers and community/technical college faculty to campus, 5 at each site, for in-person research during summer 2021. In addition to research, all the teachers participated in regular virtual meetings and a nano-careers webinar series featuring industry speakers who are also users of site facilities. The educators will present their experience and lessons at the 2022 annual National Science Teachers Association Meeting. Their lessons will also be posted on the NNCI’s searchable database and nanoHUB, and the teachers are recording short videos intended to help their peers implement the lessons. RTNN and SDNI also offered RET programs to their local educators. In addition, SDNI virtually hosted their Annual Education Symposium with the theme, “How to Optimize our Knowledge Management Strategies to Ensure Streamlining and Sustainability of K-12 Nanotechnology Education” in September 2021. The symposium featured talks by teachers who are currently integrating nanotechnology into their classroom. Many of the speakers were former RETs of NNIN/NNCI or alumni of Nano Summer Institute for Middle School Teachers (NanoSIMST).

NNF, SDNI, SENIC, and nano@Stanford offered the Nano Summer Institute for Middle School Teachers virtually or in-person. Teachers engaged in 4 to 5 days of instruction on nanotechnology and how to implement it in the classroom. Classroom supplies were provided to teachers (mailed in advance or at the workshop) to facilitate hands-on activities. Teachers also participated in virtual/in-person cleanroom tours, listened to guest speakers, and alumni of the program shared their implementation strategies. Nano@Stanford plans to offer NanoSIMST each summer as a virtual workshop to further expand the reach of the program beyond the standard areas reached by NNCI sites. KY Multiscale developed their first high school teacher training program which they offered to 8 educators. Another resource used during NanoSIMST and available to the community are two new talks on nanotechnology careers posted on the NNCI’s YouTube channel. Matt Hull from NanoEarth recorded his presentation, “X/Nano: The enabling Potential of a Career in Nanotechnology” (210+ views), and Jim Marti from MINIC recorded “Careers in

Nanotechnology: Opportunities for STEM Students" (430+ views). The education coordinator from nano@Stanford also started 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 will receive an email highlighting 1 or 2 NSE education resources with information on how they connect to the Next Generation Science Standards and tips on implementation.

As part of building a skilled workforce, NNCI sites provide technical workshops, short courses, seminars, webinars, and/or symposia for undergraduates, graduate students, post-docs, and other professionals. The network continues to maintain a strong connection to this group by providing virtual and in-person resources. NNI contributes to programs at the University of Washington which are designed to help retain the most vulnerable incoming STEM undergraduates. These bridge programs are for underprivileged students who were disproportionately impacted by COVID-19 and the economic conditions caused by the pandemic. After having canceled almost all REU activities in summer 2020, NNCI sites were able to offer this opportunity to students once again, although some sites still had to contend with COVID-19 related restrictions. SDNI's REU program was completely virtual with an emphasis on professional development activities for the students. MANTH was able to allow students on-campus to do research but all meetings with the cohort took place virtually. Because only Cornell students were allowed on their campus, CNF offered their REU just to Cornell undergraduates. Other sites that had in-person REU programs include NCI-SW, NanoEarth, TNF, SENIC, SHyNE, KY Multiscale, MONT, and CNS. RTNN successful secured an REU grant from NSF and will offer the program beginning in summer 2022. The 2021 REU Convocation was virtual, held over 3 afternoons, and organized by the NNCI Coordinating Office. Fifty-six students presented short talks and posters on their summer research. They also heard remarks from the NSF and the NNCO, a career panel featuring an academic, an industry worker, a graduate student and former NNCI REU, and a cleanroom manager, and they learned about graduate fellowship opportunities.

NCI-SW continues to provide hands-on lab sessions for community college students enrolled in Rio Salado College's Nanotechnology AAS/Certificate programs. MANTH started expanding the hands-on programming for the "Introduction to Nanotechnology" course offered at the Community College of Philadelphia. MINIC, in collaboration with MNT-EC, provided a virtual 4-day course on NSE environmental health and safety to 2-year college instructors. CNS hosted 15 community college students for a workshop on NSE. RTNN and nano@Stanford are launching internships for technical/community college students and have met with the Workforce Development working group lead to learn more about what other sites have been doing in that space. As part of the NNCI renewal, MONT added a scholarship program for undergraduate underrepresented minorities in STEM attending Montana State University. The program, now in its second year, has awarded a total of 10 scholarships to students in disciplines ranging from physics to mechanical, environmental and biological engineering.

Over a hundred attendees from around the world gathered virtually on March 8, 2021 to celebrate International Women's Day at the *Women in Microscopy Conference* organized by SHyNE. 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 sparse. Sites continued to offer webinars, virtual Tech Talks, workshops, and short courses, create online training modules, and provide virtual office and coffee hours to give users opportunities to talk to technical staff or each other. SHyNE intends to keep their Tech Talks virtual moving forward because of the increased reach that format provides. NanoEarth's Nanotechnology Entrepreneurship Challenge pivoted to a virtual format as well. Sites also increased remote access to their instruments in order to continue to serve professionals.

NNCI sites participate in science festivals, science cafes, science days at their institutions, and National Nanotechnology Day and Nano Days celebrations to help enable an informed citizenry. MANTH once again organized online presentations with hands-on demos (materials shipped in advance) by several research labs for high school students for National Nanotechnology Day. In celebration of National Nanotechnology Day, SENIC's JSNN hosted the 2021 NanoImpacts Conference with a forum on "Strengthening Partnerships for University-Industry Research," a presentation on "Emerging Nano-Inspired Research and Technologies," a Nanotechnology Art Exhibit, and a science demonstration event for K-12 students. SHyNE's annual celebration, NUANCE Fest and Image Contest, continued to be virtual. RTNN offered a Nano Innovation Challenge for National Nanotechnology Day. They asked students to create a 3-minute multimedia presentation in the format of a video to pitch an idea for using nanotechnology to address one of the Sustainable Development Goals. Winners in middle and high school categories won a gift card and an SEM demo. Videos are posted here: https://www.fi.ncsu.edu/projects/the-nano-innovation-student-challenge-using-tiny-science-to-solve-wicked-problems/.

Education and outreach coordinators have embraced the move to virtual outreach as an opportunity to reach a larger and more diverse audience. While sites are moving back to in-person activities, the online content that has and continues to be developed will be integrated into sites' programming. Moving forward, sites are working together to engage with larger organizations including other NSF-funded NSE education and workforce development efforts, expanding the opportunities they offer to students, implementing teacher workshops developed by other sites, and creating more virtual content for training and outreach. More details on education and outreach efforts across the NNCI can be found in the education working group reports. The report of the *Workforce Development and Community Colleges* working group (Section 6.10), led by Dr. Ray Tsui from NCI-SW, includes information on activities related to workforce development and community college engagement over the past year. The *Technical Content Development* working group, co-led by Daniella Duran from nano@stanford and Eric Johnston from MANTH, report (Section 6.12) provides future plans for the group after leadership changes during this past year. The report of the *K-12 Teachers/RET, Students, and Community Outreach* working group (Section 6.9), led by Dr. James Marti from MINIC, discusses their future plans to improve access to NNCI education resources. The report of the *Evaluation and Assessment* working group (Section 6.11), led by Dr. Quinn Spadola from SENIC, shares results from the student worker/mentor surveys that were developed in collaboration with the *Workforce Development and Community Colleges* working group.

4.2. Societal and Ethical Implications

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

Jameson Wetmore (also part of the NCI-SW site) is leading these activities. This year, in conjunction with NCI-SW, we hired a graduate student research assistant, Martin Perez Comisso, to assist with the SEI program.

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

SEI coordinators at the different sites spent a major part of the fifth year of the NNCI working to formulate activities that other NNCI sites could partner with to expand the impact of the SEI work already being done. The sixth year has been spent developing those programs and making them available. LeeAnn Kahlor at TNF has continued to develop SEI lab training materials that it is sharing with the rest of the network, as well as piloting the development of online resources for integrating SEI into K-12 education. Jan Youtie at SENIC developed and piloted two major instruments for beginning to quantify the economic impact of NNCI sites and has begun to generate a fair amount of interest across the network. And David Berube at RTTN developed a report on future nanotechnology infrastructure needs for food security and is reviewing the SENIC evaluation instrument in order to deploy it at their site.

In addition to coordinating the other SEI sites, Wetmore has been participating in online workshops and community outreach projects to extend the reach of NNCI SEI activities. In March he developed an online public engagement model (with the help of NCI-SW) that used examples from ferrofluids to help people better understand the social implications of nanotechnology. In April he sought to help graduate students better prepare for future careers by hosting a roundtable discussion about science policy fellowships available in Washington, DC. In May 2021 he contributed to international policy development by presenting lessons learned from nano and society to the 13th Meeting of the OECD Working Party on Bio-, Nano- & Converging Technologies being held in Paris. In June he offered an REU/RET webinar on “Science Policy: Where Values meet the Laboratory” that was open to participants from a number of REU and RET programs. And in July, he organized the first NNCI SEI seminar, bringing together David Berube and Andrew Maynard to describe the evolution of nano in society over the past 20 years.

The flagship exercise of NNCI CO SEI effort is the Winter School on Responsible Innovation and Social Studies of Emerging Technologies. The Winter School is held every January at Saguaro Lake Ranch, just east of Phoenix and has typically been designed to train the next generation of social science scholars interested in the future of science and technology. In 2021 we cancelled the Winter School due to COVID-19 and used the time to ramp up a new type of program for 2022. Instead of focusing on only social science scholars, we aimed for a mix of social scientists, natural scientists and engineers. We also developed a new focus for the event. We have been hearing more and more from graduate students that they want to make a difference in the world, so this year’s event explored the idea of “impact” from a variety of different viewpoints and in different areas.

During the Fall of 2021 we recruited 15 graduate student participants including 10 students from 6 different NNCI universities. From January 3-10, 2022 a team of organizers including Ira Bennett (ASU), Nich Weller (ASU), Martin Comisso Perez (ASU), and Vasiliki Rahimzadeh (Stanford) worked with the participants in two phases. First the students met with about 8 faculty who have found different ways of having an impact with their scholarship including public engagement, teaching, mentorship, policy, and media. Second, the program facilitated a sandpit-type exercise wherein the participants formed teams and pitched possible ideas to facilitate impact beyond the 7-day program. On the last day we had a final pitch and funding will be allocated to support at least some of these ideas. We look forward to having participants report back about their activities a few months after the program's conclusion.

This was the fifth NNCI sponsored winter school and the eighth overall winter school which means we now have well over 100 alumni of the program. We organize alumni meetups at international meetings at least once a year and have helped to foster not just individual researchers, but a cohort of scholars who continue to support each other long after their time in the desert is over.

From June 1-11, 2021 we held our other major program of the year – the NCI-SW sponsored Science Outside the Lab program in Washington, DC. The program brings together graduate student scientists and engineers from across the NNCI to get a crash course in how science influences policy and how policy influences science. Traditionally that is a weeklong program held in Washington, DC. Unfortunately, due to COVID we were forced to cancel our 2020 program. In early Spring 2021 it became clear that there were unlikely to be many policymakers available to meet with our students face to face if we were able to make it to Washington, DC, so we pivoted to a virtual program.

We extended a seat in the 2021 program to all the students who were chosen for the 2020 program. Due to graduation, new jobs, and finishing dissertations, many of the previous year's candidates were not available. But five students transferred their 2020 acceptance to 2021 and we then made an open call to the NNCI sites for additional participants. Fifteen additional students were accepted to the program and we are proud to say that this year's cohort included representatives from 12 different NNCI universities (including students from 4 NNCI universities that have not participated in this program previously). The participating universities were Stanford, Washington, Texas, ASU, Georgia Tech, North Carolina A&T, University of Pennsylvania, Oregon State, NC State, Harvard, Montana State, Minnesota, as well as the University of Cambridge.

The program met for three hours/day for 10 total days. Thanks to several years of developing relationships with policymaker speakers in DC, the transition to an online format was relatively seamless. Over the course of the two weeks, we met with a variety of people including EPA regulators who discussed how they choose what to regulate and not regulate; a senior NIOSH official who described how federal agencies respond to changes in administrations; program managers from the NSF and the Sloan Foundation who explained how to optimize the funding application process; and an editor at Slate who helped the students understand how to get their ideas to a wider audience. A number of alumni from the program have made the transition from academia to DC policy work and our students were excited to meet with Moriah Locklear (SOtL class of 2018, Nebraska) who is now a Research Fellow at the Potomac Institute for Policy Studies and Michelle Solomon (SOtL Class of 2019, Stanford) who was a AAAS S&T Policy Fellow in Senator Markey's Office.

New this year is that all the participants were trained in basic techniques to bring what they learned in the program back to their home institutions. Each student developed their own independent projects to continue the conversations they had in the program with others at their universities. These "SEI Ambassador" projects have been carried out over the summer and into the fall of 2021. Many students worked with the education coordinators at their NNCI site to more fully integrate them, and SEI work, into their local programs. Projects include outreach efforts to K-12 students, podcasts on the struggle to fund research at traditionally black institutions, and gatherings of graduate students to discuss science policy issues.

Feedback from this year's program was quite positive and it's clear that everyone involved believed it was time well spent. Many students expressed regret that they were not able to participate in a traditional "Science Outside the Lab" and get the experience of exploring Washington, DC firsthand. But they appreciated the opportunity and believed they got a lot out of it. Planning for the 2022 version begins soon and we will be monitoring the pandemic situation before we make a final decision as to whether to hold the program in person or to do another virtual version.

Finally, the addition of a Research Assistant to the SEI team has enabled us to expand our operations. Since his addition in May 2021, Martin Perez Comisso has supported and participated in the Science Outside the Lab (SOtL) program, helped to coordinate the SEI ambassador project, and has begun to lay the groundwork for a SOtL alumni program. Because of Martin's background and expertise, he has also made it possible for us to reach a more diverse and international audience.

4.3. Computation

Modeling and simulation play a key role in enhancing nanoscale fabrication and characterization as they can guide experimental research, drastically reduce the required number of trial-and-error iterations, and enable more in-depth interpretation of the characterization results. The main objectives of the computation activities within NNCI are (1) to facilitate access to the modeling and simulation capabilities and expertise within the network, (2) to identify the strategic areas for growth, and (3) to promote and facilitate the development of the new capabilities.

To facilitate access to the modeling and simulation capabilities and expertise available within various NNCI sites, an inventory of available modeling and simulation resources and expertise has been complied. The directory is hosted by nanoHub.org and can be accessed via https://nanohub.org/groups/nnci_computation. So far, 10 sites have reported collectively more than 65 commercial simulation tools and 40 internally developed simulation tools available for internal and/or external users (with and without fee).

In addition to software resources, 9 supercomputers or major computing clusters are available at various sites. Most of these hardware resources serve internal users with the exception of the UT-Austin computing cluster which can be accessed by external users with a nominal fee and the CNF Nanolab Computing Cluster that is available to all users. The users of the CNF Computing Cluster have access to a wide range of modeling software packages tailored for nanoscale systems. Several classes of nodes, all linked via Gigabit Ethernet, are available on the cluster. The cluster runs Scientific Linux 7 with OpenHPC and a batch job queuing system. The staff would install new scientific codes on the cluster upon user request. The users can also remotely access software tools via "CNF Thin" Hotdesking service such as Computer Aided Design (BEAMER, L-Edit, Java GDS, AutoDesk); Simulation (Coventor, Cadence, PROLITH, Layout LAB, TRACER) and Image/Data Analysis (ProSEM, NanoScope Analysis, WinFLX). For tasks that are heavily memory or time demanding, Amazon Web Services (AWS) conversion capabilities are also available. More information on CNF computing resources is available at http://computing.cnf.cornell.edu/Cluster.

On the modeling and simulation side, Professor Dragica Vasileska from Arizona State University (NCI-SW) and her team have developed a modeling and optimization framework for low-power Si FinFETs accounting for Ballistic effects, Multi-Gate Granularity (MGG) and Hot-Carrier Degradation (HCD). They have also developed a simulation framework for GaN metal-insulator-semiconductor field-effect transistors (MISFET) which includes a 3D Poisson solver, a 2D Schrödinger equation solver and a 1D Monte Carlo solver.

Prof. Frank Register and his collaborators at UT-Austin (TNF) have developed a more rigorous approach to addressing band *alignments* in 2D material heterostructures and have explored alteration of the band alignment in black phosphorus/transition metal dichalcogenides (BP/TMD) heterostructures by applied strain and electric fields.

Prof. Naeemi's team at the Georgia Institute of Technology released their recently developed circuit-compatible SPICE model for phase-field simulations of multi-domain ferroelectrics on nanoHUB. The models solve the time-dependent Ginzburg-Landau (TDGL) equation and Poisson's equation self-consistently in three-dimensional space with the SPICE simulator. In addition, the FE domain structures captured by the phase-field model can also be simulated in a circuit-compatible manner with the proposed framework.

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

Another major education activity was a webinar series on computation which launched in 2021 with talks from three modeling and simulation experts. The talks were recorded and are available on the NNCI YouTube channel.

4.4 Innovation and Entrepreneurship

The 2021 NNI Strategic Plan calls for *"innovative mechanisms to realize the transformational societal benefits that flow from faster commercialization of nanotechnologies"*. The NNCI is well-positioned and resourced to contribute such mechanisms through its newly established (April 2021) NNCI Innovation and Entrepreneurship (I&E) program. The mission of the NNCI I&E program is to connect and amplify an ***NNCI-wide Innovation Ecosystem*** focused on training a new generation of "nano-savvy" innovators and entrepreneurs, identifying and meeting the unique needs of industry users, particularly start-ups and small to medium-sized enterprises (SMEs), and supporting the translation of nano-enabled innovations to society. Unlike NNCI programs around education and outreach, societal and ethical implications, and computation, I&E activities are undertaken at sites in a more indirect and decentralized manner (i.e., dedicated funding and reporting mechanisms are not specifically defined or required for I&E activities). Consequently, I&E activities pose both unique challenges and opportunities for collaboration across the 16 NNCI sites. The sections below summarize NNCI I&E accomplishments during the past year.

I&E Working Group

In 2021, the NNCI CO established a new I&E Working Group (Figure 3), which met virtually three times during the year (July 19, September 27, and October 25). The objective of the I&E

Working Group is to ensure site-level representation in NNCI I&E programming development, decision-making, and assessment. The activities of the I&E Working Group will complement and support those of other NNCI working groups.

Figure 3: NNCI I&E Working Group, including representatives from 12 of the 16 NNCI sites.

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

- **NNCI I&E Speaker Series** – recommendations for NNCI-wide speakers who can speak on topics pertinent to I&E and industry engagement
- **NNCI-wide Entrepreneurs-in-Residence (EiRs)** – faculty/staff entrepreneurs based at individual sites (including external users from small companies) who may be interested in serving as EiRs in an assortment of capacities
- **NNCI-wide Student-led Nanotechnology Entrepreneurship Challenge (NTEC)** – strategies to develop/sustain student-focused entrepreneurship at the site-level and NNCI-wide
- **"REEU" program** – collaborative effort with the NNCI education program focused on sharing and scaling an "entrepreneurship" module/experience to complement existing REU programs
- **Development of an "NNCI Innovators Academy"** – coupling of virtual learning modules across sites to train and support "nano-savvy" innovators and entrepreneurs
- **Industry user recruitment** – sharing of strategies to recruit/engage industry users, particularly users from start-ups and SMEs
- **Underrepresented and Minority Entrepreneurs** – focused engagement and support of nanotech entrepreneurs from diverse & underrepresented groups
- **Lessons Learned** – general sharing of I&E lessons learned across sites from the first 5 years
- **Goals** – establishing and refining I&E goals for the next 5 years and beyond

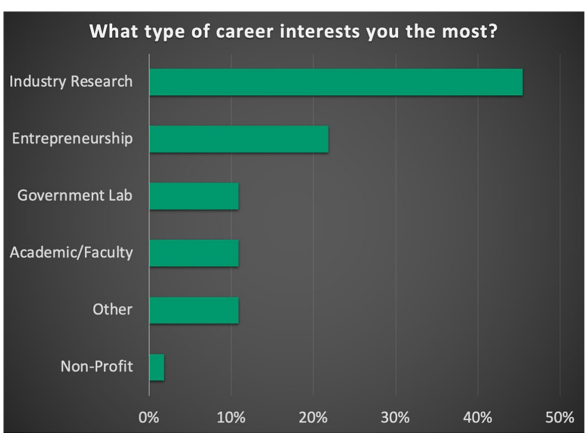
<u>Research and ENTREPRENEURSHIP Experience for Undergraduates (REEU)</u>

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

- **Level 1:** Brief discussion of entrepreneurship
- **Level 2:** General/theme-focused (i.e., aligns with REU theme) entrepreneurship lecture and Q&A (~1 hr)
- **Level 3:** Series of I&E lectures/seminars and/or visit/tour at nearby start-up facility
- **Level 4:** Extended duration project ("I-Corps lite")

REU program coordinators can contact NNCI Associate Directors Matthew Hull or Quinn Spadola to discuss incorporating an entrepreneurship module within their REU program.

In 2021, REEU modules were rolled out at five NNCI sites in collaboration with the NNCI Assoc. Director for E&O (Quinn Spadola) and local REU coordinators: SDNI (Yves Theriault), KY MultiScale (Ana S. Galiano), MANTH (Kristin Field), NCI-SW (Ray Tsui), and SENIC (Leslie O'Neill). More than 50 REU students participated in the program in 2021. Based on feedback from REEU participants (Figure 4), two thirds (67%) expressed interest in careers in industry or entrepreneurship with the remaining third interested in government labs, academic/faculty positions, non-profit organizations or other. Entrepreneurship was favored by double the number of students who were interested in academic/faculty careers. More than half of the REU students claimed that they did not know much about entrepreneurship, whereas 20% claimed to know "a good bit" about the topic. Overall, the students had a favorable opinion of entrepreneurship. They used terms like "creativity" and "innovation" as entrepreneurship descriptors and referenced well-known entrepreneurs like Elon Musk, Peter Thiel, and Tai Lopez. Conversely, students also noted less favorable aspects of entrepreneurship including "stress", "risk", "conartist", and "difficult". Assessments of REU student perceptions of entrepreneurship can help the I&E and E&O working groups better understand student interest in entrepreneurship and tailor program content for maximum efficacy.



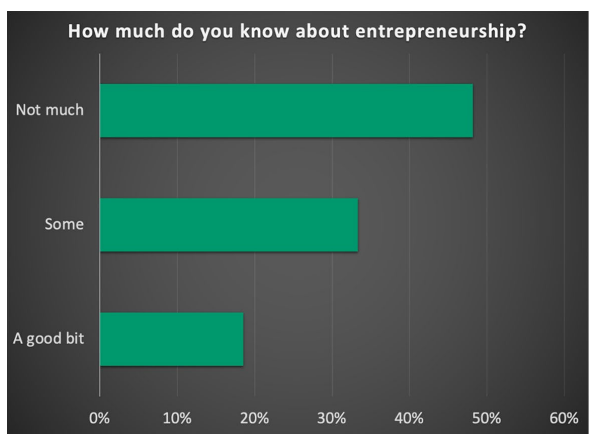


Figure 4: Feedback from REU students participating in the 2021 NNCI REEU module when asked (left) about the type of career interests that interests them the most and (right) how much they know about entrepreneurship.

NNCI I&E Seminar Series

Two I&E seminars were 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. A similar industry seminar series hosted at the NanoEarth site yielded a near 100% user recruitment success rate. The series has been especially effective at enabling 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). The two NNCI industry seminars hosted in 2021 were:

- Terrance Barkan, Executive Director, The Graphene Council, "2D Advanced Materials and US National Priorities" (5/27/2021)
- 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]

Live online attendance at the two seminars totaled approximately 50 guests but the majority of attendees viewed the archived seminars on the NNCI YouTube channel, asynchronously, where total views (as of this report writing) are more than twice that figure. 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. Planning is currently underway for the 2022 seminar series and should be announced in late January/early February.

NNCI Nanotechnology Entrepreneurship Challenge (NTEC)

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

In 2021, the I&E Working Group developed a scaled approach for implementing the NTEC program across multiple NNCI sites on a completely voluntary basis (there is no requirement for sites to participate). Figure 5 illustrates the resulting roll-out concept for the NNCI NTEC program. Tentatively, the program will be announced by the NNCI Coordinating Office on January 10, 2022 with applications due February 11, 2022 (National Inventor's Day). The NNCI I&E Working Group will review the applications and recommend top applicants to the NNCI sites from which the applications were submitted. Sites will have the final say in which program they do/do not support based on their available resources (i.e., personnel, instrument time, funds for materials and supplies).

Multiple award types are planned – from in-kind instrument time to $500 team awards and $1,000 NTEC Diversity awards (to encourage teams led by underrepresented groups and minorities) – to allow for the broadest participation possible. Similar to the site-level implementation, winning teams will participate in a seven-week, virtual NNCI NTEC Accelerator program aimed at providing teams with a gentle introduction to the concepts of the minimum viable product (MVP), business model generation, and customer discovery. Teams will work at their own pace but will have weekly readings, work with NNCI staff to use NNCI tools in the creation/evaluation of their MVP, and have the opportunity to engage with an NNCI NTEC mentor via weekly virtual office hours. An NNCI-wide NTEC showcase is envisioned for May 2, 2022. Participation in the NNCI NTEC Accelerator program can help teams prepare for local/regional start-up pitch competitions or more intensive and highly successful programs like NSF I-Corps. Ultimately, the aim of the NTEC Accelerator program is to help inspire a generation of "nano-savvy" innovators and entrepreneurs across the United States who have both the technical competence and business acumen to translate nano-enabled breakthroughs from the lab bench to society.

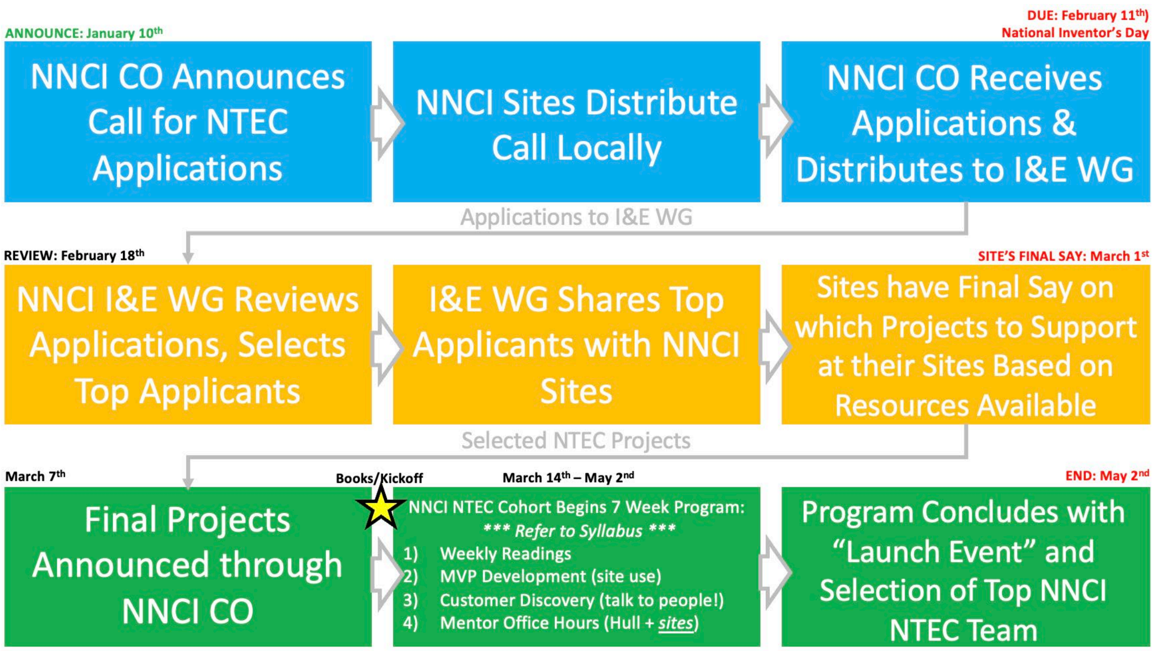


Figure 5: Roll-out plan for the NNCI NTEC program in 2022.

Entrepreneurs-in-Residence (EiR)

In 2021, the I&E Working Group made progress toward scaling the EiR model to other sites. Currently, there are four identified NNCI EiRs as shown in Table 4. The I&E Assoc. Director serves as the NNCI EiR in situations where a site-specific EiR has not been identified. In 2022, we will work to identify additional EiRs at other sites, establish regular office hours during which EiRs can be consulted by prospective student and faculty entrepreneurs, and meet regularly with EiRs to evaluate activities and ensure successful outcomes. The role of the NNCI EiR is to help mentor (typically on an ad hoc and informal basis) NNCI users, faculty, students, and staff about topics related to entrepreneurship and commercialization, such as starting (or not starting) a new venture, where to find start-up capital, what local I&E resources (e.g., business accelerators) are available, how to navigate the university intellectual property process, and what common pitfalls to avoid. Developing entrepreneurs can benefit greatly from this mentorship and many established entrepreneurs are more than willing to provide it. As noted by Dr. Kurt Petersen during his 2021 NNCI seminar, *"Many experienced entrepreneurs enjoy mentoring new start-ups."* 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. Those considering an EiR role with the NNCI can contact Matthew Hull.

Table 4: 2021 NNCI Site Entrepreneurs-in-Residence

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

I&E Breakout Session at 2021 NNCI Annual Conference

An I&E breakout session was held virtually during the 2021 NNCI Annual Conference. Objectives of the session were to 1) gage attendees' perceptions of I&E within their sites and across the NNCI, 2) improve our understanding of attendee I&E needs, and 3) conceptualize strategies to address identified I&E needs. A detailed report on the breakout session is provided in Appendix 14.2, but the following is a summary of key points.

Participants recognized the value of I&E and want to participate in I&E programming development and implementation. They recognized the NSF I-Corps program and its tremendous value, but few have been able to participate in the program given its intense and focused time commitment. All attendees recognized the need for improved metrics on economic impact and measures of economic return-on-investment. Incubators and accelerators were noted as critical resources for entrepreneurs and start-ups, and co-location of incubator space with NNCI facilities, such as at KY Multiscale, was described as yielding highly successful collaborative outcomes. Participants also described offering a variety of other incentives for encouraging NNCI engagement with small businesses, such as in-kind instrument time, waived training costs, and subscription-style access strategies. The group valued a "startup showcase" event to bring together successful startups and investors, annually.

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 5). Positions on these committees were offered to each member of the Executive Committee (site PIs), along with any site co-PIs who wished to participate. Most Site Directors serve on two of these subcommittees with a subcommittee chair selected by the Coordinating Office. Additional input may be sought from members of the External Advisory Board and other experts as needed. Members of the Coordinating Office serve on some of the subcommittees as ex-officio members. As a starting point, the Coordinating Office created a number of guiding questions for each subcommittee. One of the subcommittees is selected to report to the full group of site directors and coordinating office (Executive Committee) every other session during the regular monthly meetings. Subcommittee topics, chairs, and members were reviewed and updated during 2021. The Entrepreneurship and Commercialization subcommittee was sunset, replaced by the new Associate Director and working group, the New Equipment and Research subcommittee was refocused on Research and Funding Opportunities, and a new subcommittee on Nanotechnology Infrastructure of the Future was added. Reports of the subcommittees on current and future activities are presented below as provided by the subcommittee chairs.

Table 5: NNCI Executive Committee Subcommittees

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

5.1. Diversity Subcommittee

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

2021 activities: The committee's discussions and work in the year 2021 were dominated by considerations for re-structuring the team to enable promoting inclusivity, equity, and diversity, post-pandemic, during a time of global pandemic and racial reckoning. This included efforts promoting equitable access and diversification of our NNCI site staffs.

Last summer as a response to the continued period of national racial equity dialog, the committee recognized a need for connecting, learning, and facilitating dialogue within the NNCI community around the topics of racism and anti-racism, and their impact on staff. In 2020 the committee organized an Anti-Racism Town Hall that was held online using a Zoom webinar on June 24, 2020. Over 230 individuals registered to attend the online Town Hall event and approximately 170 participated. Several questions were answered by the attendees:

- 2% of respondents viewed the Town Hall topic as "insignificant" to NNCI. 56% thought it was highly significant and 38% thought it was significant.
- 92% of respondents would like to be an ally for anti-racism within their NNCI facility.
- 3% of respondents have seen clear and obvious racism related to shared nanotechnology facilities.
- 66% of respondents think that implicit bias or systemic racism exists in users, staff, or leadership of NNCI facilities.
- 39% of respondents do not know how to respond if they witness racism.

These statistics pointed to a staff and user base that wants to act, though many may need more information on how to have impact and what actions to take. As a follow-up, the site PIs were asked to bring up the results from these survey questions during NNCI site meetings and facility staff meetings with an objective to identify actions that can be taken utilizing the local, unique resources available within their universities.

Let's recap where the Network currently stands, (from J. Jones's report 2020):

<u>Diversity</u>: The "state of diversity" in the NNCI can be assessed by considering several different aspects of wide variety of groups participating in the NNCI.

- Institutional characteristics of NNCI sites (e.g., HBCU, MSI status): In the first five years of awards, institutional participants included one HBCU (NC A&T in SENIC), one Minority-Serving Institution or MSI (UNC Greensboro in SENIC), one Primarily Black Institution (Community College of Philadelphia in MANTH), and four *emerging* Hispanic Serving Institutions or HSIs (UT-Austin in TNF, Arizona State in NNI SW, UC San Diego in SDNI, and Stanford in Nano@Stanford). Note that *emerging* MSI status is not well-defined nationally but is defined here as an institution with undergraduate student populations that are between 15% and 24% minority students. In the renewal awards of 2020, additional educational and research partnerships were established across the NNCI with Salish Kootenai College, Chemawa Indian School, Morgan State University, and FAMU-FSU. Northern Arizona University was also added as an equal partner to the NCI-SW site.
- PI/co-PI of NSF NNCI grants (i.e., NNCI site leadership): In the final year of the initial 5-year NNCI awards, of the 61 individuals listed as PI or co-PI on the NSF awards, 9 (or 15%) were women, which is comparable to the number of women in the Electrical and Computer Engineering professoriate (13%) and the Engineering professoriate (17%). In the 2020 renewal awards, of the 66 individuals listed as PI or co-PI on the NSF awards, 20 (or 30%) are women, demonstrating a significant broadening of participation by gender. In addition, several of these PIs/co-PIs are African American or Latino/Latina, demonstrating broadening participation by race and ethnicity.

- NNCI/Site user institutional characteristics (e.g., HBCU, MSI status): The institutional characteristics of external users of NNCI facilities is described in the site reports.

So how do we build on this?

Plans for 2022: The subcommittee is preparing to focus on the input collected during the Diversity breakout session at the NNCI Conference 2021. The new chair, Bill Wilson, served as moderator. The discussions focused on recruiting and staffing concerns. A summary of the session is below.

DIB Subcommittee Breakout Focus: Staffing, hiring, training, support, and workforce development.

Session preliminary questions:

1) How do we recruit and hire diverse talented staff? As a network, can we help each other diversify?
2) What training do we need for "new" staff? Is training adequate for current staff? What training models are needed?
3) How can we "standardize" careers in our facilities? What's needed to improve retention?
4) How can we develop the talent pool available to us?

We will explore actions and issues:

First issue, local hiring constraints, no relocation for new hires, limited resources for pay, local HR groups at Universities have not been broadly advertising in places where diverse candidates may be found.

*Possible solution**:** Develop some best practice guidelines to be shared about where to find candidates. Make sure all available positions are posted broadly throughout the Network. In addition, it was suggested that NNCI could make funds available for advertising position in venues likely to yield more diverse candidates. For example, ensure underrepresented group trade organizations like NOBChChe and NSBP are targeted for advertisement. Consider a Networkwide engagement for Community Colleges helping develop "Nano-infuse" content for their use. Shared intern pools were also suggested.*

Second issue, helping Staff via better staff development activities, offering more opportunities for publication, PI rights, etc. Again, a clearing house on best practices is needed. Some discussion of development of a network wide uniform Career ladder could help with staff retention.

Possible solution: A number of programs targeted at retention. Stanford, for example, has developed a grant program for staff to enable some research. This mini grant program offers (100K/year for 3 years). At some sites local cost for housing, etc. are an issue. For example, Stanford is developing housing assistance programs for staff. It was also noted that Stanford created a faculty committee specifically looking at staff recruitment/retention/DEI and exploring reward options when salary is noncompetitive with market conditions. NNCI could leverage this effort as a model to develop best practices for the network. Offering professional development opportunities is key. This should also include conference travel for staff. Staff exchange program were again suggested, (the cost here is prohibitive). NSF support is key here.

*Important Take-Aways**:** Centers need to better highlight the contributions we make to teaching, training, and workforce development. We must consider taking advantage of the NSF supplement*

(15% of total award), option and programs like the NSF INTERN program. It is clear that our lack of emphasis on our contribution to workforce development and the important role we play in training is a hidden gem which could help us supplement staff support and staff recruitment activities. We need to focus on the barriers of implementing staff exchange activities. One idea option is the creation of a Research Experience for Staff (RES) program. It would offer a wide variety of flexibility, enabling technology exchange between sites, Nano-Infusion efforts in community colleges, and contributions to outreach. A combination of RES activity and Mini Grants, (as Nano@Stanford has implemented), could be of great value.

NNCI DIB Subcommittee: Summary of ongoing Issues for Focused Discussion of Staffing Needs

Hiring:

a) Broadening the Candidate Pools
   - How to do this collectively as a network
   - Creating Programs to enhance pool – Vet training programs / Community College Coordination / Development of intern pools network wide
b) General DIB training / User interaction training for new staff
   - Exploring current staff training needs (what's needed / missing?)

Retention:

a) True career path development
b) Continuing Education Opportunities
c) Issues of pay equity

Workforce Development Activity:

a) Nano Infused training at Community Colleges
b) Teacher Programs expanded throughout the network

Examples of Active Community College Partnerships

UPenn / CC of Phila. (3 interns) – Curriculum support
Harvard Vet Program (Bunker Hill Community College)

Open Questions:

Postdoc programs possible? (Could ask NSF for a grant supplement?)

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

5.2. Metrics and Assessment Subcommittee

This subcommittee report is based on the November 18, 2021 virtual subcommittee meeting.

Past Achievements

In order to set the stage for subsequent discussions concerning goals and future tasks, the subcommittee reflected on its past achievements under leadership of Steven Campbell. In Steven's own words the main achievement of the subcommittee has been the "development of assessment tools that provide hard quantitative data for the impact of the network on academic research." David Gottfried added that the committee has served as "sounding board for the coordinating office and the site directors". The subcommittee decided early on that for reasons of continuity metrics established by NNIN, the previous incarnation of today's NNCI, will be adopted by NNCI. For new metrics suggested *e.g.* by an NNCI advisory board, NSF, or the site directors, the subcommittee tried to work out best practices to collect and present the data as a network.

<u>Advanced Metrics and Potential New Foci</u>

In the past, metrics were primarily tailored to assess the impact on academic research of individual sites and the network as a whole. There is a need, or at least a need for discussion, on advanced metrics which go beyond the focus on academic research. Those advanced metrics include data on *research funding sources*, collected annually per NSF request. Potentially additional useful metrics include data on *students graduated by degree and academic department*, *courses supported by facilities* including number of enrolled students, *longitudinal outcomes* such as REU students and users and new foci on *economic impact* and *workforce development*.

In the context of advanced and additional metrics the subcommittee feels strongly that a *<u>Peter Parker principle of Metrics and Assessment</u>* must be enacted:

With the subcommittee's power to request ever more data there must also come great responsibility to lay out how these data can be effectively collected.

The need to lay out guiding principles for data gathering for the sites became apparent when discussing the recent request to collect data on graduated students. General data privacy concerns at universities and the hurdles associate with accessing databases which contain the data make it difficult to extract the data with reasonable effort. As a result, Trevor Thornton described what seems to be, in the absence of institutional support, the most efficient way to obtain the data on graduates. The site director and/or facility specialists, analyze the commencement book listing the names of every graduate the university produces in a given semester. The team cross-references this list with the list of users. It takes a couple of hours each semester for each person involved in this task to identify the graduates associated with NNCI.

<u>Assessment</u>

In the past the metrics and assessment committee has not discussed the important component of assessment in the context of education and outreach. This is because NNCI has a working group on E/O assessment. The subcommittee on metrics and assessments does not want to duplicate efforts or interfere with their work. However, considering the importance of this subject, the subcommittee thinks that it is imperative to better communicate between the subcommittee, the working group, and the NNCI sites to propagate best practices which go far beyond assessment via surveys and allow to gather information about impact on larger timescales including the entire pipeline from K-12 and beyond.

<u>Coordinating Work between the Subcommittees</u>

Of particular interest is coordination of work between the subcommittee on Metrics and Assessment and the Building the User Base subcommittee. Here the question emerged whether we can help the subcommittee on building the user base to define in a broader sense what a user is. Traditionally we "count bodies", *e.g.*, in the cleanroom or the microscopy lab etc. but are there other types of users? Examples could be students in classes we teach, users from community colleges, new users we attract via mini-courses we teach to educate what facilities are available and what kind of problems the facilities and our experts can attack. Metrics in this context could be the number of courses taught, frequency with which we teach them and number of students attending. In addition, we could try to measure what impact these means of building the user base have. Ideally, we want to find a way to get the data for building the user base from data mining the data base we already collect.

Can additional data be requested without lowering the reporting burden?

The subcommittee has the impression that we need to be very conservative with adding more requests for data from the sites. The subcommittee has the strong believe that additional efforts should only be considered if they serve the purpose to demonstrate how useful NNCI is and that some form of a national nanotechnology infrastructure needs to continue after NNCI. The subcommittee has the task to provide the necessary feedback to the coordinating office about what data are needed to achieve this goal. There are best practice examples for how to present data on economic impact and connection between academic institution using NNCI facilities. The subcommittee can help share these best practices.

Members: Christian Binek (Nebraska), Trevor Thornton (Arizona State University), David Berube (RTNN/NC State), Jan Youtie (SENIC), Sanjay Banerjee (Texas), Mitsu Murayama (Virginia Tech), David Gottfried (SENIC)

5.3. Global and Regional Interactions Subcommittee

The primary objectives behind the NNCI Global and Regional Interactions (GRI) subcommittee are the following:

i) engage and leverage local NNCI node activities with regional programs and local institutions,

ii) explore plans and develop ideas to identify and potentially connect our NNCI network to analogous programs across the world.

The subcommittee encourages individual NNCI sites to identify their local partners and regional collaborators. The examples of SHyNE, CNF, and SDNI interactions are meant to provide suggestions and ideas for the GRI subcommittee to explore similar plans for local leveraging. In this first year of the new second NNCI cycle, the subcommittee interactions included bilateral dialogue between subcommittee membership and less formal interactions in this initial stage of the program. The GRI efforts fall into the following categories.

Regional Interactions:

SHyNE Resource regional coordination in the Chicago Metropolitan Area: The subcommittee has initiated and discussed individual site examples for regional coordination and leveraging of local programs to enhance visibility and attendance in NNCI and related events. Within the SHyNE Resource, we have taken efforts to establish collaborative relationships with local colleges and universities in the Chicago metropolitan area. As examples, these institutions include Chicago State University (CSU), Oakton Community College and Northern Illinois University. We have also reached out and connected to public institutions such as the Art Institute of Chicago and Chicago's Field Museum of Natural History.

These efforts, among other things, include such programs as the Research Experience for Undergraduate (REU) program and the Research Experience for Teachers (RET) program. We also continuously, and consistently, strive to facilitate the success of our local start-up companies within the greater Chicago metropolitan area. At the same time, we strive to form relationships, collaborations and partnership with various mid-size and large-size corporations within our area. We strive to facilitate the success of K-12 schools, and K-12 organizations, and to provide them with various resources needed in order to enhance the education of their student communities.

CNF regional interactions in the New York State area: CNF has been working with regional academic nanofabrication facilities and companies in the NY state to identify areas of partnership in research, work force training and resource acquisition. Four topical workshops were held in 2020-2021 to discuss these focus areas. Schools participating included SUNY Albany, SUNY Binghamton, RIT, Columbia, RPI, Clarkson, SUNY Buffalo and CUNY. Companies included IBM, CREE, Global Foundries, TEL and AMAT among others. We expect to organize a NY State Regional Nanofabrication showcase event in the next 6 months.

SDNI regional interactions in the Southern California area: SDNI collaborated with Zeiss and Hitachi America on remote SEM teaching and remote-hands-on experiment to bring nanotechnology to high school and middle school science classes. SDNI interacted with 22 high schools in California to run nanotechnology Summer Institute in August 2021. We collaborated with 6 other NNCI sites, companies (Omni Nano, Hitachi), community colleges and high schools (Pasadena City College, Southwester College, Valencia High School, Kearny High School), and other UC campuses (UC Irvine, California NanoSystems Institute at UCLA) in an education and outreach symposium to discuss how to optimize our knowledge management strategies to ensure streamlining and sustainability of K-12 nanotechnology education. SDNI also collaborated with Southwestern College on a program for nanotechnology and semiconductor workforce development, with particular focus on training of technicians.

Moving forward, the GRI subcommittee intends to widely share examples of regional coordination for other sites in order to explore any possible regional and local opportunities. The GRI sub-committee will meet quarterly with formal agenda and yearly goals.

National and NNCI Network Interactions:

We have had a number of meetings with various organizations around the USA, and also with several NNCI partners, in an effort to form mutually beneficial relationships with various organizations around the country. We are using the Rules of Life (RoL) theme as a means to bring the entire NNCI organization together in an effort to form a unified and cohesive coalition that can position the NNCI organization as the leading global scholarly community in the world in the area of RoL. For details, refer to the update report covering the activities of the RoL research community. We organized annual educational and outreach conferences that involved all NNCI sites of interest in a focused theme about K-12 education. Two meetings were held in 2020 and 2021 with the participation of 7 NNCI sites and local colleges, middle schools and high schools.

Global International Interactions:

We have been exploring means and ways for collaborative relationships with various academic institutions, research institutions and industrial corporations around the world. In the first cycle of NNCI program, we have been developing internal synergy and national coordination. The natural extension of this philosophy is to expand the impact of NNCI across the world through potential thematic and targeted international relationships. With the Covid-19 global pandemic, travel and other means to explore global partnerships are severely challenged. Thus, we will explore and develop plans for remote-access and cyber-enabled activities such as virtual workshops and meetings.

We plan to explore complementary and mutually beneficial relationships with targeted organizations around the world. Some examples include the nanofabrication facility program at KAIST (South Korea) and exploratory dialogue with a European consortium. We hope to explore ideas for exchange of students and staff, and also joint research and academic programs.

The CNF site of NNCI is in the Global Quantum Leap AccelNet program supported by NSF. NNCI members of the steering committee include U Minnesota (lead), Georgia Tech, and U Chicago. This program organizes student and young researcher exchanges when possible and works on how quantum science will impact academic facilities such as those of NNCI. We are working with Japanese and European networks that also focus on quantum science. We hold monthly leadership meetings and meet regularly with international partners. SDNI has collaborated with the IPIC (Ireland) on integrated photonics packaging for education and convergence research.

One major obstacle for global interactions and collaborations is ITAR and export control and more recently, confidential unclassified information (CUI). Potential violation of current rules can put individuals involved in the collaboration at risk with serious legal consequences. As a topic for the next year, the subcommittee will discuss this issue and form a strategy of engaging global collaborations and interactions in a meaningful way under these guidelines.

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

5.4. Research and Funding Opportunities Subcommittee

Meetings

The NNCI subcommittee on research and funding opportunities has met twice (May 20, 2021 and December 9, 2021), delivered a report to the NNCI Site Directors (June 9, 2021) and established quarterly meetings for 2022.

Opportunities

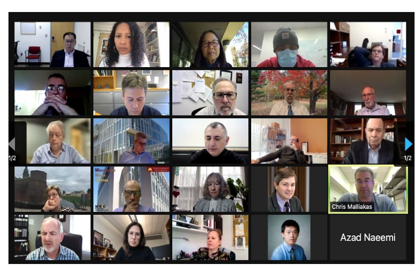
The subcommittee has identified three opportunities to monitor and/or develop over the coming year. These include:

1. New federal opportunities connected to the U.S Innovation and Competition Act that have potential for synergistic interactions with the NNCI network. The subcommittee is staying apprised of any developments toward passage and appropriation of funds for this act. Particular attention is given to focus areas that could work synergistically with the NNCI network, particularly artificial intelligence and machine learning, high performance computing and semiconductors, quantum technology, robotics and automation, communications technology, biotechnology, materials sciences, 2D materials, et al.

2. Industry relations: Industry has been identified as a potential partner to the NNCI network to enhance workforce training and ensure access to state-of-the-art instrumentation to maintain U.S. competitiveness. The goal is to facilitate deeper industry engagement with the NNCI network and core facilities to foster a less transactional relationship and better engage industry in the success of NNCI. Two threads are in process:
    a. An NNCI student conference and career fair. This conference/career fair would be open to top graduate students and post-docs at each of the NNCI sites. It would serve both as a conference to showcase their research, and also as a career fair to facilitate interactions between industry and their future workforce. The conference/career fair would be a vehicle to facilitate deeper industry engagement with the NNCI network, allowing the network to better meet and anticipate workforce training needs.
    b. Development of best practices for industry relations. Industry presents different needs compared to typical academic users, so a list of best practices is in development for facilitating positive industry interactions.
3. Training grant opportunities. The NNCI network and core facilities present potential opportunities to disseminate new techniques and capabilities to a broad user base. We are investigating the NSF Research Traineeship (NRT) program as a potential collaboration between several NNCI sites. One potential focus could be artificial intelligence/machine learning (AI/ML), where an NRT program is used to develop expertise in how AI/ML can be interfaced with NNCI tools (e.g. cleanroom equipment, imaging tools) to facilitate new research directions. This could train students in this important topic before starting a career, enable new capabilities in our NNCI cleanrooms, and help form an important bridge between different sites.

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

5.5. Nanotechnology Infrastructure of the Future



Screenshot of the participants (partial) of the "Futures" breakout session at the 2021 NNCI conference.

This subcommittee, focused on the future of NNCI after 2025, was formed in 2021 and is currently chaired by Prof. Debbie Senesky (nano@stanford). This subcommittee is composed of 11 members, representing numerous NNCI sites. The core mission of this subcommittee is to provide insights that help shape the strategic planning for the future of nanotechnology infrastructure. This year, the futures subcommittee held three meetings, led a breakout session during the 2021 NNCI Annual Conference, and gave a report out during the NNCI Director's Meeting in December 2021. The major focus of the subcommittee this year was conducting an ethnography-based examination of networked nanoinfrastructure. More specifically, we conducted interviews of our networked peers (e.g., EuroNanoLab, AccelNet Network, and DTU Nanolab) to obtain feedback on best practices and potential growth areas. In addition, we obtained internal feedback during the "*The Future of NNCI after 2025*" breakout session held during the 2021 NNCI Annual Conference. To gain focused feedback and ideation from participants, three topics (preselected via a survey) were raised: (1) What would the perfect nanotechnology network of 2025 look like? Dream big! What is the NYTimes headline about us?; (2) How can we impact training, numbers and diversity of the nanotechnology workforce through our networked facilities?; and (3) Consider the mechanics of implementation: What infrastructure is needed for success in the network of 2025? What are the metrics for success? During the breakout session, participants were asked to share their opinions on the three topics either verbally or on a shared Google document. Based on the recent activities, the subcommittee has identified potential solutions and growth areas for improving our network. For example, providing more mechanisms for translation of research to commercialization, exploration of intra-agency funding of nanoinfrastructure, developing new platforms for information exchange, and working with regional community college networks to significantly scale up (from 10's to 1000's) outreach efforts. The plan for 2022 is to continue to conduct ethnography studies and expand our interviews to members of industry and program directors to identify actionable items that may shape the future of NNCI.

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

5.6. Building the User Base Subcommittee

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

In 2021, the BUB subcommittee discussed at length how to rebuild the user base, particularly on redefining the meaning by "build" and "user base". Questions raised were:

1. Is user base only in terms of quantitative numbers or can there be other forms of impact?
2. Will it be useful to focus on impact from user success stories (e.g., center-level grants or SBIR, venture investments, jobs etc.)
3. Are there other ways to showcase impact, diversity of users, interaction between sites?
4. Can BUB work with the Metrics subcommittee on new metric(s) for the above?

In addition, the BUB subcommittee conducted a survey among NNCI sites to collect information specifically on the non-traditional userbase, interactions with Research Communities, and user success stories (for use as a qualitative measure of success in addition to quantitative metrics). Twelve out of the sixteen NNCI sites responded to the survey.

The results of this NNCI site survey are summarized as follows:

Which non-traditional user area(s) is your site focused on
1. Biomedical Sciences – medicine, biotechnology, synthetic biology, Pharmacology
2. Environmental Sciences
3. Earth/Geosciences, agriculture, food, water
4. E&O - Community colleges, museums, K-12 – teachers, students
5. Small businesses, start-ups
6. Textiles, and others – astronomy, aerospace, multiscale fab

How do you promote or intend to promote your site in above identified non-traditional area(s)
1. Direct communication with non-traditional user groups, invites, visits, local area conferences (in non-traditional fields), focused symposia, seminars, meetings, visits, presentations, courses.
2. Establish engagement through social media marketing, data mining etc.
3. Tools/capabilities that cater to non-traditional users
4. Partnerships with research centers, economic development offices; SBIR/STTR – 10-55 small companies from survey results
5. Engagement through Research communities; seed grants
6. Funding for E&O activities

Which strategies have worked best in attracting users
1. Word of mouth, excellent service to existing users
2. Networking through existing users, user ambassadors, referrals
3. Visits (virtual/in-person) to universities and/or industry
4. Robust and active communication, exciting materials – websites, brochures, YouTube videos, internet search, other social platforms etc.
5. Targeted engagement with non-traditional disciplines (talks, seminars, short courses), engaging with SBIR/STTR awardees , start-up companies
6. Partnerships with other centers, industry, others – seed grants
7. Link to site education & outreach activities

Effectiveness of free/subsidized user access programs
• **Yes, effective in attracting new, first-time users** • Primarily as remote users, new faculty, enabled collaborations • Successful with medical school and industry users • Worked well for one-off projects from K-12 schools, high school student projects, museums, community and small colleges etc
• **Mixed in terms of returning users** • Not very effective in creating a sustainable user base • Exceptions - several returning industry users, geographical proximity etc

How are you engaging with Research Community (RC) activities
• Some sites are engaged in RCs – organizing/leading and participating in workshops, other RC seminars, meetings, networking groups • RCs are opportunity to engage with wider potential user base (mostly non-traditional)

Plan to utilize Research Community (RC) activities as a tool to BUB
1. RC events (first year) have helped to identify needs and potential users
2. Direct engagement with potential users from RC events
3. Other avenues – workshops, short courses targeted to attract new users from RC activities

If possible, please share a user success story that demonstrates impact. Several sites have provided user success stories, particularly small business successes in raising venture capital, SBIR Phase II awards and acquisition.

The main conclusions of the survey are:

1. **Major non-traditional area for most sites is** biomedical sciences (medicine, biomedical devices, biotechnology, synthetic biology, pharmacology etc.)
2. **Best strategy(ies) that has worked in attracting new users are** (1) word of mouth, (2) excellent service and networking through existing users, and (3) robust, active, and targeted engagement with potential various user groups.
3. **Free/subsidized user access programs** have largely been effective in attracting new, first-time users. In the case of returning users, it has been successful with industry users and with some non-traditional user groups, e.g., medical schools.
4. **Intentional engagement with Research Communities** (understanding their needs, priorities etc.) may be a potential avenue to attract new and diversity of users, primarily from non-traditional areas.
5. **Work with NNCI Metrics subcommittee** on a new user success metric that captures impact.

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

6. Working Groups

One of the greatest strengths of the NNCI network is the combined staff expertise of the individual sites. To leverage this expertise at the network level, the Coordinating Office initiated the formation of working groups composed of staff members from the NNCI sites. While these working groups meet primarily via phone and video conferences, they also have the ability to organize workshops and/or dedicated sessions at the annual NNCI Conference. We have created and are encouraging working groups (Table 6) in (1) important "network" responsibilities, such as environmental health & safety, vendor relations, or equipment maintenance, (2) particular process technologies, such as lithography or characterization (although these are only examples of possible topic areas), and (3) education and outreach activity. Most of these working groups began in Year 1, while new ones were added in Years 2 and 3. In addition, some topical areas (EBL, Etch, and ALD) have begun working groups through grass-roots efforts of NNCI staff, with support from the Coordinating Office. The outcomes of these working groups can have many forms, including process recipes, recommendations to vendors for future equipment development, maintenance and training videos/webinars, recommendations on how to evaluate the safety of new processes, or direct recommendations for new users. Each working group has one or more dedicated coordinators selected from one of the NNCI sites, and staff participation in the working groups can be one measure for site performance. Participation in these working groups can also be considered as a mechanism for staff growth and career development or as support for an NNCI Outstanding Staff Award. During 2021, leadership the working groups was examined and some changes implemented, and all working groups were opened to new members from NNCI staff.

Table 6: NNCI Working Groups (2021)

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

Workforce Development and Community Colleges	Ray Tsui (Arizona State)
Evaluation and Assessment	Quinn Spadola (Georgia Tech)
Technical Content Development	Daniella Duran (Stanford) Eric Johnston (Penn)
4-H	Lynn Rathbun (Cornell)
Societal and Ethical Implications (SEI)	Jameson Wetmore (Arizona State)
Innovation and Entrepreneurship (I&E)	Matt Hull (Virginia Tech)

During NNCI Year 6, sites or groups of sites hosted seminars and technical workshops related to fabrication, research, or education topics (see Section 10.1). The Coordinating Office encourages working groups to use these programs as opportunities for the working group to meet in a face-to-face setting, as a supplement to virtual discussions, although the pandemic has continued to restrict most meetings to virtual formats this past year. When travel is available, the Coordinating Office provides financial support (up to $1000 travel funding each for 5 attendees) to encourage staff participation. Recent and planned events include:

- NNCI Etch Symposium (virtual), December 9, 2020 (Cornell)
- Advanced Lithography Unsymposium (virtual), January 21-22, 2021 (Stanford)
- NNCI Etch Symposium, April 21-22, 2022 (Univ. Pennsylvania)

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

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

This year marks the transitioning and refocusing of our efforts on maintenance, as the training aspects have been taken up by a separate working group. Further discussions are necessary to formalize a plan but going forward we hope to develop new avenues for sharing information regarding various vendor offerings and how best to configure them for optimal utility. We would also like to extend opportunities for vendors to showcase their offerings to us a group, if need be through Zoom presentations. These sorts of interactions would allow all of us to review options collectively and summarize how new or growing technologies compare with our existing solutions.

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

6.2 Vendor Relations

Working Group Structure

Based on the experience of the first two years of the NNCI Vendor Relations Meetings, the following structure has evolved: There are multiple points for communications and project leadership instead of a top-down structure. This allows whomever wants to initiate a project to lead it and then communicate their findings to all.

Working Group Successes

A Reliable and Economical ZEP520A Supply: The Nippon Zeon Corporation supplies a material critical to nanofabrication research, the relatively expensive electron beam resist *ZEP520A*. Zeon's main customers purchase large quantities of this resist so that accommodating small research needs is problematic. After years of discussion, a win/win situation has been negotiated; Zeon has lowered the cost of *Zep520A* from $2,500 to $1,600 for 100 ml quantities, and from $10,500 to $9,500 for liters - a price reduction of 36% to 9.5%. The second phase of the project is to find a domestic company to take over the distribution of *ZEP520A* for all US nonprofits and government labs (presently only Mid-Atlantic Schools receive the above price reductions). Such a company was identified this year, Transene, and it will soon begin distributing ZEP in 25 and 100 ml bottles.

Expanding Supply Collaborations: The next step is to use the Zeon/Transene model to combine other important manufacturers with distributors that can respond to the research community. We are working with Pelchem, an important supplier of the etch gas XeF_2, and with Transene. This relationship could lead to at least a $3,500 savings per 600 gram cylinder of XeF_2.

New Mask Supplier: We continue to work with the start-up US manufacturer for cleanroom/surgical masks, Pi & Pie. They manufacture top quality masks and are also among the lowest priced. Information about this firm is regularly sent out to the NNCI members, other academic research labs, and Mid-Atlantic region government labs.

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

6.3. Environmental Health & Safety

The EHS working group met in December 2021 and discussed two topics relating to safety. First, we revisited and revised a poll sent by Mary Tang (Stanford SNF) and Ron Olson (Cornell CNF) in May 2020 addressing lab safety during the COVID pandemic. The updated survey will probe COVID rules, policy changes, staffing, training, and compliance issues. We plan to resend the poll on the 2-year anniversary of the original, in May 2022.

Next, we explored creating an NNCI-wide, shared document for recording and anonymously disseminating safety incidents in NNCI facilities. Similar records are kept by universities (e.g. the University of Washington has an Online Accident Reporting System, OARS), but they often include too much detail or events that are not relevant to NNCI cleanrooms and imaging facilities. Our intent is to update and maintain this list annually, starting in 2022, to keep tangible reminders of the importance of safety policies and procedures. We believe that concise, real-world examples will help reinforce safety training, improve compliance, and prevent future incidents. Two examples are shown below:

Date	Severity	Category	Incident Details	Corrective Actions
Aug. 19	Incident	Physical	A student fainted in the lab.	Read fainting first-aid. Position a fainted person flat and hold their legs up about 12”. Covered fainting during safety trainings. Reiterated need to work when feeling healthy and to not lock knees.
July 05	Near-miss	Chemical	A student poured HF into a glass container.	Updated safety training with explicit examples of incompatible containers. Instituted new quiz. Showed new users etched glassware as real-world example of mistake.

Members:

Name	Affiliation
Andrew Lingley	MONT (Mont. State U.)
Nasir Basit	SHyNE (Northwestern)
Greg Cibuzar	MiNIC (U. Minnesota)
Philip Infante	CNF (Cornell)
Robert Rose	SENIC (Georgia Tech)
Mark Walters	RTNN (Duke)
Shane Patrick	NNI (UW)
Darick Baker	NNI (UW)

6.4. E-Beam Lithography

We are an active working group that hosts at least two meetings a year. The leadership model of having two co-chairs has been a really helpful and encouraging way to lead our working group. We can help each other stay accountable with setting up semi-annual meetings, bouncing around relevant topics, and have a bit more fun with EBL jokes.

As 2021 continued with the COVID-19 pandemic, the working group met twice online. Our first meeting was on April 8, 2021 with 12 tool owners in attendance. We covered the topics of how to best keep track of user tool hours and tool use efficiency. The overall discussion helped Univ. Minnesota think through how to set up their tool reservation and determine tool utilization. Kevin’s comment was “My lab manager, Greg Cibuzar, and I are thinking over what to do, and these suggestions are really helpful." One of the users also shared about a unique project and sought suggestions from the group in which several users responded with helpful advice. We also had each site provide highlights of new tools or new research.

Our October 2021 meeting also had 12 tool owners in attendance. We went through a round of site and tool updates. The group discussion this time revolved around how to decommission retired tools and have them de-installed. At least one site mentioned they were retiring a 12-year old tool and they will plan to use a re-seller to purchase and remove the tool. Other examples were having the tool be removed to state surplus as it was state-owned property and could not be resold. However, other NNCI sites use a compatible tool that may be able to use the holders. The sites were encouraged to coordinate to see if those holders can be up for auction for the other NNCI site. Another process question was proposed for suggestions on how to approach "100 nm lines on glass, with Al layer and 50 nm SiN trying to use 120 nm PMMA." The tool owner came away with 4-5 helpful suggestions to try to accomplish the goal with the simplest method of using a high-contrast and highly etch resistant resist like ZEP or CSAR. Overall, these working group meetings have been helpful to provide good cross-pollination of ideas for tool owners and research.

Co-leads Devin Brown and Stanley Lin completed a brochure project to promote the different EBL tool capabilities and locations across the NNCI network. The document, "NNCI Electron Beam Lithography Working Group Resource Guide, highlights each site by providing a photo, specifications, description, and staff contact for more information. It also contains six research highlights with quality photos and descriptions of the research from various NNCI tools. The project was finalized and debuted at our April 2021 Working Group meeting. There was great praise for the helpfulness of the project and was distributed among the NNCI working groups as an example of what can be done to help the NNCI network and users. It is posted on the NNCI webpage and the NNCI Site webpages.

We also encouraged any of our members to consider serving as a co-chair. Devin will continue to serve until someone takes up the mantle. This has shown to be a great responsibility that site management likes to see as it provides the sites with great NNCI visibility. This also helps with personal career growth. As an example, Stanley Lin was awarded one of the NNCI Technical Staff Awards for 2021. Co-chairing played a role in this nomination.

Overall, our EBL working group had a successful year with two meetings and fruitful discussions. Our working group is well attended by about 12 people, and everyone willingly participates in discussions.

Members:

NNCI Site	Institution	Tool Owner
SENIC	Georgia Tech	Devin Brown
SENIC	NCAT/UNC JSNN	Steven Crawford
RTNN	NC State	Greg Allion Backup: Saroj Dangi
RTNN	Duke	Talmage Tyler Backup: Jay Dalton

RTNN	UNC Chapel Hill	Amar Kumbhar Bob Geil
MANTH	U. Penn	David Jones Hiro Yamamoto Sam Azadi
CNS	Harvard	Yuan Lu Backup: Jiangdong Deng
CNF	Cornell	Alan R. Bleier Backup: Amrita Banerjee Backup: John Treichler
KY MMNIN	Univ of Kentucky	Brian Wajdyk
SHYNE	Univ of Chicago	Peter Duda
MINIC	Univ. of Minnesota	Kevin Roberts
NNF	Univ of Nebraska-Lincoln	Anandakumar Sarella
TNF	UT Austin	Ansh (Starting January 2022)
NCI-SW	Arizona State Univ	Kevin Nordquist
SDNI	UC San Diego	Maribel Montero Backup: John Tamelier
nano@stanford	Stanford (SNSF Spilker)	Rich Tiberio Stanley Lin Grant Shao
NNI	Univ. of Washington	Brant Hempel

6.5. Etch Processing

The objective of the Etch Processing Working Group is to provide an interactive forum for etch personnel from all the NNCI participating sites. This interaction includes but is not limited to the sharing of information regarding etch capabilities, established etch processes, processes under development, maintenance issues, preventative maintenance, baselining efforts, equipment modification, and the acquisition of new etch tools/technologies. Identification and documentation of the broad and complementary etch tools within NNCI allows us to effectively process wafers within the network to meet the diverse specifications of individual projects, and to provide back-up systems within the network to avoid any extensive downtimes in user processing. An updated (December 2021) NNCI Dry Etch Capabilities listing has been uploaded to the NNCI website. This listing identifies each site's dry etch based equipment. In addition to the above referenced tool set listing, we have composed and updated (December 2021) the listing of common and various NNCI plasma etch technologies along with the network sites and specific platforms that support those processes. This document of supported processes will also assist users who seek etch process capabilities when requirements cannot be satisfied at a specific university and which need to be fulfilled on a specific etch platform.

Throughout 2021, a subcommittee of the etch working group (V. Genova-Cornell, Ling Xie-Harvard, Usha Raghuram-Stanford, & Meredith Metzler-Penn) has been meeting bi-weekly via zoom to prepare for an on-site in-person symposium to be held at the University of Pennsylvania on April 21-22, 2022. The 2022 NNCI Etch Symposium is titled "**Advances in Micro- & Nanoscale Etching for Novel Electronic, Photonic, and Quantum Based Devices".** This 2-day symposium will include an internal meeting of NNCI technical staff and invited non-NNCI staff on day 1 (Apr. 21). Member NNCI sites are invited to give updates on new etch equipment and newly developed etch processes. A portion of day 1 will be dedicated to an open discussion of any etch related equipment or process issues. In addition, we have invited etch equipment vendors including Oxford Instruments, Plasmatherm, SPTS, Samco, and others to give technical presentations which highlight their latest developments in etch processes such as atomic layer etching (ALE) and those processes critical for electronic, photonic, and quantum-based devices. The vendors will also have exhibit booths available so that attendees can meet and discuss the manufacturers' most recent etch products and ancillary equipment offerings. Day 2 (Apr. 22) will be an open, public event with invited and contributed talks by experts from academic and government labs. We have confirmed invited talks from Princeton, Stanford, Cornell, Harvard, MIT, and NIST. The topics will discuss etching aspects in a broad range of nanotechnology, including quantum and nanophotonic device fabrication and the role of artificial intelligence (AI) in the fab.

The subcommittee during its 2021 meetings has addressed a number of questions and issues from NNCI etch personnel regarding etch processes and equipment. The current communication paths include a LinkedIn-NNCI Etch Group and an NNCI Etch listserv, where etch questions can be posed to the NNCI etch technical staff. There is also an Etch Working Group page on the NNCI website (https://www.nnci.net/working-groups), which contains a news blog where announcements can be made as well as postings of interest to all etch staff and users. Currently the page contains links to workshop and symposium presentations, in addition to the NNCI etch tool and capabilities listings.

Members:

- Cornell University (V. Genova, T. Pennell, J. Clark, G. McMurdy)
- Harvard University (L. Xie, K. Huang)
- Stanford University (J. Tower)
- Georgia Institute of Technology (T. Averette, H. Chen, M. Thomas, T-V. Nguyen)
- 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. Hua)
- University of Pennsylvania (E. Johnston, H. Yamamoto)
- University of Texas-Austin (J. James,)
- University of Washington (M. Morgan)
- Arizona State University (S. Ageno, S. Myhajlenko)
- UC San Diego (X. Lu,)

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

6.6. Atomic Layer Deposition

The NNCI ALD Working Group is being co-led by Malcolm Hathaway (Harvard University) and Michelle Rincon (Stanford). The ALD Working group met approximately bi-weekly until April 2021 to discuss staff concerns and best practices regarding the Covid-19 re-starts. The forum has been a valuable place for group members to exchange ideas and solutions for safe operations and training specifically around ALD as well as lab operations in general. Since April, we have been communicating via the email list to discuss process and equipment issues that members have been interested to get group input on. The goal is to organize another conference in the upcoming year. Initially, a virtual conference in the spring had been postponed in favor of a potential in-person conference in the fall, but Covid-19 resurgence resulted in additional postponement. The group will be surveyed as to the timing and the nature (in-person vs. virtual) of the 2022 ALD Working Group conference.

We also were able to complete the first of the animation series that was initiated in 2020. The goal is that these animations would be used by staff during user training sessions as well as reside online as a reference and resource for researchers who are interested in depositing films. These animations are intended to not just teach researchers about what tools do, but to help highlight the pros and cons of different deposition methods and how the topography of their substrates should influence the methods they choose. The animation for evaporative deposition has been completed and is being piloted as part of the deposition training for the Harvard CNS labs. The next steps will be to make that video more broadly available and to begin work on the ALD deposition animations.

Members:

Name	**Institution**
Anil Dhote	Northwestern
Bangzhi Liu	Penn State
Bill Mitchell	UC Santa Barbara
Darick Baker	University of Washington
Don Leber	Virginia Tech
Fred Newman	University of Washington
Bob Geil	University of North Carolina
Hang Chen	Georgia Tech
Ben Hollerbach	Georgia Tech

J. Provine	Stanford
Jeremy Clark	Cornell
Julia Aebersold	University of Louisville
Kyle Keenan	University of Pennsylvania
Mac Hathaway	Harvard
Matthew Oonk	University of Michigan
Michelle Rincon	Stanford
Mahendra Sunkara	University of Louisville
Paul Kimani	University of Minnesota
Tom Penell	Cornell
Robert Amundson	University of Minnesota
Gary Spinner	Georgia Tech
Stefan Myhajlenko	Arizona State University
Tony Whipple	University of Minnesota
Vince Genova	Cornell
William Drawl	Penn State

6.7. Photolithography

The NNCI Photolithography Working Group is composed of representatives from 12 NNCI sites, plus representatives from UC Berkeley, and is charged with sharing photolithographic techniques and processes with member sites and the larger research community.

The working group held no meetings in 2021, but in place of our traditional meeting that coincides with an advanced lithography workshop at Stanford, group members at Nano@Stanford instead organized an online "UnSymposium" in January 2021, which many of us attended. Presentations were made by 4 of the working group members from Stanford, Penn, UCB, and Cornell. Details may be found here: https://nanolabs.stanford.edu/events/about-un-symposium/agenda

Members:

Pat Watson, Penn
Allison Dove, UCB
Ben Hollerbach, Georgia Tech
Garry Bordonaro, Cornell
Brian Wajdyk, Kentucky
Mark Brunson, Washington
Shivakumar Bhaskaran, Stanford
Curtis McKenna, Louisville
Christine Yi-Ju Wang, Harvard
David Jones, Penn

Emily Beeman, UCB
Eric Johnston, Penn
Mark Fisher, Minnesota
Guixiong Zhong, Harvard
Jiong Hua, Nebraska
Jean Nielsen, Washington
John Tamelier, UCSD
Paul Kimani, Minnesota
Gyuseok (Q) Kim, Penn
Mahnaz Mansourpour, Stanford
Mary Tang, Stanford
Laura Parmeter, Minnesota
Phil Himmer, Stanford
Kevin Roberts, Minnesota
Grant Shao, Stanford
Shu Xiang, UCSD
Swaroop Kommera, Stanford
Stanley Lin, Stanford
Rich Tiberio, Stanford
Tran-Vinh Nguyen, Georgia Tech
Xuekun Lu, UCSD
Sarice Jones, Washington

6.8. Imaging and Analysis

The annual NNCI Imaging and Analysis working group meeting was to be held at the 2020 Microscopy and Microanalysis conference in San Antonio, TX, but this conference was cancelled due to Covid-19 and hence we will schedule the annual meeting for the 2022 Microscopy and Microanalysis meeting in Portland, OR, July 31-August 2, 2022. This leverages the fact that the majority of participants will be attending this meeting.

There will be a questionnaire that will be emailed to group participants in February 2022 that will discuss group questions in general, how best to feed into the NNCI, and what if anything extra is needed and topics for the first topical workshops that work well virtually. Currently the tentative topical workshop focus will be on ion beam preparation of nanomaterials and in-situ microscopy.

The first meeting of 2022 will be held in March 2022, virtually via Zoom, most likely in the third week.

Members:

David Bell	Harvard University
Evgenia Moiseeva	University of Louisville
Jasmin Beharic	University of Louisville
Jillian Cramer	University of Louisville
Phillip Strader	RTNN (NCSU)
Vacant	TNF (UT-Austin)
Recep Avci	MONT (Mont. State Univ.)
Tobi Beetz	nano@stanford (Stanford)
Vacant	NCI-SW (ASU)
Matthew Brukman	MANTH (U. Penn.)
Lanping Yue	NNF (Univ. Nebraska)
Jeff Wu	SDNI (UCSD)
Weinan Leng	NanoEarth (VT)
Mark Brunson	NNI (UW)
Ellen Lavoie	NNI (UW)

Kyle Nowlin	SENIC (JSNN)

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

The K-12 Teachers/RET, Students, and Community Outreach working group (hereafter, "K12") did not meet regularly over the past year. Live education and outreach programming was shut down across the NNCI network starting in spring 2020, and the working group has been paused throughout much of that time. While several NNCI sites pivoted to remote education activities, these efforts were planned and implemented locally with no involvement by the K12 working group.

As NNCI sites begin to emerge back into normal operations, the K12 working group is in the process of redefining its role and mission within NNCI. A reorganizational meeting was held on Oct 12, 2021 to consider a new or retooled mission for the group. During this reorganizational meeting, members suggested several areas that the group could choose to focus on in the coming year. Among these areas were:

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

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

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

Members:
Dan Ratner, University of Washington (NNI)
David Mogk, Montana State University (MONT)
Yves Theriault, University of California San Diego (SDNI)
Sheryl Singerling, Virgina Tech (NanoEarth)
Phillip Strader, North Carolina State University (RTNN)
Daniella Duran, Stanford University (nano@stanford)
Jim Marti, University of Minnesota (MiNIC)
During the past year, the following group members left the K12 working group:

Angela Hwang, Stanford University (nano@stanford)
Maude Cuchiara, North Carolina State University (RTNN)
Terese Janovec, University of Nebraska (NNF)

6.10. Workforce Development and Community Colleges

The working group collaborated with the Evaluation and Assessment working group to create and distribute surveys for non-REU related undergraduate internship programs. The objectives were to evaluate performance of the interns and seek recommendations on how the sites can better prepare their student workers. Separate online surveys were sent during May-June 2021 to the interns and to their mentors/supervisors, respectively. The results of these surveys are provided in Appendix 14.3.

Discussions continued with SEMI regarding potential network-wide collaborations on their SEMI Works program of workforce development for the electronics industry. A virtual meeting on Nov. 11, 2020 was followed up with another on May 6, 2021, at which time SEMI had completed their competency models for various types of positions in the industry, rolled out pilots in NY and NC, and felt ready to start incorporating knowledge/skills in nanotechnology into their competency models. Since then, the program's management has moved from SEMI to the National Institute for Innovation and Technology (NIIT). A virtual meeting was held October 12, 2021 for an update, and to discuss potential next steps for the NNCI to be involved with. (Note: Meetings with SEMI are coordinated through Joe Magno, a member of NNCI's Advisory Board.)

As for activities at individual sites, there continued to be a broad range of events related to work-force development and community college engagement during the past project year despite limitations presented by the COVID-19 pandemic. The following contains highlights from a number of NNCI sites (the listings are not meant to be comprehensive).

MANTH	Conducted processing labs for students in the Intro to Nano course at the Community College of Philadelphia (CCP). Also presented via Zoom a talk on quantum dots to chemistry majors at CCP.
NanoEarth	Virginia Tech again hosted the NanoTechnology Entrepreneurship Challenge (NTEC), with participation from student-led teams including ones from Community Colleges (for additional details, see entry for NNF below). NanoEarth staff also actively engaged industry through interactions with companies such as Micronic Technologies and GeoMat, as well as with the EU-funded NanoFabNet program.
NCI-SW	In the continuing collaboration with Rio Salado College (RSC) in its AAS degree in Nanotechnology, ASU held 5 lab sessions for RSC students. Two students from other AZ CCs participated in NCI-SW's REU program in-person. The site also conducted a survey of technology companies in the metro Phoenix area on hiring needs.
NNF	Multiple SEM and XRF lab sessions were held for students from Central Community College (CCC). A student-teacher team from CCC was selected

	as a winner in the NTEC hosted by NanoEarth, and 2 CCC students were participants in NNF's REU program.
NNI	UW continued its internship program to train student workers in the fab. The 20 student participants include 7 women, 1 Native American, and 2 Hispanics.
SENIC	Two students from Forsyth Technical CC participated in internships at the Joint School of Nanoscience and Nanoengineering.

Members:

Maude Cuchiara (RTNN)
Kristin Field (MANTH)
Dave Mogk (MONT)
Allison Weavil (SENIC)
Steven Wignall (NNF)
Daniella Duran (nano@stanford)
Micah Glaz, Dan Ratner (NNI)
Tonya Pruitt (NanoEarth)
Ray Tsui and Trevor Thornton (NCI-SW)

6.11. Evaluation and Assessment

Over the past year, the Evaluation and Assessment working group developed surveys for student assistants/interns working in facilities (non-REU students) and their mentors. With feedback from the workforce development working group lead and multiple working group meetings, Mary White (NCI-SW) developed the surveys. Members needed to provide feedback because each site classifies their student workers differently and we wanted to reflect all of the different nomenclature used. Additionally, sites emphasis different aspects of the experience and the group also wanted to include questions on the type of climate each facility trains their students in. The working group lead collected email addresses of interns (132) who worked in the facilities from summer 2020 through spring 2021 and their mentors (43, some have multiple mentees). The surveys were distributed via email, with 16% of interns and 44% of mentors responding. Due to personnel changes, Wendy Barnard (NCI-SW) oversaw distributing and collecting survey results. The results are included in Appendix 14.3 of this report.

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

6.12. Technical Content Development

Current Activities

The Technical Content Development working group consists of four NNCI sites: RTNN, MANTH (UPenn), ShyNE (Northwestern), and nano@stanford. Our goal is to develop and share educational materials to support existing users, potential users, and non-traditional users to lower the barriers to entry in our facilities and improve foundational knowledge. All sites have continued to create online resources to support the education of users as well as growth of the user base.

Due to staff changes during the past year, the working group has new members and leadership and convened in early December 2021 to reorganize and refocus.

Future Work

We hope to continue to enhance the collaborative nature of NNCI and universally support sites with their respective training. It is clear that online training is a pivotal part of all sites, especially due to these unprecedented times. Our current goals are to increase awareness and the accessibility of the already existing materials that were developed over the last year:

- webinar focused on how to develop and disseminate online content
- toolkit to help NNCI sites develop their own training content
- library of source materials

In addition, we aim to collect feedback on the quality of the existing materials and support the development of new high-quality content based on network needs.

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

6.13. 4-H

With the renewal of NNCI in 2020, four sites (Cornell, Virginia Tech, Nebraska, and Montana State), committed to working together to interface with 4-H on both a regional and national scale. These 4 sites represent the most "rural" of the NNCI sites and have recognized the leverage that 4-H can provide in reaching a larger community. 4-H is the largest youth development organization in the country, and has adopted a strategy focused on STEM. 4-H is a mission of Cooperative Extension; as such, it is directed in each state out of the Land Grant universities, and through Cooperative Extension has an office and staff in every county in the country.

The 4-H working group consists of members from the above 4 NNCI sites, which are all Land Grant universities and thus 4-H in each of their states is run from an office on campus. This makes interfacing with 4-H at the state level effective and convenient. To date, each site has independently pursued activities with their local 4-H. As with all outreach activities, this effort has suffered considerably due to COVID. We look forward, however, to a return to normalcy, to increased efforts with our state 4-H organizations, and to sharing our experiences with each other.

We have also envisioned interacting on a more national scale, and involving all the NNCI sites in a larger 4-H activity. 4-H has had a weekend STEM focused Youth Academy held at their residential campus in Chevy Chase, MD, and we envisioned NNCI hosting a Nanotechnology themed hands-on weekend for youth from around the country. Unfortunately, with COVID and the subsequent sale of the Chevy Chase campus, these weekend residential events have been terminated. In September 2021, however, 4-H held a virtual national event focused on Space Exploration. Through our discussions with 4-H we were invited to participate in the Space event, with a one-hour activity on nanotechnology. Since it was short, this was handled entirely by Tom Pennell at Cornell and included a video cleanroom tour and a discussion of nanotechnology and nanomaterials, leading up to a hands-on activity related to a "space sail". It was extremely well received. The weekend event finished with a career/question and answer panel session. We were fortunate to have Prof. Mason Peck, Cornell Mechanical & Aerospace Engineering and former NASA Chief Scientist, join in. We plan to use this weekend as a model for a similarly themed, weekend, remote nanotechnology activity either through the National 4-H office or our regional state offices.

Members: Lynn Rathbun (CNF), Tonya Pruitt (NanoEarth), Steve Wignall (NNF), Heather Rauser (MONT), Tom Pennell (CNF)

7. Research Communities

Research Communities are groups of faculty, students, and staff from NNCI sites organized around a particular research topic, national priority, or grand challenge, many of them based on NSF 10 Big Ideas. In contrast to NNCI working groups which are focused on a particular tool or process with the objectives of sharing best practices, the Research Communities are more outward facing helping to develop products that benefit the larger scientific and engineering communities. The current Research Communities are shown in Table 7 along with the lead sites and participating sites. The Research Communities provided an overview of their past and planned activities at the 2021 NNCI Annual Conference, and these can be viewed along with other resources on the Research Community page of the NNCI website: https://nnci.net/research-communities

Table 7: NNCI Research Communities

Research Community	Leader(s)	Participants
Nanotechnology Convergence	Jacob Jones (RTNN)	NCI-SW, SDNI, KY-MMNIN
Nanoscience in the Earth and Environmental Sciences	Trevor Thornton (NCI-SW), Mitsu Murayama (NanoEarth), and David Dickensheets (MONT)	nano@stanford
Nano-Enabled Internet-of-Things	Mark Allen (MANTH)	CNF, SENIC, NNF, KY-MMNIN
TransformQuantum	Andrew Cleland (SHyNE), Robert Westervelt (CNS), Steven Koester (MINIC)	TNF, NNF, NNI, MONT, RTNN, SENIC, CNF
Understanding the Rules of Life	Vinayak Dravid (SHyNE)	MINIC, NNI, MONT, CNF, MANTH, SENIC

Activities of the communities may include:

1. NNCI-sponsored symposia/workshops/webinars
2. Road-mapping exercises
3. Identifying future infrastructure needs

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

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

7.1. Nanotechnology Convergence

The NNCI ***Research Community for Nanotechnology Convergence*** is a collaboration between the RTNN, SDNI, KY Multiscale, and NCI-SW sites. Major individual contributors in 2021 included: Jacob Jones (RTNN), David Berube (RTNN), Maude Cuchiara (RTNN), Trevor Thornton (NCI-SW), Paul Westerhoff (NCI-SW), Kevin Walsh (KY Multiscale), Ross Sozzani (RTNN), Katya Bogomoletc (RTNN), Yuhwa Lo (SDNI), and Yves Theriault (SDNI).

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

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

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

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

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

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

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

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

It was originally envisioned that the specific Research Community topic would be dynamic and change each year. For Year 1, some areas ripe for consideration included:

- Food and Nutrition Security
- Micro- and Nanoplastics in the Environment
- Work Beyond Mass Production
- Additive Manufacturing
- Affordable and Universal Access to Clean Water
- Per- and polyfluoroalkyl substances (PFASs)
- Phosphorus and nitrogen pollution in water resources

The 2021 topic was selected as: **Convergence in Nanotechnology for Food and Nutrition Security**. This was a topic thought to be timely given the food supply chain disruptions and related issues experienced throughout the Covid-19 pandemic, placing the topic at the forefront of minds. It was also a topic that was timely with respect to the announcements of a new NSF ERC on the Internet of Things for Precision Agriculture (IoT4Ag, UPenn lead) and a new NSF STC on Science and Technologies for Phosphorus Sustainability (STEPS, NC State lead). The headquarters of the latter Center, STEPS, includes a 3,000 sq. ft. lab space in a building that is designed to bring together engineers and plant scientists. Thus, new knowledge on how to converge nanotechnology for food and nutrition security could influence how such space is equipped and organized.

A major activity in 2021 involved an event designed to bring stakeholders together and learn more about research community needs (see Figure 6). The event, held March 9 from 10:00 AM until 2:00 PM Eastern time, attracted ~150 registrants and >100 participants who were from academia, industry, government agencies, NGOs, consortia, policy fellows, etc. The schedule included two plenary speakers who were well known in this area:

- Prof. Antje Bäumner, University of Regensburg: "Can distributed nanotechnology as evidenced in new sensor developments enable the advancements required for a sustainable farm-to-fork process?"
- Dr. Hongda Chen, USDA: "Opportunities and challenges of nanotechnology towards sustainable food and nutrition security"

Figure 6: Promotional Material for the March 9, 2021 Event

Five breakout rooms were designed on complementary topics and IRB approval was received to record transcripts for research purposes:

- Water and fertilizer *(for those giving consent for research)*
- Crops and animals *(for those giving consent for research)*
- Pests and pathogens *(for those giving consent for research)*
- Food products *(for those giving consent for research)*
- All topics *(for those **not** giving consent for research)*

PollEV was used throughout the meeting to provide input and perspectives from all virtual attendees, including those who are unlikely to speak up. Moderators of each room facilitated verbal discussion, sometimes launching from incoming pollEV comments. Questions that guided the discussions included:

1. Are you from?: 1) academia, 2) government, 3) industry, 4) other
2. How familiar are you with THIS BREAKOUT SESSION topic? 1) very familiar, 5) not familiar
3. Where do you currently conduct your research/work? (e.g., field work, greenhouses, clinical setting, wet lab, …)

4. At what stage is your work/research? (e.g., basic or applied research, commercialization, manufacturing, other)
5. What ambitious vision do you think should be achieved in the next 25 years?
6. Who are the key stakeholders for this vision?
7. What is the biggest obstacle in reaching these visions?
8. What is highest priority skill that will be needed for future workers in this field/to help reach these visions?
9. How frequently does your lab use open-access shared facilities? (options were provided)
10. Please rate your familiarity with existing shared, open-access facilities and instrumentation that supports research in this specific breakout session area: 1 (no familiarity), 5 (high familiarity)
11. What are **key research gaps** in this breakout area that can be aided by analytical tools, facilities, and infrastructure?
12. Are the **current shared instrumentation and facilities** (including field sites, research greenhouses, pilot plants, etc.) adequate to support **TODAY's needs** in this breakout session topic area? 1) inadequate, 5) very adequate
13. Do current facility personnel (technical staff, research scientists, leadership, etc.) possess the experience and expertise to support **TODAY's needs** in this breakout session topic area? 1) no experience/expertise, 5) extensive experience/expertise
14. Are the **current shared instrumentation and facilities** (including field sites, research greenhouses, pilot plants, etc.) adequate to support **FUTURE needs** in this breakout session topic area? 1) inadequate, 5) very adequate
15. Do current facility personnel (technical staff, research scientists, leadership, etc.) possess the experience and expertise to support **FUTURE needs** in this breakout session topic area? 1) no experience/expertise, 5) extensive experience/expertise
16. What do you see as future needs that are not available?
17. To what extent do facilities need to change their operations to better support this breakout topic? 1 (significant changes needed) to 5 (no changes needed)
18. What is the highest priority need in data sciences, data sharing, data storage, data streaming etc.?

Using Room 4 (Food products) as an example, the respondents' answers to question 12 (whether current shared instrumentation and facilities are adequate to support today's needs in food products) and question 14 (whether current shared instrumentation and facilities are adequate to support future needs in food products) is shown in Figure 7 in histogram format. In both cases, the answer "very adequate" was the least selected option. The most common selected answers were "slightly inadequate" for current needs and "very inadequate" for future needs. **These responses and others (not shown here) suggest that the NNCI can better serve the needs of researchers in these research areas.**

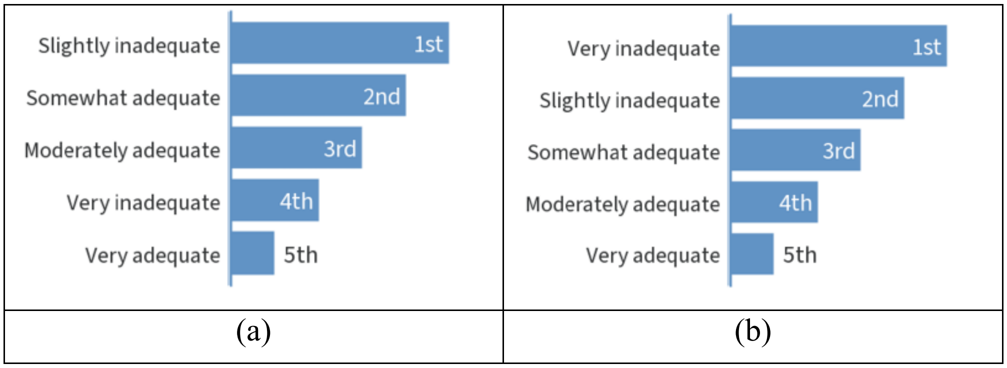


Figure 7: Responses in the Food Products Breakout Session for Questions 12 (a) and 14 (b).

Content analysis of the recorded transcripts is underway by social scientist David Berube (RTNN). In the short term, the two main consensus takeaways by the organizers are:

1. NNCI Could Accelerate Reaching Non-Traditional Disciplines:

- For some attendees, this was the first-ever invitation to provide input to a shared facility
- A shift may be required in promotional strategies, e.g. on serving certain research areas instead of organizing ourselves by specific tools or capabilities
- A "Concierge" mechanism was suggested to effectively liaison with specific non-traditional research communities, e.g. as a staff member or communications specialist
- The NNCI was encouraged to consider how to diversify disciplinary expertise of facility staff, e.g. through hiring practices or offering professional development opportunities to existing staff members to expand into new areas
- The NNCI was encouraged to engage stakeholders from non-traditional areas in future planning, e.g. advisory boards, steering committees or the Research Communities themselves

2. NNCI Could "Go Outside" & Work With Messy Matrices:

- Analytical capabilities are needed "in the field", i.e. on farms, greenhouses, air outdoors, etc. for real-time measurements in dynamic environments (in contrast to bringing samples to NNCI labs)
- New tools and techniques could increase compatibility with the following unusual or messy matrices:
  - Air
  - Soft tissue including living plant roots
  - Soils
  - Water
- "Higher-hanging fruit" would be on-site nanofabrication in the field, e.g. for sensors or functional materials that interact with *specific environments* in intentional ways

The March 9, 2021 event was executed in collaboration with an NSF AccelNet project, AI2EAR: International Collaboration to Accelerate Integration of Engineering, Plant Sciences, and Agricultural Research using Artificial Intelligence (PI: Ross Sozzani, NC State). AI2EAR links international collaborative efforts focused on sensor science, multiscale modeling, and data analytics, particularly through artificial intelligence, to promote strategies to improve yield, reduce crop loss, decrease crop resource demands, and increase food nutrition toward global food security.

AI2EAR involves 14 partnering U.S. and international organizations.

Moving forward into 2022, the following two primary activities are being pursued by the Research Community for Nanotechnology Convergence:

1. Social science research on the March 9, 2021 event continues and involves both content analysis and interviews with experts. A public report will be published once the research findings are complete.
2. In addition to continuing to work on "Convergence in Nanotechnology for Food and Nutrition Security," the Research Community started to advance the topic of "Convergence in Additive Manufacturing and Nanotechnology." This new topic is inspired by, and supportive of, the 2022 NNCI Nano + Additive Manufacturing Summit led by KY Multiscale (https://nanoamsummit.com/). As a multi-site interaction, the RTNN is contributing to the Nano + Additive Manufacturing Summit.

References:

[1] https://www.nsf.gov/news/special_reports/big_ideas/convergent.jsp
[2] https://www.nsf.gov/od/oia/convergence/index.jsp
[3] Frechtling, Gajaray, Schnell, Desai, Silverstein, Misra, and Wells, "Exploring Convergence Research: An Initial Examination of What it Means and What it Hopes to Accomplish," Westat - Clarivate, April 30, 2021.
[4] Roco and Bainbridge, J. Nanoparticle Research, 15, 1946 (2013)
[5] Head, B. "Wicked problems in public policy," Public Policy 3, 101–118 (2008)

7.2. Nanoscience in the Earth and Environmental Sciences

A. 2021 Nano EES-RC Workshop

The inaugural ***Nanoscience in the Earth and Environmental Sciences Research Community*** (Nano EES-RC) virtual workshop was convened May 22-24, 2021. Lead institutions for this event were: MONT (David Mogk, David Dickensheets), NanoEarth (Tonya Pruitt, Mitsu Murayama), NCI-SW (Paul Westerhoff, Trevor Thornton), Nano@Stanford (Kate Maher), and the Science Education Resource Center at Carleton College (Monica Bruckner). This workshop built on earlier workshops sponsored by NNCI to introduce nanoscience to the Earth and Environmental Sciences community (convened by MONT and NanoEarth) at the 2017 and 2018 Goldschmidt Conferences of the Geochemical Society, and an invitational workshop in 2018 that resulted in the publication of a review article in *Science* that already has 245 citations [January 3, 2021; Hochella, et al., 2019, Natural, incidental, and engineered nanomaterials and their impacts on the Earth system. *Science*, *363*(6434)].

The goals of the 2021 Nano EES-RC workshop were to:

- Introduce the geoscience community to new advances and opportunities to do research in nanoscience through the National Nanotechnology Coordinated Infrastructure (NNCI) program.
- Help participants stay current about data, tools, services, and research related to nanoscience.

- Address the "big science questions" related to nanoscience: nanomaterials in the Earth system, impacts on biogeochemical processes, characterization of nanomaterials and their chemical properties at the nanoscale, impacts of nanomaterials (natural and incidental) on the environment and human health.
- Build collaborations; develop research networks to facilitate nanoscience research in the Earth and Environmental Sciences.
- Introduce education outreach efforts for nano-ES.

The workshop program included 20 invited speakers, small group breakout sessions intended to be “listening sessions” to help inform NNCI principals about current and expected community needs, and an optional set of “office hour” sessions that facilitated one-on-one or small group discussions between experts and novices to jump start new collaborations. The virtual format allowed for greater participation and inclusivity for diverse audiences and reached an international audience. All presentations made at the workshop are posted on the program webpage at: https://serc.carleton.edu/nnci_spring2021/index.html.

The workshop was attended by 136 participants. The tables below (provided by the SERC Evaluation Team) demonstrates the profile of participants by institution type, professional role, ethnicity, race, gender and discipline. The workshop was advertised broadly through numerous professional listservs (AGU, GSA, MSA among others), and we did indeed attract a broad audience from the Earth and Environmental Sciences; however, diversity measured by ethnicity and race remains a confounding issue in the Earth and Environmental Sciences, and we must redouble efforts to recruit a more diverse cohort of nanoscience researchers. The workshop was well-received by the participants with aggregated review scores of 3.5-4.0 on a 4-point Likert scale.

Participant Institution Type (n=98)

Institution Type	Counts
Academic	86
Government	10
Commercial	2

Participant Role (n=101)

Participant Role	Counts
Academic Faculty	52
Government Employee	8
Industrial User	2
Industrial User- Small Business	2
Undergraduate Student	2
Graduate Student	22
Other Student	3

Other	19

Participant Ethnicity (n=98)

Ethnicity	Count
Hispanic or Latinx	3
Not Hispanic or Latinx	87
Prefer not to answer	8

Participant Race (n=101)

Race	Counts
American Indian or Alaska Native	1
Asian	25
Black or African American	5
Native Hawaiian or Pacific Islander	0
White	67
Prefer not to answer	9

Participant Gender (n=99)

Gender	Count
Female	38
Male	57
Do not identify as male or female	0
Prefer not to answer	4

Participant Research Discipline (n=101)

Discipline	Counts
Geology/Earth	66
Chemistry	38
Electronics	5
Educational Lab Use	7
Life Sciences	19
Materials	34

Medicine	7
MEMS/Mechanical Engineering	6
Optics	4
Physics	9
Process	6
Other	5

Narrative feedback from workshop participants was quite positive:

- “I got a lot of great information out of the workshop. The only issue was related to the constraints of the virtual format (i.e., not as interactive as an in-person event), but that's by no means any fault of the organizers. They did an excellent job!”
- “A big contribution of the geology to environmental science is integrating what we discover at the nanoscale to the big picture in space and time, and within the complexity of natural systems. For this workshop it is important to focus on the nanoscale, but not lose site of the big picture. The workshop was great. The time flew by, and I look forward to the next one. I also hope that we will have smaller, more focused sessions for particular communities of interest.”
- “Overall, the workshop was well-organized, comprehensive, timely, and personally of great value. In the future, please consider the following suggestions: I realize this workshop was focused on NNCI and its capabilities. Also, I may be wrong, but most of the attendees appeared to be specialists focused on nanoscience or similar fields related to analytical instrumentation. To expand the network of geoscientists who will embrace nanoscience in the future, it is critical to show a wide range of the applications of nanoscience to their fields… Perhaps an extended introductory overview presentation on the applications of nanoscience would attract more people like myself who have to take the basic research, assimilate it, and then apply it to solving practical questions related to people and the environment. As pointed out in the town hall at the end, maybe this approach would be more appropriate at a large geoscience meeting like AGU and GSA. Finally, good work by all of the organizers. Thank you.”
- “The breakout session that I was in was informative as we learned the problems that researches are dealing with.”
- “The most valuable part of the workshop, for me, was meeting people with similar research interest and/or whom work at facilities that understand my nano needs. This really made me feel that I finally have a community with which I can discuss ideas, collaborate, and learn.”
- “Survey of available instrumentation and methods from different labs. Because one can learn what's available and get up to speed on current methods.”
- “…Will be a better collaborator with colleagues in other departments who are already doing nano-research…”

- "In so many ways, such career skills in enhancement, research collaborations and networking"
- "I plan to reach out to some of the experts in the attendance for possible collaboration and joint grant proposals."
- "Networking"
- "I now have many resources to help me develop my nano research/teaching and I'm excited to dive into all of that material. I will also be emailing several people I met through the workshop to continue/start conversations about future collaborations."

B. Additional web-based resources were developed to support the workshop.

- A Nano EES-RC listserv has been established with 225 members who attended any of the series of workshops convened with NNCI support. This listserv is open to new members and is intended as a forum for participants to submit queries and to solicit advice from experts in the Nano EES-RC.
- Additional "primers" or tutorials on Instruments and Analytical Methods Common to Nanoscience have been posted (e.g., Auger Electron Spectroscopy; X-ray Photoelectron Spectroscopy), and additional webpages (e.g., Transmission Electron Microscopy, FTIR) are being solicited to expand this collection. https://serc.carleton.edu/msu_nanotech/methods.html
- A new Registry of Analytical Instruments available in the NNCI and collaborating laboratories commonly used in EES research has been developed. This is designed to be a clearinghouse service a) for lab managers who are seeking to build their user base; b) for researchers, instructors and students to gain access to analytical equipment to support their scholarly work; and c) to build capacity by optimizing the use of existing analytical equipment to support excellence in science and the training of geoscientists. This is more than a list of instruments. Essential information about each instrument and lab is provided including contact information, instrument type, capabilities and limitations, sample requirements, typical applications, and related resources to help a novice user to make informed decisions about whether or not to pursue collaborations. The current NNCI listing does not have a search category for EES, so this new search instrument has the potential to reach a targeted set of new users from across the EES community. The Registry has a simple template for lab managers to enter information specific to their lab and instruments and search capabilities for new users to discover instrumentation available by instrument type or free text searches. This Registry can be accessed at https://serc.carleton.edu/242625.

C. Next Steps for the Nano EES-RC

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

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

- Preparations are in progress for a second annual workshop for the Nano EES-RC, building on the successes of the previous year.

7.3. Nano-Enabled Internet-of-Things

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

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

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

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

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

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

Welcome
Mark Allen, University of Pennsylvania

IoT4Ag
Cherie Kagan, University of Pennsylvania

Impact of Autonomy on Transformative Transportation and Logistics
Kaydon Stanzione, Logistiwerx

Irrigate? Ask the tree! Implantable MEMS to measure plant hydration
Michael Santiago, FloraPulse

Enabling IoNT: Internet of Things Infrastructure
Rick O'Brien, SemperCon

CNF Site Overview
Christopher Ober, Cornell University

SENIC Site Overview
Oliver Brand, Georgia Institute of Technology

MANTH Site Overview
Mark Allen, University of Pennsylvania

NNF Site Overview
Christian Binek, University of Nebraska, Lincoln

KY-Multiscale Site Overview
Kevin Walsh, University of Louisville

Concluding Remarks
Mark Allen, University of Pennsylvania

A total of about 160 unique registrants signed up for the symposium including:

- 78 from MANTH
- 34 from NNCI sites that are part of this research community
- 9 from other NNCI sites
- 39 external to NNCI

- A total of 65 unique attendees signed in throughout the day; typically 30 attendees for any given presentation
- About 80% of feedback respondents rated the content with a 4 or 5 (out of 5). About 90% approved of the format of the meeting.

Video recordings of the event are available at: https://www.nano.upenn.edu/nano-iot-research-community-symposium/

In a follow-up discussion with members, we decided to hold the next Nano-IoT research community meeting (hopefully) in-person on the Cornell campus, hosted by site member CNF.

7.4. TransformQuantum

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

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

To provide a communication center and organizational structure, TQ has pursued the following activities:

- Assembled a website: https://hbar.uchicago.edu/tq/
- Organized workshops dealing with nanofabrication and its implications for quantum hardware;
- Organized a group of researchers from academia, industry and the national laboratories to create a roadmap relevant to this topic.

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

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

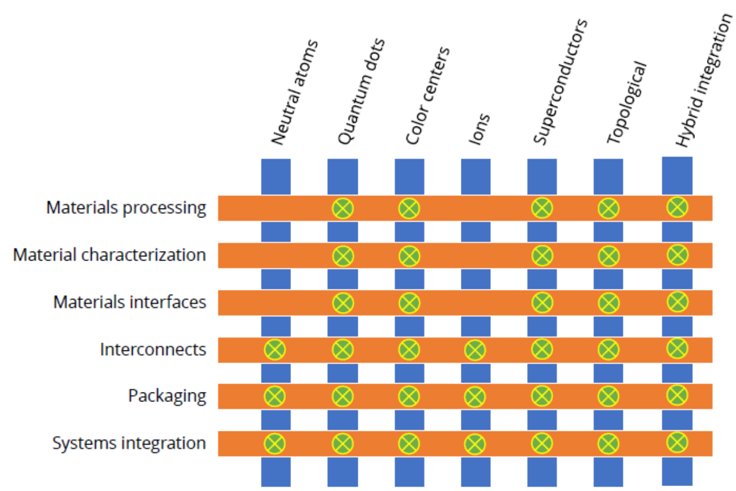


Figure 8: Graphic showing the cross-cutting nature of the technologies that nanofabrication facilities need to be providing to the quantum information community (horizontal rows), for each of the quantum information hardware platforms (vertical columns). Note that while, for example, each hardware platform will need interconnect technology, the specific technology needed will likely differ from platform to platform.

Figure 8 includes a graphic illustrating the range of different platforms and the cross-cutting technologies that impact their development and performance. The radically different needs of each of the hardware platforms makes it difficult to find a generic approach where any given nanofabrication facility can meet the needs of multiple different platforms. Whether facilities will need to focus on just one or two platforms to make significant progress is open to debate.

Partner organizations: TransformQuantum is partnering with other organizations in its effort to forward its stated mission. This includes the NSF NNCI member institutions; the Chicago Quantum Exchange, based at the University of Chicago; the Chalmers University of Technology (Gothenburg Sweden); the Julich Research Center (Julich, Germany); the NSF AccelNet-supported Global Quantum Leap (PI Steven Koester, University of Minnesota), which has put together a network-of-networks including TransformQuantum; ML4Q, a Germany-based network including Aachen, Cologne and Bonn; OpenSuperQ, a European-wide collaboration to build a superconducting quantum computer; NIMS, the Nanotechnology Platform Japan, based in Tsukuba; and EuroNanoLab, a Europe-wide distributed research infrastructure based in INSIS-CNRS, Paris.

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

Workshop on quantum engineering infrastructure: One notable event that involved TransformQuantum and its members was an NSF-sponsored workshop on quantum engineering infrastructure, organized through the NSF-funded Global Quantum Leap program mentioned above. This workshop was held virtually from April 13-15, 2021. It had over 400 participants; with over 20 presentations, including overview presentations from each NSF NNCI node, with pairs of presentations on a number of hardware platforms being developed for quantum information applications, including color centers; superconductors; ions; spins; and topological qubits. These presentations were followed by hardware-specific breakout sessions, each run by a moderator and including a panel of experts, with reports back to the main workshop following these sessions.

A post-workshop report was prepared for the NSF on the main conclusions and take-aways from this workshop; the report is available in PDF format on both the TransformQuantum and Global Quantum Leap websites. The report provides a summary of the workshop goals, summaries of the presentations, principal conclusions from the breakout sessions, and recommendations for accelerating/advancing quantum capabilities via the NNCI nanofabrication network. The key takeaways from the workshop, as summarized in the report, are that:

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

- Uniform and accepted characterization methods for quantum devices

Roadmapping: TransformQuantum is also engaged in developing a quantum roadmap, including specific roadmapping for each hardware platform. Led by Chris Ober (Cornell), Vlad Pribiag (UMinn), and Steven Koester (UMinn), we have identified a panel of experts in each of five hardware platforms, and are working to build a larger panel covering more areas. The goal is for the panel to generate a first draft roadmap by 2023 and develop a more complete and comprehensive roadmap by 2025. The plan is to publish the roadmap in an archival journal to make it accessible to a broad range of researchers and program managers. Table 8 shows the current makeup of the panel, which continues to be developed.

Table 8: Roadmapping panel of experts covering different hardware platforms, with the goal of developing a comprehensive roadmap for nanofabrication as it relates to quantum information science.

Platform	Person	Institution	Partner?
Organizer	*Vlad Pribiag*	*UMN*	----
Organizer	*Christopher Ober*	*Cornell*	----
SC	Heike Riel	IBM	No
SC	Jonas Bylander	Chalmers	Yes - OpenSuperQ
SC	Mark Nelson	Skywater	No
SC/Topo	Valla Fatemi	Yale	No
Topo	Vlad Pribiag	UMN	Yes - NNCI
Topo	Sergey Frolov	U Pittsburgh	No
Topo	Chris Palmstrom	UCSB	No
Topo	Srijit Goswami	QuTech (Delft)	Yes - CQE
Trapped ion	Patty Lee	Honeywell	No
Spin	Ruoyu Li	IMEC	No
Color Center	Shangying Cui	HRL	No
Color Center	Greg Fuchs	Cornell	Yes - NNCI

7.5. Understanding the Rules of Life

Research communities are meant to provide for a forum and a platform for the NNCI community in order to engage in a unified theme such as some of the "NSF's Big Ideas". ***Understanding the Rules of Life (RoL)*** is one such "NSF Big Ideas" that was unveiled in 2016. RoL is one of the 10 bold, long-term research and process ideas that identify areas for future investment at the frontiers of science and engineering. The Big Ideas represent unique opportunities to position the United States at the cutting edge of global science and engineering by bringing together diverse interdisciplinary perspectives to support convergence research.

RoL is about understanding how living organisms work at a fundamental molecular level, then building new artificial organisms. Design and synthesize artificial molecules that nature did not think of making. Create complex systems, such as novel bioelectronic systems, based on these new synthetic molecules. Thus, RoL is a multifaceted, multilevel and complex interdisciplinary theme that encompasses numerous technical and scientific fields as well as connects with numerous social and humanities undertones.

SHyNE Resource has the initial undertaking to formulate the RoL theme as a research community within NNCI, given its emphasis on "soft" and soft-hard interface issues. The RoL RC has initiated its work to identify the breadth of opportunities in this work and has attempted to put a reasonable framework for subsequent activities. The RoL technical scope is considerable, spanning not just biological and biomedical topics but how "life" connects to broader society at large.

Progress, Update and Plans

SHyNE Resource has initiated and formed the RoL research community which has been accelerated recently with the launch of a new RoL research community website, https://sites.northwestern.edu/rulesoflife/. and ownership of this activity by Dr. Mobarhan, who is the Senior Director of Operations for the SHyNE Resource.

The RoL research community convenes leading academic researcher centers, top scientific facilities, and the most innovative industry partners in the world to advance the science and engineering of RoL science. In doing so, our mission is to inform the public, train the next generation of scientists, engineers, educators, entrepreneurs, and business leaders, and drive the RoL economy. The RoL research community facilitates interactions between member institutions and partners, and provides an avenue for collaborations, joint projects, and information exchange.

While discussions will continue into 2022, the RoL RC has identified three major themes for focus for the NNCI wide activities. These three areas are:

1. Synthetic Biology, with a focus on "road-mapping" for infrastructure and facility needs
2. "Seeing and Sensing the Invisible", spanning sensing, diagnostic and imaging fields
3. Outreach and Workforce Development for RoL.

The RoL RC believes that these three themes may form the centerpiece on which other topics may anchor in the future. As part of these three themes, we plan to undertake periodic activities and meetings in order to address the NNCI role in these emerging areas of opportunity.

For example, we plan to organize several RoL related NNCI "webinars" that would be presented during the coming months and throughout 2022. These seminars are the most effective way to bring together everyone from all NNCI sites, and to get them excited about RoL. Building a strong NNCI RoL coalition is important and these seminars will help achieve this objective.

These seminars will also be a very powerful tool in generating new leads for potential new users of the NNCI facilities. In fact, this is the most effective way to draw the attention of potential new facility users to the NNCI organization and their facilities, and in doing so to increase the number of our users.

We hope that in the year 2022, we see more activities on the part of the various NNCI sites in the area of RoL. The RoL research community shall strive to encourage and to lead these activities and to rally the activities and the efforts of the NNCI group around the RoL initiative.

8. NNCI Network Promotion

8.1. Marketing and User Recruitment

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

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

Discussion:

Facility managers were surprised to hear repeated comments such as: "I didn't know this (*fill in the equipment/capability)* existed on campus." As well as ignorance to facility existence!

We should be doing continuous internal marketing including:

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

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

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

Sites had some of the same challenges that impact usage:

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

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

Sites also had some very unique challenges:

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

Ideas for increasing external users:

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

<u>Action Items:</u>

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

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

1. *Represent the network at national conferences.* While normally the Coordinating Office would have hosted a booth at conferences such as TechConnect or MRS, this activity was suspended in 2020 and 2021 due to pandemic-related travel restrictions.

2. *Provide an NNCI website with tools and expert databases.* At the January 2017 NNCI Conference, there was significant discussion about the website and a desire to present a more applications-focused user experience. During the first year of its existence (2017), the website contact forms generated approximately 25 inquiries related to becoming a new user, education/outreach, or other general information, and this increased to 75 inquires during 2018-19 but decreased in 2020-21. Any potential users are referred to NNCI sites for follow-up, and we have recently begun tracking of outcomes in order to assess the efficacy of this user recruitment mechanism. More discussion of the website is provided below.
3. *Create an NNCI email list.* During 2017, a listserv was created for subscription by all interested NNCI site staff to share information on site activities, as well as provide another mechanism for sites to solicit assistance on technical and user support matters. Currently there are more than 130 subscribers to this email list with approximately 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.* This is currently under discussion.

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 have been added during Years 3-5.

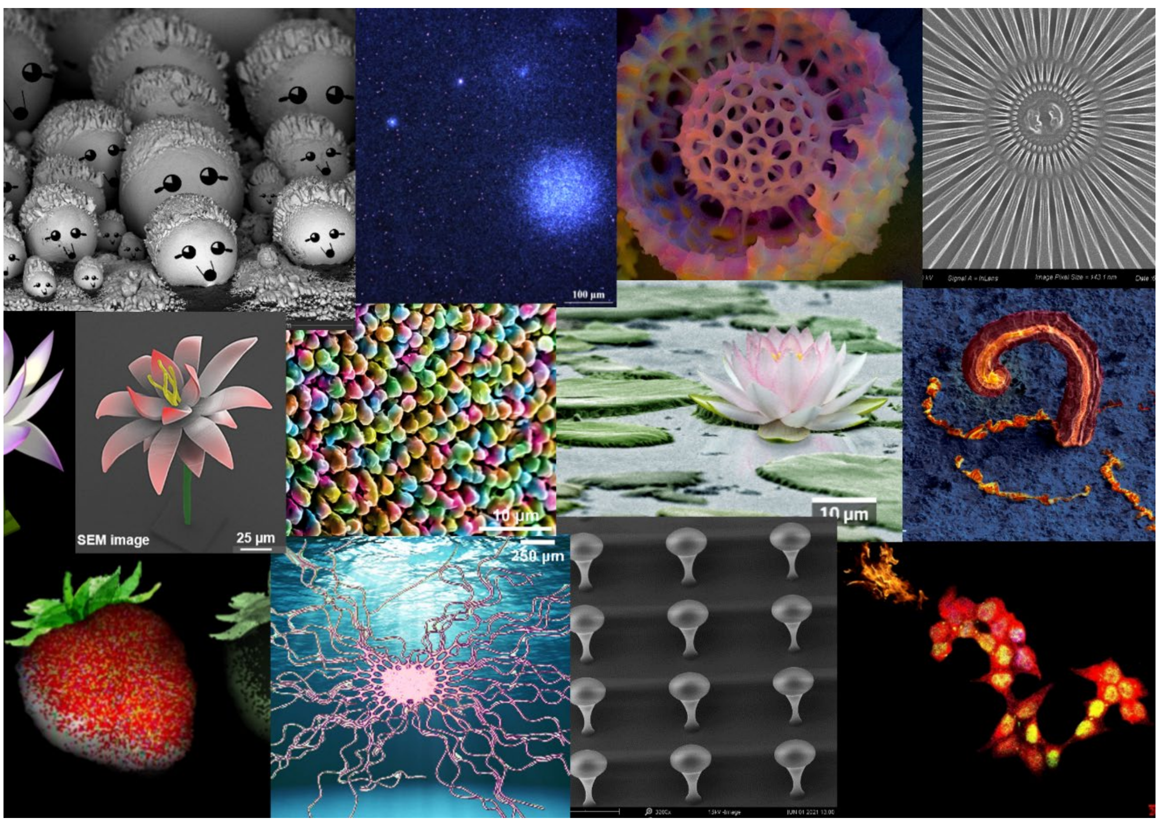
The NNCI Introduction Video was produced at the end of 2017 and publicly released in February 2018. It was posted to the NNCI home page with the 2019 upgrade. The YouTube URL is https://youtu.be/72ZXh-ESt3U. As of Dec. 31 2021, the video had been viewed more than 1,800 times. During 2021, the NNCI YouTube channel was added to the home page, and more details on this are provided later in this report.

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

1. News items on the blog (16 news items in 2021)
2. NNCI Annual Reports
3. NNCI Annual Conference agendas and presentation materials
4. NNCI On the Road (list of upcoming NNCI site presence at meetings and conferences)
5. K-16 Educator Resources
6. Technical Resources, including Research Communities and Audio/Video content
7. Home page news spotlights
8. Updates to site pages
9. Backend improvements, changes, and bug fixes

During the past year (Year 6), the only significant upgrade made to the NNCI website was limited to combining the previous two contact forms into a single form. The Spanish language form was not altered. Since December 2016, the website contact forms have received nearly 500 inquiries (2 per week on average). In recent months, much of the contact has been "spam", however. In those cases where contact is genuine, inquiries are forwarded to the appropriate site for action on technical requests, or to the Coordinating Office education and outreach director for answering questions related to those matters. On the backend, the website was migrated from our old hosting platform (Pantheon) to a new one (Platform.sh) due to issues with receiving the contact page submissions.

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 was repeated in 2020 and again in 2021, with public voting open during Oct. 8-15, 2021 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 were described in the Education and Outreach report in Section 4.1.



Google analytics for www.nnci.net indicate that in calendar year 2021 there were more than 59,500 visitors to the website, a 28% increase over the prior year. As in previous years, a large spike in visitors was observed in October, primarily to participate in the image contest voting. For the year, 90% were new visitors with 43% from the United States (down from 50% the previous year). There were nearly 113,000 pageviews, which is an 8% increase from the prior year. The average session duration was slightly more than 1 minute, with an average of 1.6 pageviews/session, a small decrease compared to 2020. During this time period, the top ten pages visited are shown in Table 9 below. Significant differences this year include large numbers of views of education-related pages ("what is nano" and "how small is nano" pages), consistent with previous year's observations, increases in views of the image contest pages (since they were reconfigured), and decreased viewing of the REU pages (likely due to continuing limitations on some of the 2021 programs).

Table 9: NNCI Website Page Visits (2021)

Page	# Pageviews in 2021	%Change from 2020	% Pageviews in 2021
/	15,456	22.70%	13.72%
/how-small-nano	11,871	47.21%	10.54%
/careers-nanotechnology	10,418	5.24%	9.25%
/what-nano	8,422	6.61%	7.48%
/plenty-beauty-bottom	4,597	25.09%	4.08%
/nature-helps-nanotechnology	3,574	1.10%	3.17%
/research-experience-undergraduates	3,321	-7.18%	2.95%
/sites/view-all	3,011	-5.05%	2.67%
/nnci-image-contest-2021-whimsical	2,347	100.00%	2.08%
/nnci-image-contest-2021-stunning	2,340	100.00%	2.08%

Since the NNCI website's debut in late 2016, the growth in annual visitors and pageviews is shown in Figure 9 below.

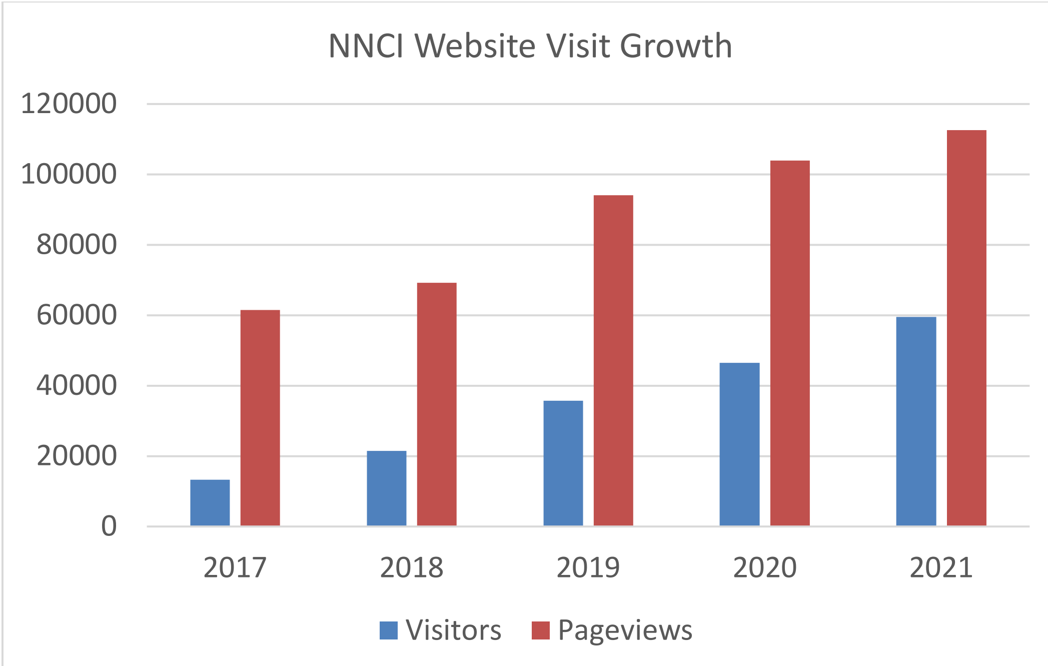


Figure 9: Growth in Annual NNCI Website Usage

Site acquisition (how visitors get to the website) is primarily through four routes: organic search, direct, referral from another website, and social media (see Figure 10). The organic search rate of 64.8% showed a slight decrease this year after several increasing years (67% in 2020) while direct acquisition increased to 29.2% (from 25.2% in 2020). Both modes showed increases in overall number of visitors compared to the previous year.

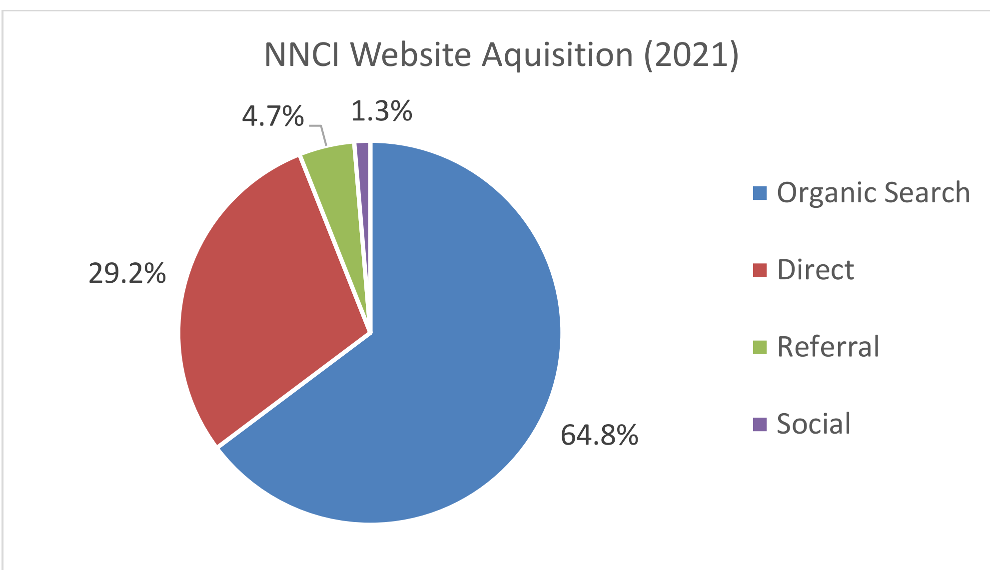


Figure 10: Site Acquisition (how visitors get to the website) for www.nnci.net (2021)

The geographic distribution of visitors to the website is illustrated by the map in Figure 11 below indicating the nearly complete global reach. The top ten locations of visitors are shown in Table 10.

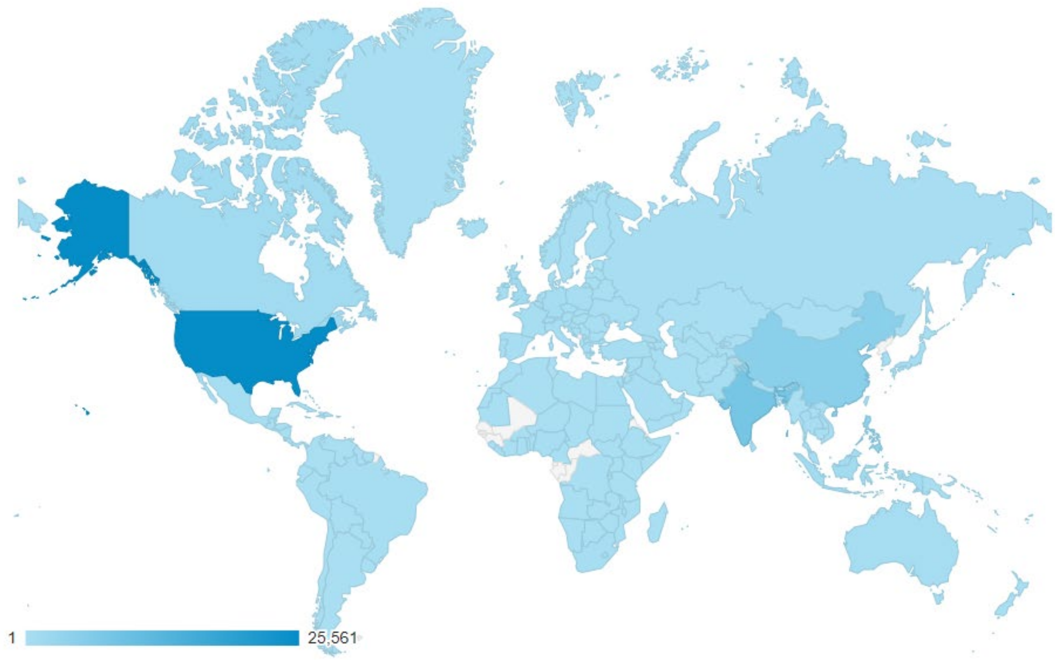


Figure 11: Geographic Distribution of Visitors to www.nnci.net (2021)

Table 10: NNCI Website Visitors by Location (2021)

Country	# Visitors	% Visitors
United States	25,561	42.72%
India	7,844	13.11%
China	4,798	8.02%
Philippines	4,016	6.71%
Canada	1,282	2.14%
United Kingdom	1,163	1.94%
Indonesia	1,058	1.77%
Sri Lanka	684	1.14%
Malaysia	595	0.99%
Germany	568	0.95%

A further examination of the US locations of website visitors (Figure 12) not surprisingly reveals that the highest densities are in states with NNCI facilities (California, Texas, Virginia, New York, and Pennsylvania are the top 5) although all 50 states are represented.

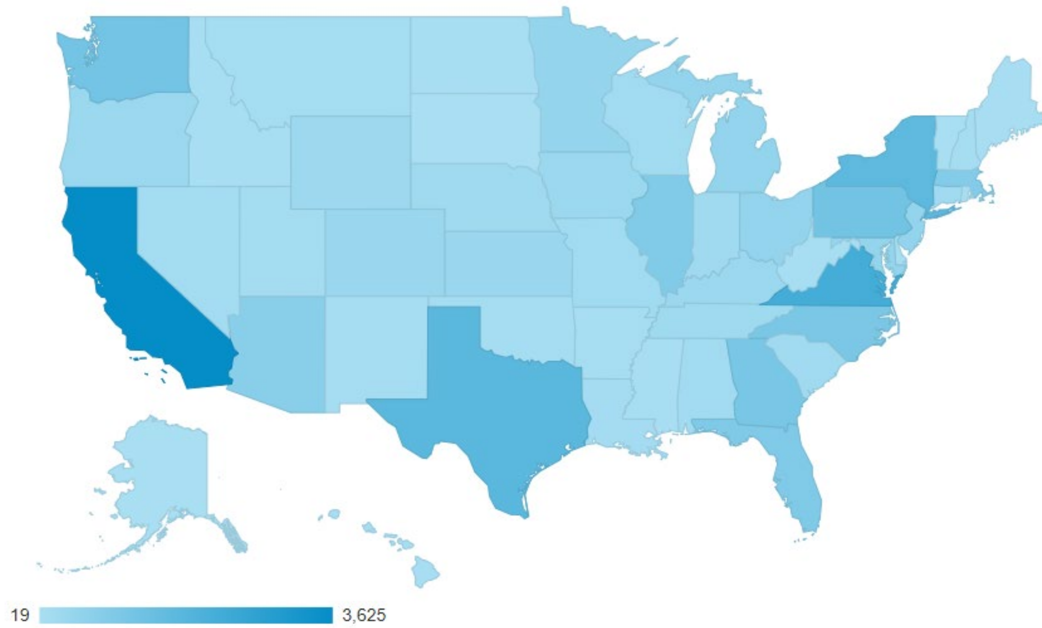


Figure 12: US Distribution of Visitors to www.nnci.net (2021)

A Google search analysis indicates that searches resulted in 3.45 M *impressions* (how many times an NNCI website page appeared in the search results) and 41.8K *clicks* (when someone selects an NNCI website page) during the 2021 calendar year. While the number of impressions is a slight increase, the number of clicks is a slight decrease, compared to 2020. However, both of these metrics are improvements over 2019. Some change in these statistics may have occurred due to the hosting platform change as noted above. While overall this resulted in a 1.2% *CTR* (click through rate) and an average *position* (position of the particular page in the search results list) of 15 (16 in 2020) in the results list, the top query terms (Table 11) produced much better performance including many searches with most nnci.net pages in the top 5 positions and CTR above ~10% (bold entries). While it is obvious that "nnci" and "national nanotechnology coordinated infrastructure" would produce the most direction to the NNCI website, most of the other queries are generic questions about nanoscale materials and structures as well as interest in careers/jobs in the field. There are several queries regarding molecular (water) size this year, which was not the case previously and it is unclear why this might be the case. The query for "entrevista a un astronauta" directs visitors to a Spanish language edition of Nanooze (Issue 9) about nanotechnology in space that includes an interview with an astronaut.

Table 11: Google Search Queries (2021)

Query	Clicks	Impressions	CTR	Position
nanometer	1,889	318,612	0.6%	5.2
nnci	**1,713**	**5,006**	**34.2%**	**1.2**
nano	676	225,203	0.3%	10
what is nano	645	25,963	2.5%	5.4
water molecule size	639	13,406	4.8%	1
size of water molecule	517	10,318	5.0%	1.1
nanotechnology jobs	244	4,541	5.4%	6
size of a water molecule	162	3,856	4.2%	1
molecule size	160	6,114	2.6%	3.9
size of molecules	158	4,913	3.2%	3.8
what are other examples of nanostructures	158	1,958	8.1%	2.5
examples of nanostructures	**151**	**1,263**	**12%**	**2.5**
what are other examples of nanostructures?	149	1,773	8.4%	2.5
nanotechnology careers	**145**	**1,477**	**9.8%**	**2.7**
nanometers	136	41,584	0.3%	5
energy transfer worksheet pdf	**126**	**820**	**15.4%**	**4.9**
how big is a water molecule	121	6,484	1.9%	1.1
nanotechnology in nature examples	**113**	**271**	**41.7%**	**1**
national nanotechnology coordinated infrastructure	**109**	**192**	**56.8%**	**2**
entrevista a un astronauta	**106**	**1,104**	**9.6%**	**3.9**

8.3. User Satisfaction Survey

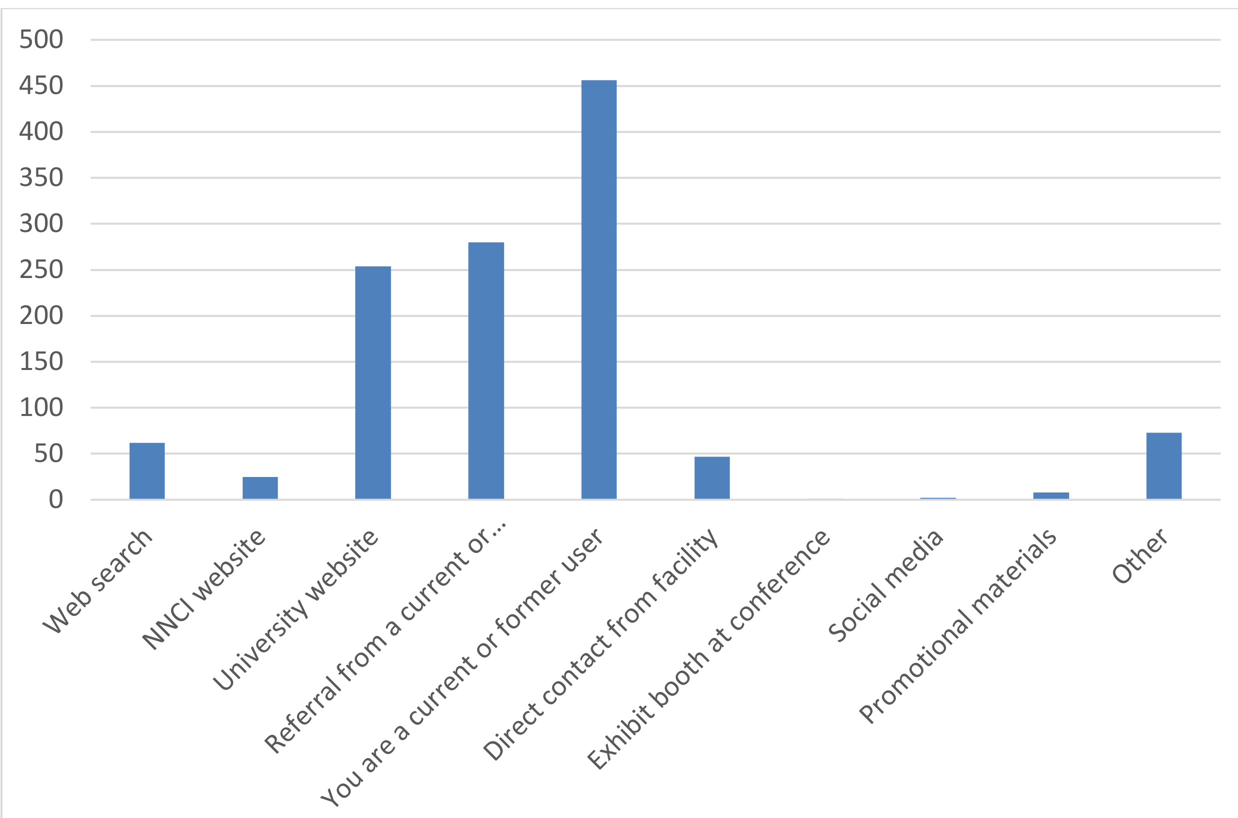
As a result of site director discussions, as well as recommendations from the Advisory Board, the Coordinating Office created a User Satisfaction Survey for implementation throughout the NNCI network. Using a *Survey Monkey* platform, the survey was first made available to sites for forwarding to their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

For the 2019 NNCI User Survey, significant changes were implemented based on recommendations from professional evaluators at Arizona State University (Mary White) and Montana State University (Carolyn Plumb). This same survey was used for 2020, with the addition of a new question regarding use of resources specific to the COVID-19 pandemic, and this version was very slightly modified for the 2021 survey shown below. All sites were encouraged to use the common survey vehicle when possible, and 14 sites had respondents to the common survey while the remaining two sites provided their own data for inclusion (N=950). Not all data were combined from the survey data submitted by these two sites, so the N is reduced for those questions. The site-specific filtered results, with comments, were provided to individual sites for identification of action as needed.

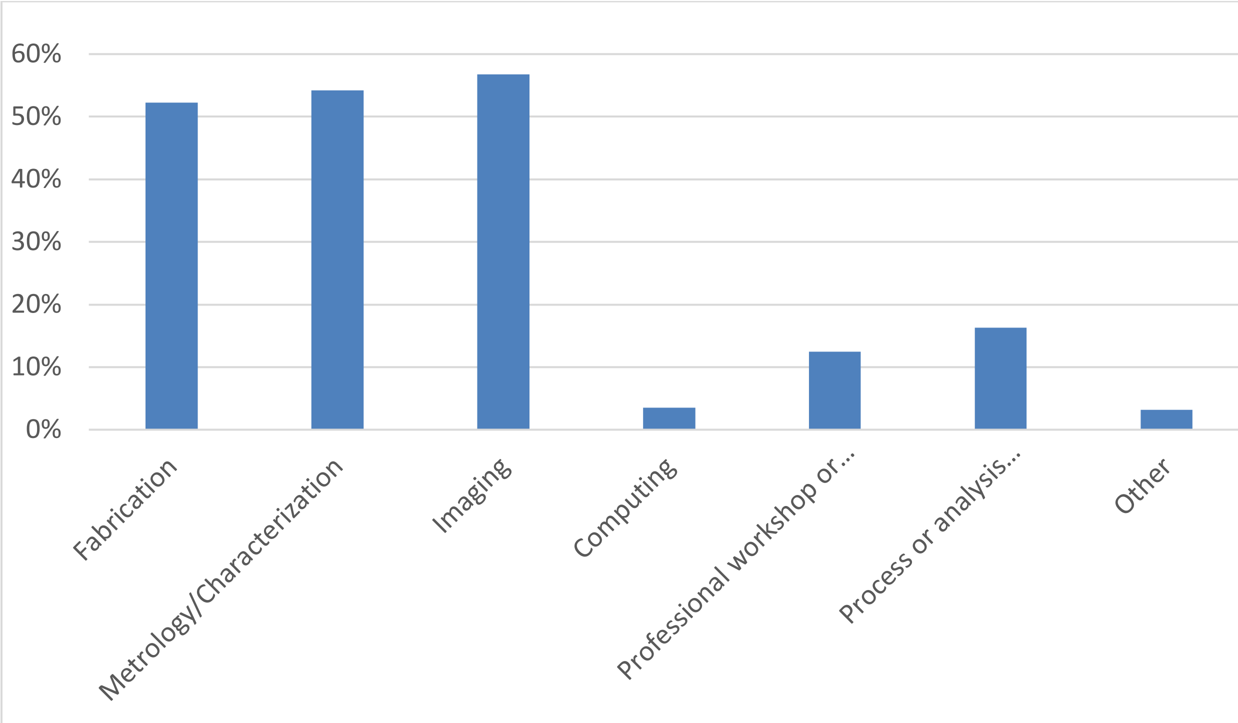
The NNCI facility that was primarily used during the previous 12 months.

The number of responses from each site varies from 15 to 238 (mean=59.4). In this year's survey, users were not asked if they used more than one NNCI facility during the past year although we know anecdotally that this number typically is around 5% of users.

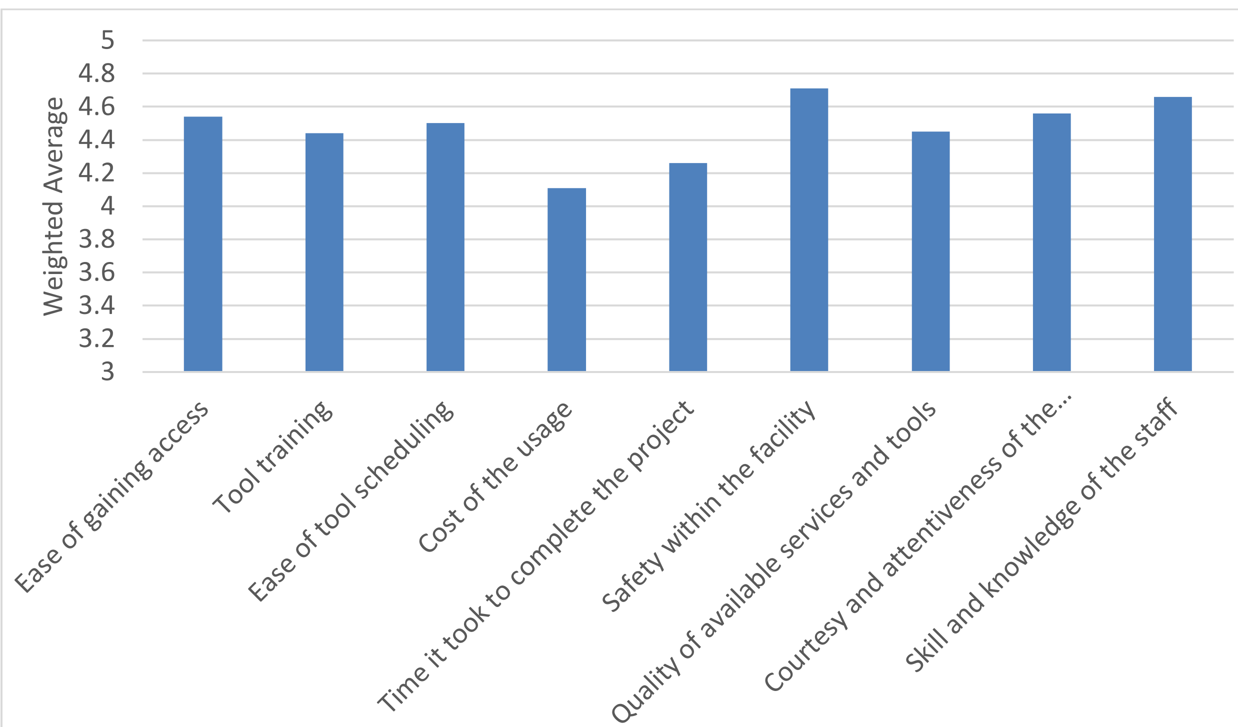
How did the user find out about the NNCI facility? (N=921)



Which services were used at the NNCI facility? (N=950)

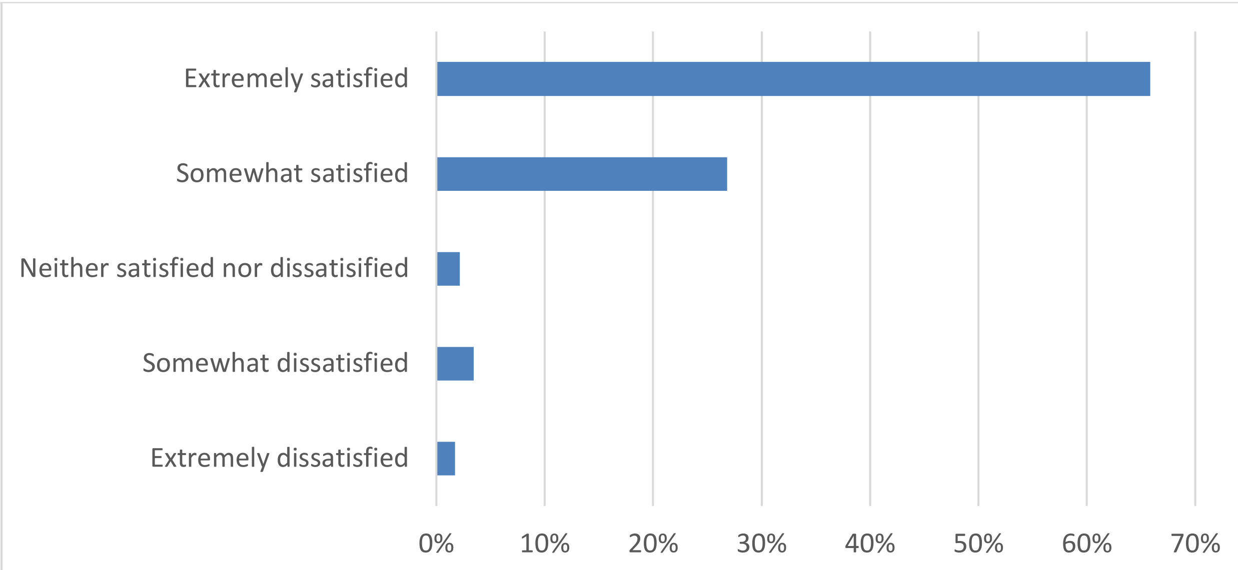


Regarding this NNCI facility, rate your satisfaction with the following (N=694; Scale=1-5, 1=extremely dissatisfied, 5=extremely satisfied)



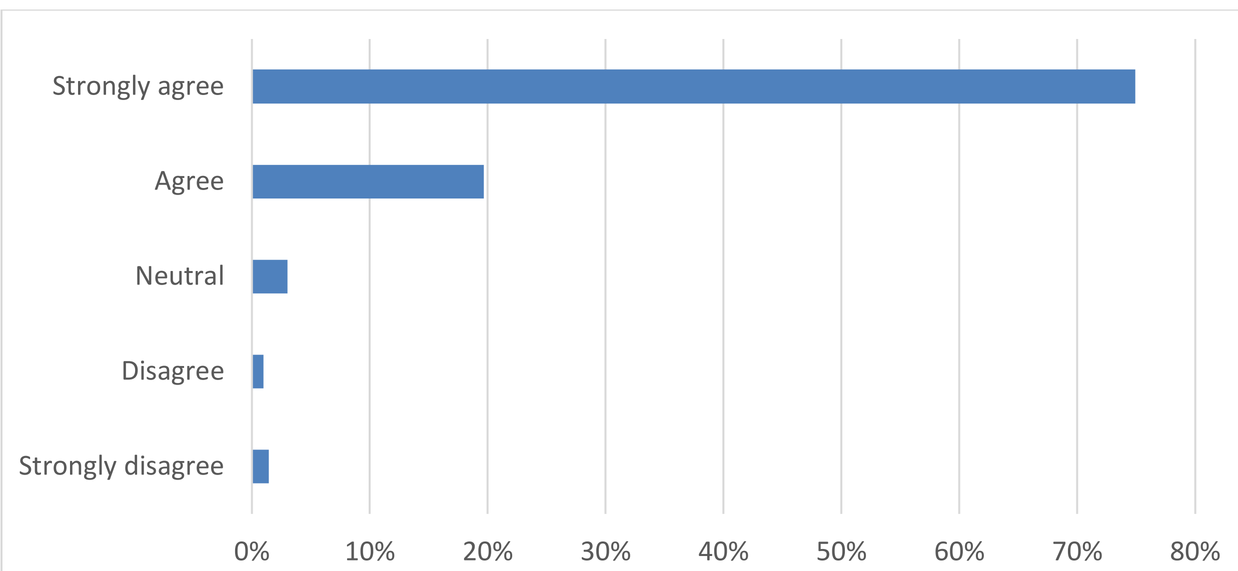
Rate your overall satisfaction with this NNCI facility (N=950)

For all NNCI sites, the average overall satisfaction rating is 4.50/5. For the common survey (N=697), the detailed ratings are as indicated below, with 92.5% of respondents indicating either somewhat or extremely satisfied.



Rate your agreement with this statement: This NNCI facility has had a positive impact on my project goals or research activities (N=697, this question was only asked on the common survey)

This question was newly asked in 2021, with 94.5% of respondents agreeing or strongly agreeing with the statement.



Would you recommend this NNCI facility to a colleague? (N=913)

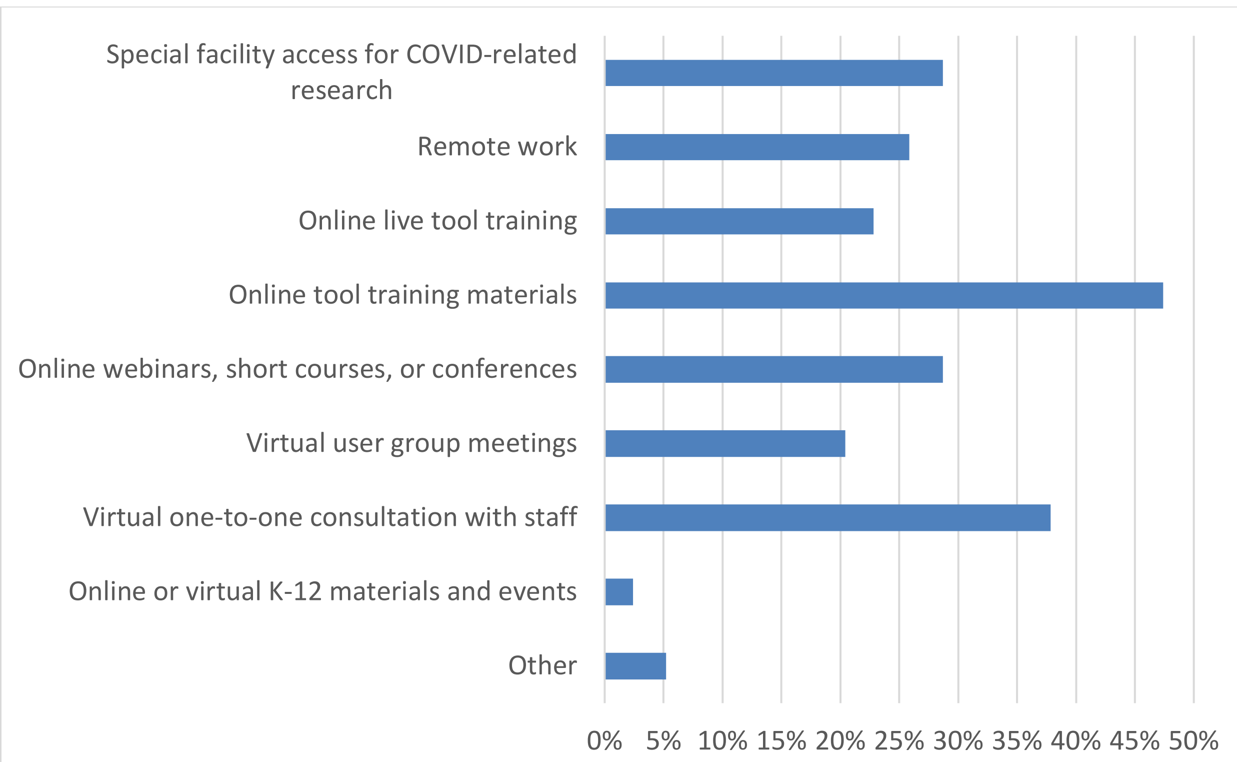
Yes: 97.5%

No: 2.5%

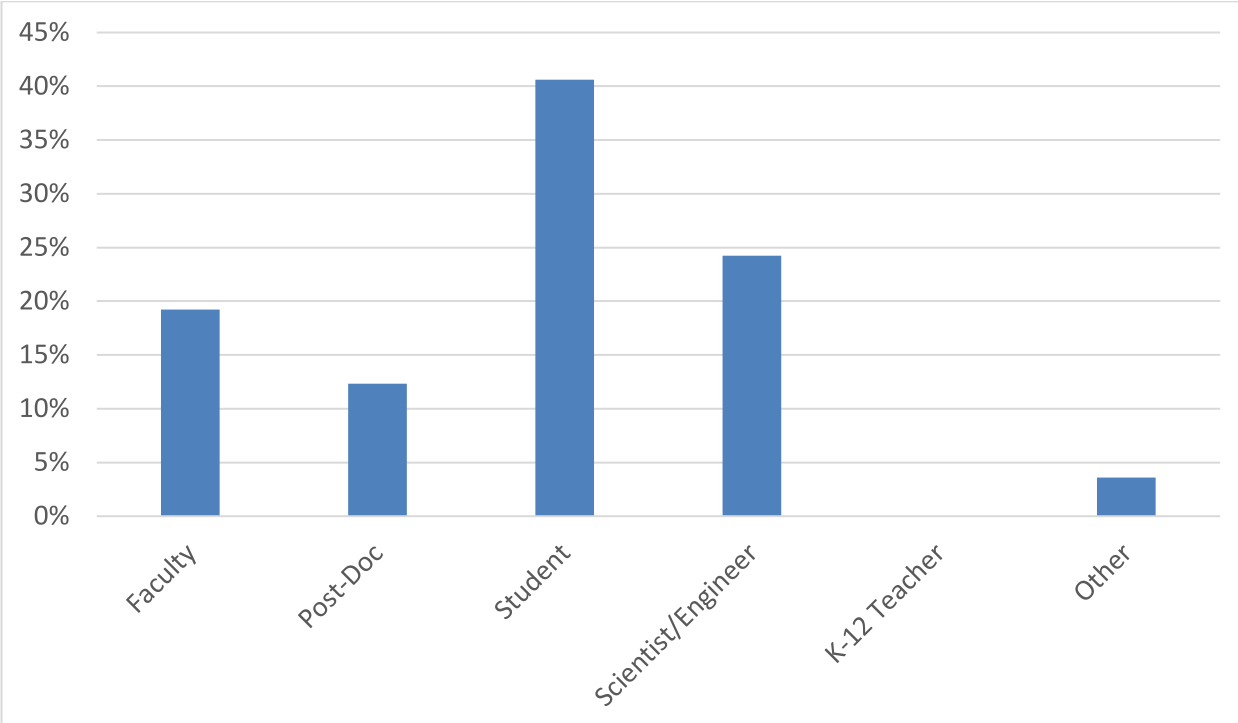
If you have any recommendations for specific new tools or services at this NNCI facility, please indicate them.

More than 170 suggestions were received and provided to the sites. Examples include characterization tools like TEM, FIB-SEM, XRD, XPS, and light microscopy, and fabrication tools such as lithography stepper, ion milling, redundant etching systems, newer E-beam lithography, and laser machining. In addition, users suggested more remote work options, improved scheduling system, and increased staff.

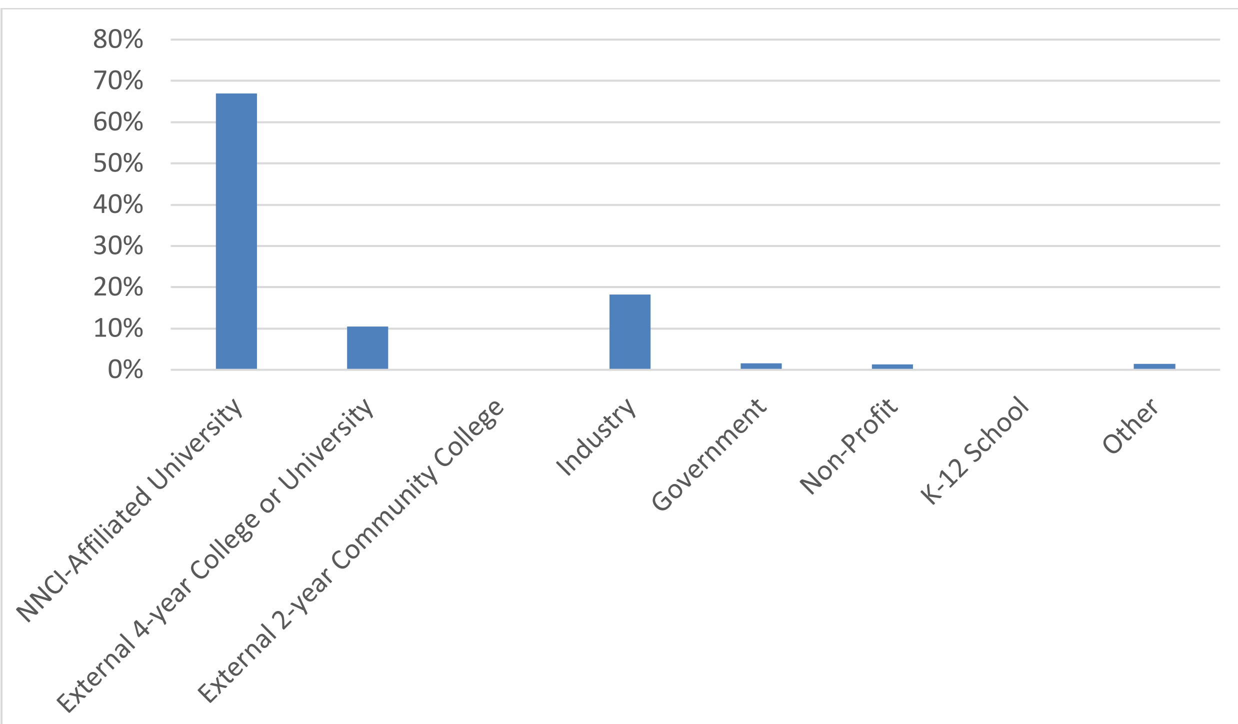
Which of the following resources offered by NNCI facilities did you use during the COVID-19 facility closures and current reduced operations periods? (N=460, this question was only asked on the common survey)



User Position (N=697, this question was only asked on the common survey)



User Affiliation (N=697, this question was only asked on the common survey)



Note that this distribution somewhat mirrors the actual user affiliation distribution for the NNCI network as a whole (see Section 11.1, Figure 24) suggesting that the survey is probing a reasonable cross-section of NNCI users.

In addition to responses to the survey questions noted above, nearly 80 individual free-text comments were provided, both positive and negative, and a selection of these is provided here (specific facility names removed):

Covid was very challenging but I appreciate that the safety of staff and users was the first priority.

The staff at … are excellent and deserve high praise and raise. They are very considerate when interacting with students and faculty and I really appreciate their expertise.

I represent a small business located near the NNCI user facility; we simply could not execute at least 50% of our current federal and commercial contracts without the support of the technology and expertise that is made available by this facility. The value of the … to our business (both commercial endeavors and our published research) cannot be overstated!

Overall excellent resource for R&D projects. However training quality and device upkeep are sometimes inconstant between tools. Despite this we will certainly continue to use the facility for prototyping.

The staff at this facility works very hard to keep the tools and space functional and accessible. I have been very impressed with the dedication and work ethic of the staff.

The facility has been a little difficult to access because of limited visitor parking, and on-campus visitor rates have recently tripled. Please look into allowing frequent industrial users of the facilities to purchase University parking passes.

I really appreciate everyone trying their best during this weird time, however I found tool training as a new student during COVID to be quite confusing. It was tough to hear the trainers behind face shields and machine noise. The printed SOPs next to tools aren't always updated. It wasn't clear to me who to contact about different things while getting started.

The staffing level in the cleanroom is excellent. The staff in the scanning probe facility (1 person) and characterization facility (2 people) are high quality, but overtaxed. The staffing is insufficient, substantially slowing down research, leading to frustration and many missed opportunities.

It has been a pleasure working with the staff at … . They are very responsive and helpful. We have used them for a few years to perform chemical analysis on our products for specific projects. The analysis is performed in a timely fashion, pricing is good, and the reports are thorough. We will continue to utilize the … and recommend them to others who may have similar needs as well.

9. NNCI Annual Conference (November 2021)

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

After holding the 2020 Annual Conference virtually, it was hoped that the 2021 meeting would be held in-person at Northwestern University. While plans and organization progressed over the summer of 2021, it became clear that travel would continue to be restricted or difficult for many throughout 2021, so the sixth annual NNCI Conference was again held virtually. The meeting continued to be organized and hosted by SHyNE with assistance from the Coordinating Office and was held November 2-3, 2021 (12-5 pm each day). The 2-day event had a registration of 178, including senior representation from every site (all 16 site directors); 7 of 9 advisory board members; 12 NSF officials including NNCI Program Officer Dr. Larry Goldberg; Dr. Lisa Friedersdorf, Director of the NNCO; as well as an invited speaker (see screen shots below). At its maximum, actual attendance was approximately 150 people.

An invited lecture was presented by Prof. John Rogers, Director of the Querrey Simpson Institute for Bioelectronics on the topic "Methods for Forming Three Dimensional Mesostructures and for Using Them in Unusual Devices."

The agenda also featured:

1. Remarks from Dr. Larry Goldberg (NSF Program Manager for NNCI) and Dr. Lisa Friedersdorf (Director of the National Nanotechnology Coordination Office, NNCO).
2. Presentations by the Director and the four Associate Directors of the Coordinating Office with an NNCI Overview and Reports on Education & Outreach, Societal & Ethical Implications, Computation, and Innovation and Entrepreneurship.
3. Short site reports from each of the 16 NNCI sites. To assist with the organization and flow of these reports, each site was requested to answer one of four questions related to their activities over the past year:

- What was your main challenge during Year 6 and how did you overcome it?
- What new program did you introduce during Year 6?
- What impactful research emerged from your site during Year 6?
- What steps did your site take to improve on diversity and equity during Year 6?

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

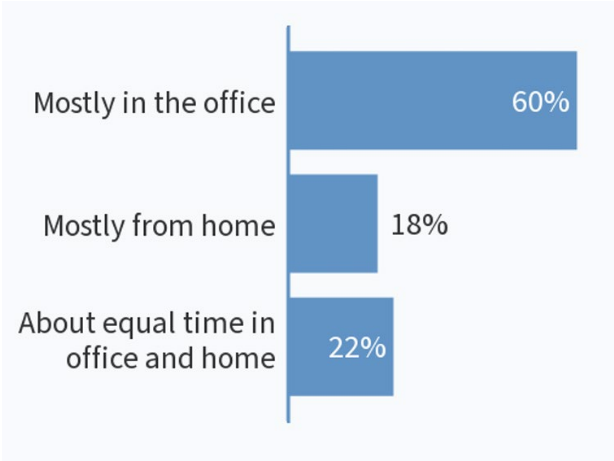
4. Six breakout groups in 2 sessions moderated by NNCI leaders:
   - Future of NNCI after 2025 (Debbie Senesky, Mary Tang)
   - Innovation & Entrepreneurship (Matthew Hull, Yves Theriault)
   - Diversity, Equity, and Inclusion (Bill Wilson)
   - Education and Outreach Multisite Activities (Quinn Spadola)
   - Facility Management and Operations (Walter Henderson, Nasir Basit)
   - Current Trends and Near Futures in Federal Science Funding (Jamey Wetmore, Mitch Ambrose, American Institute of Physics)

   Each session leader was asked to provide a written summary for distribution to attendees, and these are also included in Appendix 14.2 of this report.

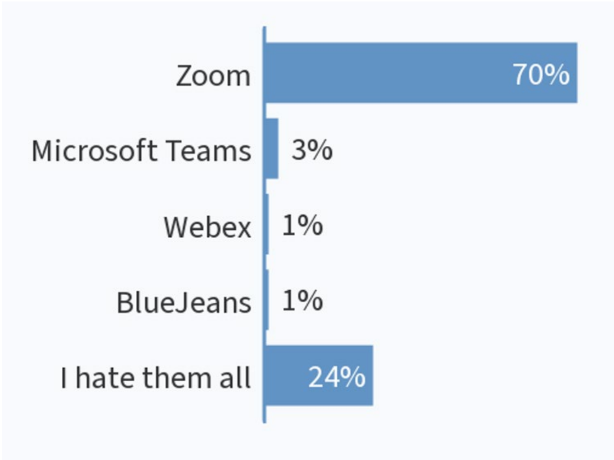
5. Research communities provided summaries of their past and planned activities:
   - Nanotechnology Convergence
   - Nano Earth Systems
   - Nano-Enabled Internet-of-Things
   - Quantum Leap
   - Understanding the Rules of Life
6. A separate meeting of SEI coordinators was held the week before the main meeting.
7. Staff awards were presented with details provided in Section 10.3 below.
8. A private meeting of the External Advisory Board. These discussions resulted in a written report to the Coordinating Office which is attached here as Appendix 14.1.

Using the Poll Everywhere platform, the Coordinating Office conducted live polling during the conference asking the following questions with responses provided:

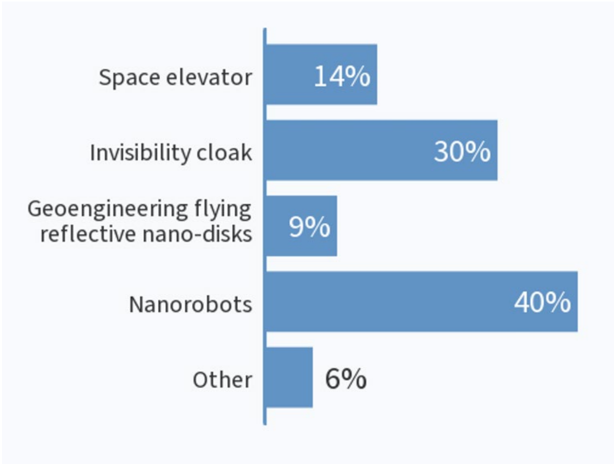
What is your current work arrangement (N=92)?



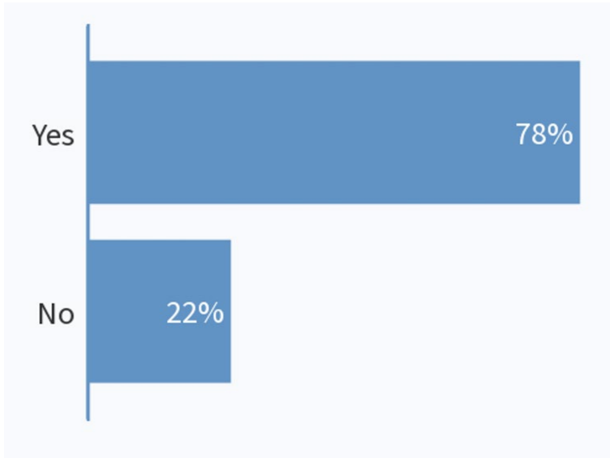
What is your favorite video-conferencing platform (N=94)?



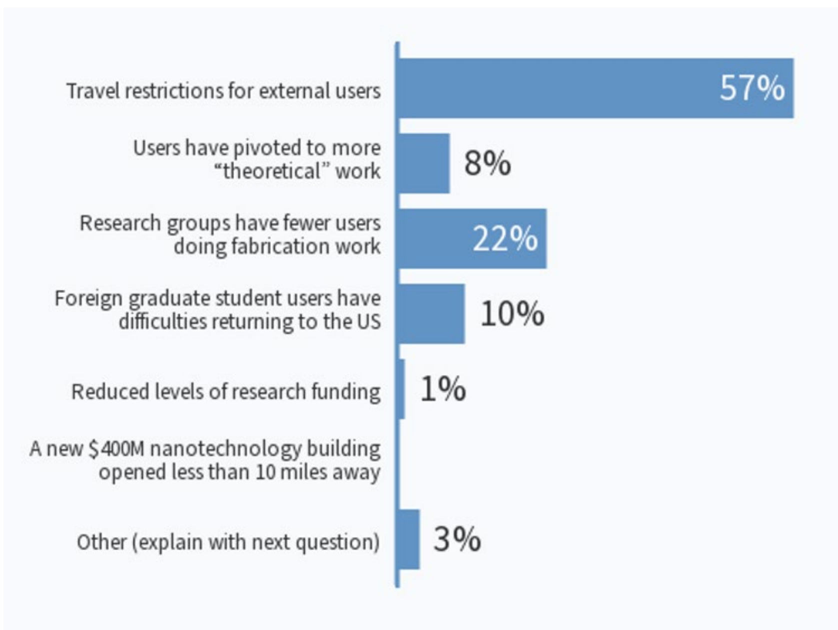
What is your favorite futuristic nano-enabled technology (N=97)?



Should we immediately start a sixth Research Community in the area of "Semiconductors" or "Microelectronics" (N=89)?

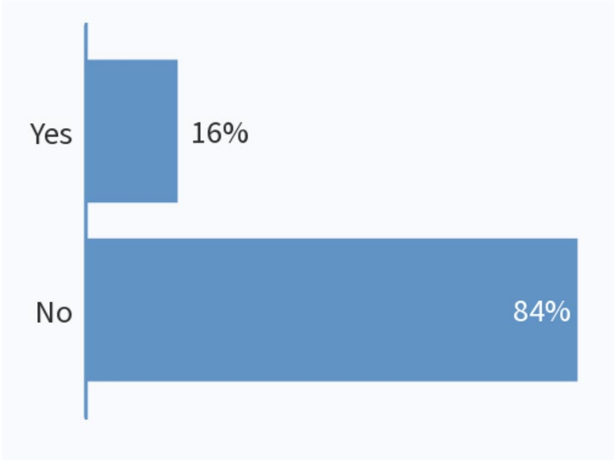


What do you see as the main reason for the reduced NNCI user numbers during Year 6 (N=93)?

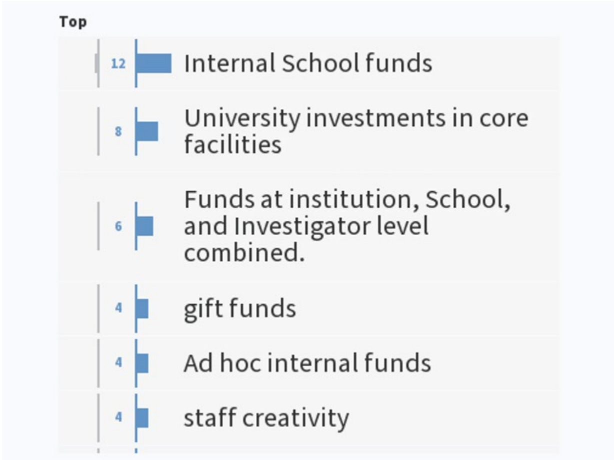


"Other" responses: Limited access to housing facilities, Caution about making major commitments, External industrial users have resource concerns - business slowdowns, Access to their own personal labs, Habits changed, Changing state and campus rules, Personal safety, Local site restrictions, Business uncertainties, PIs establishing own capability as an alternative to core facilities, State/regional authority restrictions

Do you have ways/funds to replace aging workhorse tools in your facility (N=70)?



If "Yes", what is the source of funds (top answers, by order of popularity)?

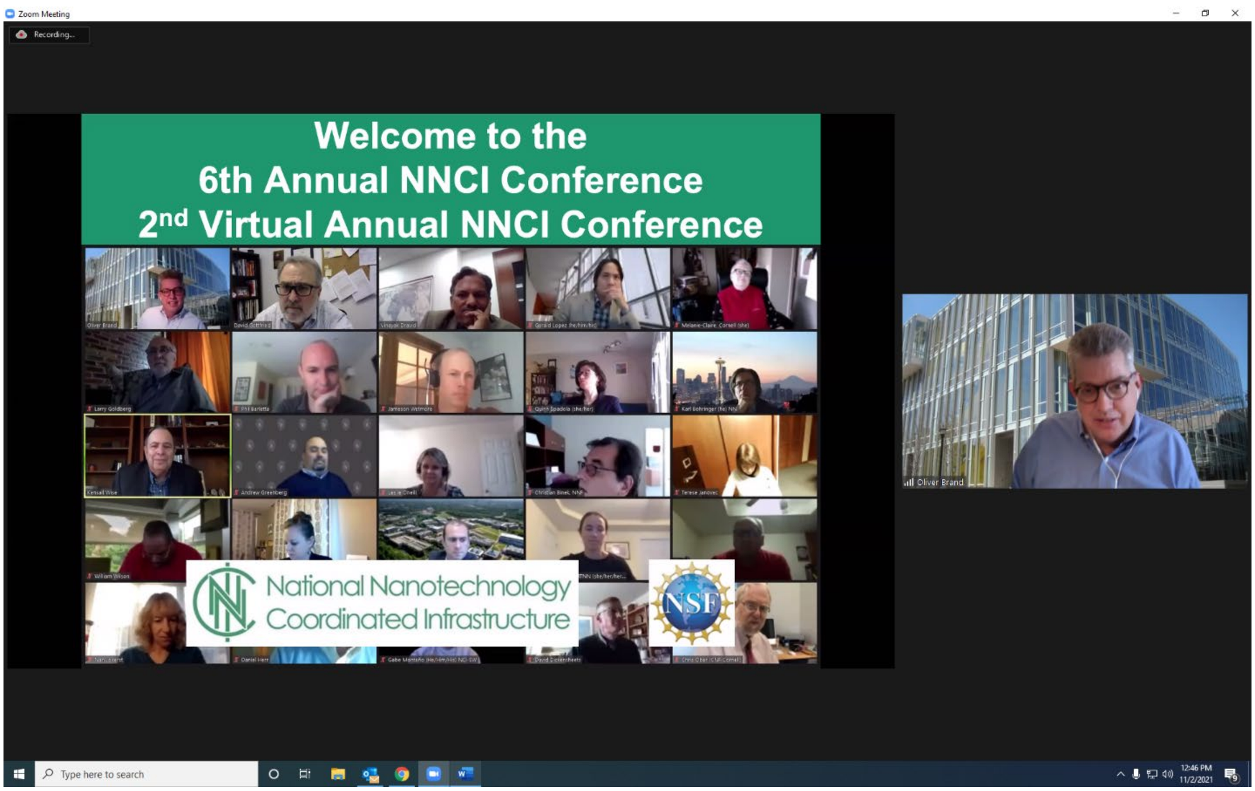


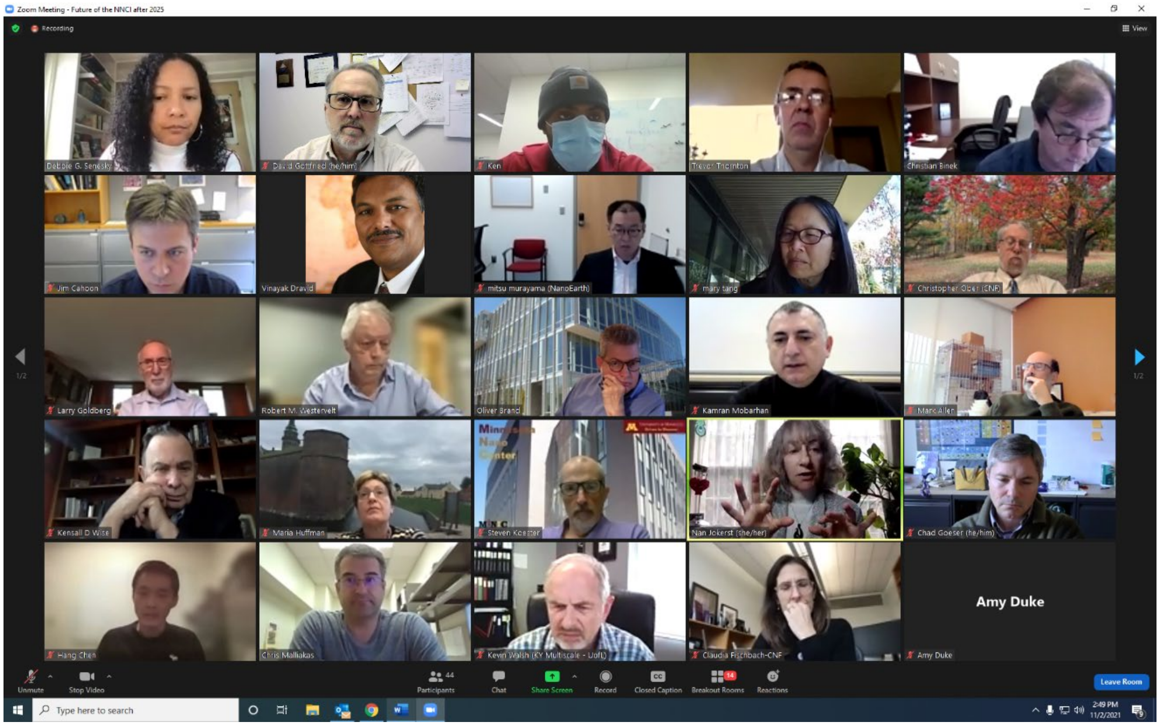
What's your site's biggest challenge? What keeps you up at night (N=36, top answers by order of popularity)?

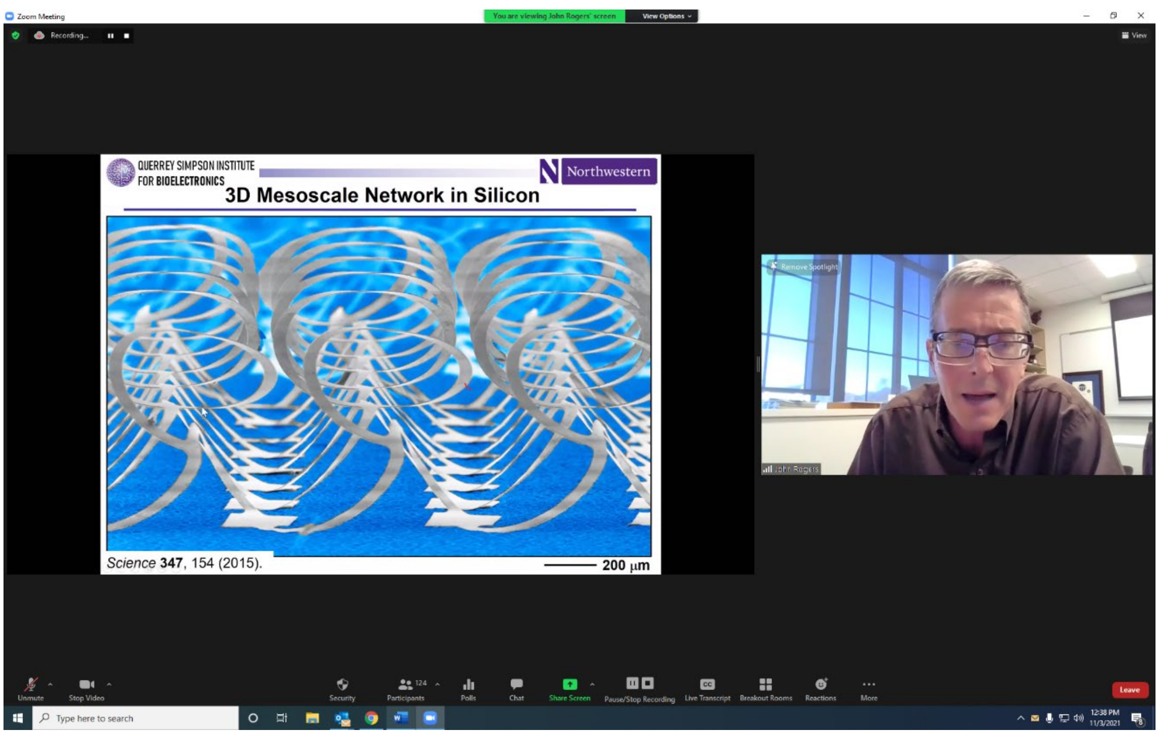
Do you know a start-up company that has used (or is using) your facility and that now has grown into a billion-dollar business? Please provide the company name. (N=17)

- Stratio Inc.
- Inpria
- Carbon
- J2 Materials
- Pacific Bioscience
- Sila Nanotechnologies

The Coordinating Office presentations, site reports, and research community summaries are provided, along with the full meeting agenda, on the NNCI website at https://nnci.net/nnci-annual-conference-2021. Selected screen shot images from the conference are shown here.







The next NNCI Annual Conference is scheduled to be held at Cornell University (CNF) on October 19-21, 2022.

10. Network Activity and Programs

10.1. Cooperative Network Activity

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

Network-Wide Activities

1. Participation in monthly NNCI site director meetings
2. Participation in monthly NNCI education and outreach coordinators call
3. Chairing and membership of Subcommittees
4. Leading and membership of Working Groups resulting in shared reports and best practices
5. Participation in National Nanotechnology Day Activities. Thirteen NNCI sites submitted entries for the "Plenty of Beauty at the Bottom" image contest in 2021. RTNN hosted a collaborative Take-Out Science Broadcast with SDNI, CNF, and NNI.
6. Attending NSF Nanoscale Science and Engineering Grantees Conference. The December 2021 conference was held virtually, co-chaired by Dan Herr (SENIC) and Bill Wilson (CNS), with presentation on the NNCI by Kevin Walsh (KY Multiscale).
7. Attending NNCI Annual Conference (November 2021)
8. Participating in NNCI REU Convocation (Hosted virtually in Aug. 2021 by the CO)
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 (see more information below)

Multi-Site Activities

1. Hosting and participation in NNCI supported or sponsored workshops and technical events (host site in parentheses), not including individual seminars and webinars:
    a. Nano Convergence Research Community Workshop on "Nanotechnology for Food and Nutrition Security" (Hosted by RTNN with NCI-SW, SDNI, and KY Multiscale, March 9, 2021).

b. NSF/NNCI Workshop on Quantum Engineering Infrastructure (Co-organized by MiNIC and CNF, April 13-14, 2021). A series of conclusions and recommendations for establishing a quantum fabrication infrastructure within the NNCI were formulated and are included in the final report which is posted on the NNCI website.

c. Nano Earth Systems Research Community Nanoscience in Earth and Environmental Science Virtual Workshop (Organized by NanoEarth, NCI-SW, MONT, and nano@Stanford, May 24-26, 2021)

d. Nano-IoT Research Community Symposium (Hosted by MANTH, with CNF, SENIC, NNI, and KY Multiscale, September 29, 2021).

e. The Nano-engineered Systems Seminar, offered weekly since 2019 as a forum for nanotechnology researchers at UW, switched to a virtual format in autumn 2020 and now alternates between speakers from UW and OSU. The seminar was offered jointly throughout 2021 (NNI).

f. Oliver Brand (SENIC) gave the fall 2021 Distinguished Practitioner in Nano-engineered Systems seminar on "Evolution of Mass-Sensitive Chemical Sensing Platform" and Vinayak Dravid (SHyNE) gave the spring 2021 Distinguished Practitioner in Nano-engineered Systems seminar "Towards 'Swab to Signal' in Few Minutes for Covid-19 Diagnostics" at UW (NNI).

g. 2021 Advanced Lithography UnSymposium/Direct-Write UnSymposium at Stanford (nano@stanford).

h. 2020 NNCI Virtual Etch Workshop (nano@stanford, CNF, CNS).

i. 2021 Raman Universe Virtual 5-part Workshop at Stanford (nano@stanford, in collaboration with Horiba Scientific). This event attracted 300+ attendees from various sites all over the world.

j. NNCI Education Symposium (Sept. 24, 2021): SDNI organized a symposium with the theme "Integrating Nanotechnology Contents with State-Wide K-12 Science Curricula: Challenges and Strategies". The meeting included presenters from 5 NNCI sites (nano@stanford, NanoEarth (Virginia Tech), SENIC (Georgia Tech), MANTH) as well as MNT-EC, Penn State, NNCO, San Diego County Office of Education, Valencia High School, Kearny High School, and around 50 attendees from local schools and equipment vendors.

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. This has been especially important this past two years due to limitations imposed by pandemic restrictions. Examples include:

   a. CNF interactions with MANTH and CNS.

   b. While MANTH repaired one of its CVD furnaces, CNF supplied MANTH researchers with SiN films grown at Cornell.

c. The nano@stanford site supplied MANTH with two 25-wafer lots of doped poly-Si on oxidized wafers again this year, filling in a gap in capabilities. These wafers are used for laboratory fabrication courses that use the MANTH cleanroom.

d. SDNI worked with partner sites at SHyNE and MANTH to leverage NNCI resources to enable a challenging dry etch fabrication project with JPL on the fabrication of Starshade mask for detection of earth-like planets by NASA.

e. SDNI staff facilitated a 3-way collaboration between SDNI, a startup company, Obsidian, and Georgia Tech for LWIR focal plane array.

3. Staff technical interactions:

   a. MANTH and CNF organized a "Joint Procurement Agreement" regarding facemasks and COVID supplies.

   b. MONT had user/technical interactions with MiNIC, NNI, NNF, and NanoEarth facilities.

   c. Georgia Tech (SENIC) continues to collaborate with Montana State University to implement facility management software at the MONT site, leveraging the extensive application development and applying it to the much smaller installation there.

4. NSF-funded Research Experience for Teachers (RET) program lead by Georgia Tech, with Northwestern, Univ. Minnesota, and Univ. Nebraska. These four universities from across the NNCI network support 20 high school/community college faculty each year in a 6-week summer research experience, with follow-up support during the school semesters.

5. Partnership in the NSF AccelNet project "Global Quantum Leap" (GQL) (MiNIC is lead, with CNF, SENIC, SHyNE). GQL establishes an international network-of-networks linking the NNCI to quantum networks in Asia and Europe. The GQL has launched a webpage (www.globalquantumleap.org), Twitter, and LinkedIn pages. The GQL has expanded to add two new international partners, EuroNanoLab and QCS Hub (UK), and has launched the first two of its international exchange programs: an International Research and Training Experience (IRTE) program at NIMS in Tsukuba, Japan and a summer internship program with the ML4Q network in Germany.

6. North Carolina Collaborations: To support outreach efforts in rural areas, RTNN collaborates with volunteers from JSNN, part of the SENIC site. Carolina Science Symposium is an annual joint symposium organized by RTNN facilities and staff with considerable collaboration/participation from JSNN (SENIC). RTNN and JSNN are both active members of the North Carolina Center for Innovation Network (NC COIN). RTNN and SENIC users have used each other facilities, when their tools have been under repair/maintenance, and JSNN staff and users have participated in RTTN and industry co-organized instrument and/or technical workshops. JSNN is a collaborative partner in NC State's NSF STC "Science and Technologies for Phosphorus Sustainability Center (STEPS)" and Duke's NSF AccelNET program "International Network for Researching, Advancing, and Assessing Materials for Environmental Sustainability (INFRAMES)".

7. SDNI had 3 remote SEM sessions in collaboration with SENIC (Nov. 2020) for a school in Atlanta, GA. This was an outcome of a collaboration with the Georgia Tech Nanotechnology

Summer Institute for High School Teachers where SDNI helped in providing scanning electron microscopy sessions.

8. Sharing of best practices:
    a. Regional facility networks such as Northern Nano Lab Alliance (MINIC), Southeastern Nano Fabrication Facility Network (SENIC), and Mid-Atlantic Region Cleanroom Facility Managers (MANTH) have continued. The NNI and MONT sites have initiated a joint effort to create the Northwest Nanotechnology Laboratory Alliance (NWNLA), a regional platform for exchange on laboratory experiences and best practices, NCI-SW has organized the Southwest Nano-Lab Alliance (SW-NLA), and RTNN Affiliates Network connects RTNN with other facilities in the Research Triangle in North Carolina.
    b. Nano Summer Institute for Middle School Teachers (NanoSIMST): This weeklong workshop, originally developed by Stanford, was implemented in 2021 at NNF, SDNI, and SENIC, virtually or in-person. In addition, due to a personnel change, 15 teachers selected by nano@Stanford also participated in SENIC's virtual NanoSIMST. Nano@Stanford plans to continue offerering NanoSIMST each summer as a virtual workshop to further expand the reach of the program beyond the standard areas reached by NNCI sites.
    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. NNCI REU joint mentor training and REEU entrepreneurship seminars.
9. Participation in SEI Programs:
    a. The SEI program hosted a half day workshop shortly before the NNCI annual conference in 2021 to share best practices, and the SEI leaders at the different sites have met to discuss issues and give each other feedback.
    b. Jamey Wetmore is working to coordinate 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. Berube and Youtie are both developing complementary toolkits for assessing the impacts of NNCI sites, Kahlor will be hosting and sponsoring an SEI engagement workshop designed to help get participants from across the NNCI up to speed on SEI efforts, and Wetmore will be redesigning the Science Outside the Lab program to train each participant as SEI ambassadors who can take what they've learned in the program back to their home institutions.
10. NCI-SW, RTNN, NNF, SDNI, Stanford, and SENIC participate in the Nanotechnology Applications and Career Knowledge (NACK) Network's Remote Access Instrumentation in Nanotechnology (RAIN) coordinated by Penn State University.

11. Several sites 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).

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

1. CNF publishes "Nanooze", and, in addition to direct distribution to classrooms, distributes it to all NNCI sites for use in their outreach activities.
2. Georgia Tech (SENIC) maintains the current NNCI website. RTNN receives requests from the Spanish language "Contact Us" form and responds to all inquiries made via this method.
3. CNF manages the iREU program that affords a second-year research experience abroad from among the highest rated REU interns from the previous summer. CNF has submitted an NSF proposal for continued iREU funding.
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 partnership with Jim Metzner with 5 new programs developed for the "Pulse of the Planet" radio show. "Pulse of the Planet" is heard on over 265 NPR radio stations by 1.1M listeners per week and is available as a podcast on Stitcher and iTunes.
6. Hosting of NNCI Annual Conference (virtual) by SHyNE (Nov. 2021)
7. KY MMNIN hosts the UGIM website and several NNCI staff are members of the UGIM Steering Committee (Aebersold (KY MMINI), Cibuzar (MINIC), Clay (MANTH), and Tang (Stanford)).
8. The SENIC SEI program developed two impact toolkits (economic impact, publications analysis) that were shared with all NNCI sites.
9. SDNI has developed the Integrated Photonic Education Kit (IPEK) as the first plug & play didactic toolkit that enables hands-on experimental integrated photonics for education institutes. SDNI is in the process of disseminating the kit on behalf of the NNCI to promote convergence research involving photonics technologies.
10. David Gottfried (CO and SENIC) and Matt Hull (NanoEarth) are partners in the EU Horizon 2020 funded project NanoFabNet and Quinn Spadola (CO and SENIC) is a partner in a sister project SUSNANOFAB. Both projects aim to develop hubs for sustainable nanofabrication.
11. Leading breakout sessions during the NNCI Annual Conference.

10.2. New Initiatives

As part of the NNCI site renewal process (Years 6-10) during 2020, all sites proposed new programs and activities that build on their previous successes and demonstrated needs in their respective communities. A table of these major new initiatives, as presented during the October 2020 NNCI Annual Conference, was provided in the Year 6 (2021) Annual Report. In addition, a new network-wide program on Research Communities was created for participation by <u>all</u> NNCI sites, and these are described in more detail above (Section 7). Other programs such as Summer Teacher Workshops, Regional Networks, Seed Grants, and SEI research/education were added by many sites. Below, we update information on the regional networks and describe the new seminar series and YouTube video channel.

<u>Regional Facility Networks</u>

Initiated by efforts at MiNIC and MANTH, a number of sites within the NNCI have established informal networks of regional fabrication and characterization facilities to provide mutual assistance, develop best practices, and provide staff networking opportunities. The map below (Figure 13) shows the updated geographic distribution and regional clustering of these networks, along with a brief description of each.

Northern Nano Lab Alliance (NNLA)
Southeastern Nano Facility Network (SENFN)
Southwest Nano Lab Alliance (SW-NLA)
Northwest Nanotechnology Laboratory Alliance (NWNLA)
Mid-Atlantic Region Cleanroom Managers Workshop
RTNN Affiliates Network

Figure 13: NNCI Regional Facility Networks

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

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

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

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

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

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

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

NNCI Seminar Series

While initially created in 2021 as a way to share technical content about computation, modeling, and simulation with the greater NNCI community, the NNCI Seminar Series quickly expanded to a (nearly) monthly series with speakers selected by the CO Associate Directors to highlight their specific topical areas. Information about the videos is shared with NNCI sites, posted on the NNCI website, and disseminated by external organizations such as the NNCO and NanoFabNet (a European consortium). Typical attendance during the live event has averaged around 25. Video recordings are then posted on the NNCI YouTube channel (see below). The schedule of 2021 seminars is provided in Table 12.

Table 12: NNCI 2021 Monthly Seminars

Date	Topic*	Speaker(s)	Affiliation	Title
May 5	C	Dragica Vasileska	Electrical Engineering, ASU	"Simulation Software Next Door"
May 27	I	Terrance Barkan	The Graphene Council and the MXene Association	"2D Advanced Materials and US National Priorities"
June 23	C	Frank Register	Electrical and Computer Engineering, UT-Austin	"Quantum-Corrected Semiclassical Monte Carlo Scaling study of Si, Ge, and InGaAs FinFETs"
July 21	S	Andrew Maynard David Berube	School for the Future of Innovation in Society, ASU Science and Technology Communication, NCSU	"Looking Back on 20 Years of Nano in Society"
August 25	E	Jared Ashcroft	Pasadena City College & Micro Nano Technology Education Center	"The Micro Nano Technology Education Center: Fostering Partnerships Between Industry, University, and Community Colleges to Grow the Micro Nano Skilled Technical Workforce"
October 28	I	Kurt Peterson	Silicon Valley Band of Angels	"What Investors are Looking for in Early Stage Start-up Companies"
November 10	C	Shela Aboud	Synopsys	"The Evolution of Process TCAD in Semiconductor R&D and Manufacturing"

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

NNCI YouTube Channel

The NNCI YouTube Channel was created in April 2018 as a way to host the NNCI Introduction Video created that year. During 2021, the channel was expanded to include additional Playlists for Education Videos, Seminar Series, and Training Videos. Education videos include careers in nanotechnology content created by Jim Marti (MiNIC) and Matt Hull (NanoEarth), which are public, as well as an RET information session (which is unlisted, but used by the RET program). The NNCI seminar series (see above) videos since May 2021 are all archived on the channel and are public. Finally, the Training Video playlist was created for future content and currently holds a video on Evaporative Deposition (unlisted) which is being tested internally. Overall, the channel has 85 current subscribers (49 new added in 2021) and 1,532 views during 2021. Analytics of the top video content during 2021 is shown in Table 13 below.

Table 13: NNCI YouTube Video Analytics (2021)

Video	Views	Average View Duration
Careers in Nanotechnology: Opportunities for STEM Students (Jim Marti, MiNIC)	465	3:38 (26.6%)
What is the NNCI?	301	1:50 (50.1%)
X/Nano: The Enabling Potential of a Career in Nanoscience (Matt Hull, NanoEarth)	228	5:31 (19.0%)
"Simulation Software Next Door" (Dragica Vasileska, ASU)	196	4:40 (7.6%)
"The Evolution of Process TCAD in Semiconductor R&D and Manufacturing" (Shela Aboud, Synopsys)	114	5:49 (9.8%)
"2D Advanced Materials and US National Priorities" (Terrance Barkan, The Graphene Council)	72	8:17 (17.0%)
"What Investors are Looking for in Early Stage Start-up Companies" (Kurt Peterson)	43	8:53 (14.8%)
"Looking Back on 20 Years of Nano in Society" (Andrew Maynard, ASU & David Berube, NCSU)	31	8:56 (15.1%)
"The Micro Nano Technology Education Center" (Jared Ashcroft, Pasadena City College)	20	3:36 (6.0%)

10.3. NNCI Outstanding Staff Awards

During 2021, the NNCI Coordinating Office organized the fourth year of the "Outstanding NNCI Staff Member" awards to acknowledge the significant efforts by NNCI site staff who endeavor to provide excellent service and support to all network users in three categories: Technical Staff, Education and Outreach, and User Support. In May 2021, nominations consisting of a 500-word narrative were solicited from site directors (maximum of one nomination in each category) and these were reviewed by the NNCI External Advisory Board. Nominations were evaluated based on the individual's activities that align with site/NNCI goals of providing facility access and/or education and outreach, as well as their impact on the site and the NNCI network. Each winner received an engraved desktop plaque and was recognized at the 2021 Annual Conference. Due the virtual nature of the Annual Conference, travel support will be provided to attend the Annual Conference in 2022 (if possible).

Education and Outreach

- Leslie O'Neill (Education Outreach Manager, SENIC)

"...instrumental in SENIC's programs for educators, providing a welcoming and supportive environment for them as they learn about nanotechnology and work to bring it to their classrooms."

- Raymond (Ray) Tsui (Education and Outreach Coordinator, NCI-SW)

"...giving back to the community after a long and successful career"

Technical Staff

- Phil Infante (Research Support Specialist/Safety Manager, CNF)

"...communicates across differences to create a collaborative, collegial, and caring community."

- Stanley Lin (E-Beam Lithography Manager, nano@stanford)

"... always listening and looking for ways to improve the experience for users."

User Support

- Jacob John (Coordinator & Program Manager, NNF)

"...instrumental to navigate the center through the perfect storm with early on in-person engagement to bring NNF back to regular service activities"

- Michael Skvarla (Research Support Specialist, CNF)

"...continual commitment to the goals of the NNCI by providing state-of-the-art, hands on education to a diverse group of users from around the world."

11. NNCI Network Usage

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

NNCI sites collect statistical data about their users in an effort to assess the strength and success of the internal and external user programs. Research disciplines can be used to help track usage in non-traditional areas. Productivity is implied from annual assessment of user research publications, patents, and presentations that rely on use of the shared facilities and the research budgets enabled. It is more difficult to quantify the productivity of industrial usage, where publications are not the norm, but data on numbers of start-up companies, their financial well-being, patent applications and personnel hiring can be used as indirect measures. In addition, sites may decide to conduct regular user and/or PI satisfaction surveys as a means of assessing site quality and making adjustments to operations as needed (see Section 8.3 above). Education and outreach evaluation plans will provide assessments to guide program improvement as well as impact and effectiveness of programs. Finally, each site's contributions to creating a unified network that surpasses the sum of its parts can be assessed by participation of site personnel in network activities (see Section 10 above).

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

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

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

11.1. NNCI Aggregate User Data (Oct. 1, 2020 - Sept. 30, 2021)

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 14 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 14: Summary of NNCI Aggregate Usage Data (Year 6)

	NNCI Network	NNCI Sites Mean (Min - Max)
Unique Facility Users	11,242	703 (189 – 1,521)
Unique Internal Users	8,449	528 (131 – 1,309)
Unique External Users	2,793 24.8%	175 (35 – 404) 25.6% (13.9% – 42.9%)
External Academic	964	60 (12 – 200)
External Industry	1,619	101 (18 – 248)
External Government	162	10 (0 – 119)
External Foreign	48	3 (0 – 11)
Average Monthly Users	4,381	274 (57 – 693)
New Users Trained	4,414	276 (38 – 692)
Facility Hours*	967,297	60,456 (7,735 – 159,720)
Facility Hours – External Users	242,926 25.1%	15,183 (1,185 – 50,307) 23.8% (5.8% – 62.9%)
Hours/User*	86	85 (31 –174)
User Fees Internal Users External Users	 $21.9M $17.8M	 $1.37M $1.11M

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

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

A comparison of the network aggregate usage data for Years 1-6 is shown in Table 15 below. As can be seen, most metrics show significant increases from Year 5 to Year 6. Of course, this needs to be taken with the context that all site facilities were closed for several months because of the

COVID-19 pandemic during Year 5, and most sites are showing robust recovery in Year 6. The exceptions to this recovery are in the external users, and even more specifically in the academic users, perhaps because of the continued hurdles for travel to NNCI facilities as well as the general pressures on research funding available. Finally, it should be noted that, with the start of the second 5-year funding period, i.e. in Year 6, a few facilities have been dropped and others have been added to the network sites (see Section 1.2). The changes in internal and external users and usage hours over the first six years of NNCI are illustrated in Figures 14 and 15. These further illustrate the improvement in Year 6 compared to Year 5, but the continued impact of the pandemic when compared to earlier years of NNCI.

Table 15: Comparison of Years 1-6 NNCI Aggregate Usage Data

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Δ Year 5 - 6
Unique Facility Users	10,909	12,452	13,110	13,355	10,501	11,242	+7.1%
Unique Internal Users	8,342	9,276	9,731	9,503	7,668	8,449	+10.2%
Unique External Users	2,567 23.8%	3,176 25.5%	3,379 25.8%	3,852 28.8%	2,833 27.0%	2,793 24.8%	-1.4%
External Industry Users	1,413	1,669	1,870	1,961	1,529	1,619	+5.9%
External Academic Users	1,060	1,295	1,365	1,531	1,064	964	-9.4%
Average Monthly Users	4,429	4,911	5,001	5,292	3,654	4,381	+19.9%
New Users Trained	4,116	4,563	4,981	5,194	2,813	4,414	+56.9%
Facility Hours	909, 151	939,230	1,006,764	1,149,788	767,255	967,297	+26.1%
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%	+23.1%
Hours/User	83	75	77	86	73	86	+17.8%
User Fees							
Internal	$20.6M	$23.0M	$23.6M	$23.2M	$16.3M	$21.9M	+34.4%
External	$13.5M	$14.5M	$16.9M	$20.5M	$13.1M	$17.8M	+35.9%

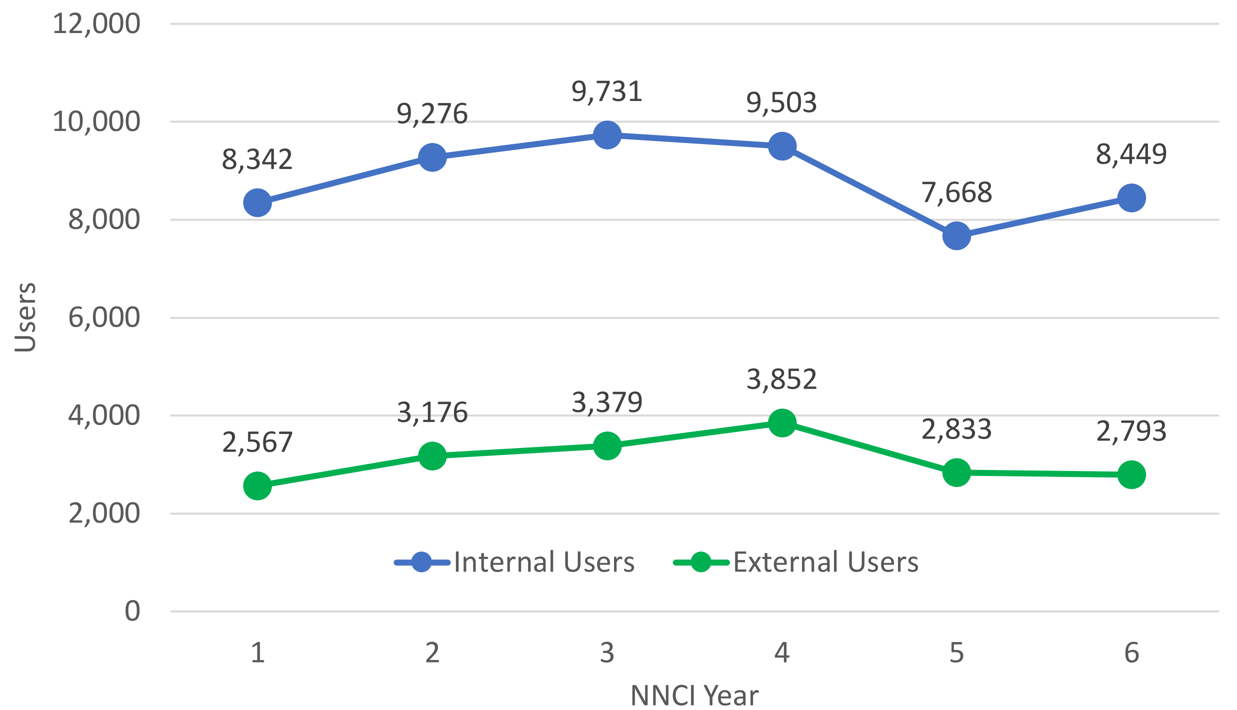


Figure 14: NNCI Users by Year

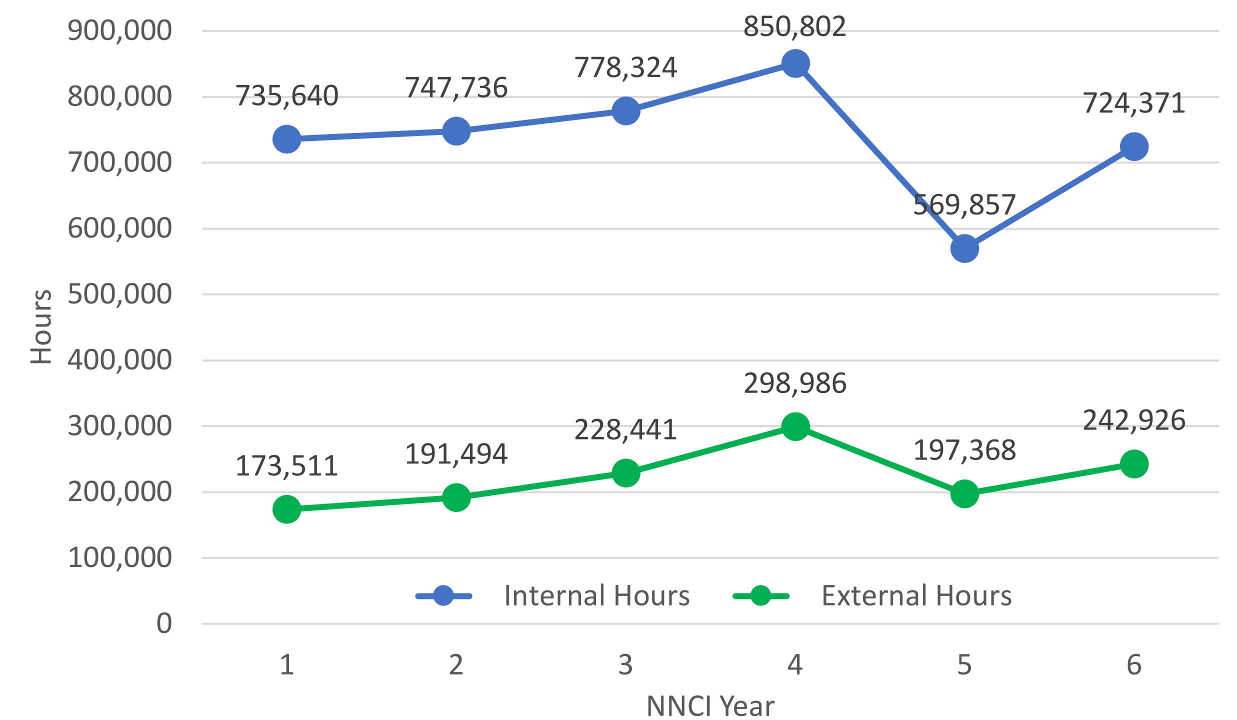


Figure 15: NNCI Usage Hours by Year

Even after re-opening of NNCI facilities during the June-August 2020 timeframe, many sites have continued to operate with reduction in usage capacity, limits on external usage, and/or eliminated training opportunities. The effects of the pandemic are most striking for external users (and training). Nevertheless, the fraction of users and hours from external sources, 27% and 26% respectively, remained relatively constant over the course of Year 5 compared to Year 4 (see Table 15) but have shown a slight decline in Year 6 (25% external users and external hours) which is the first full 12-month pandemic period.

A deeper analysis of the effects of the pandemic closures and recovery of usage is explored in the figures below. Figures 16 and 17 show the Years 4-6 monthly change in cumulative users and lab time, respectively, across all NNCI sites. It is clear that usage at the beginning of Year 5 was on a pace to match or exceed that of Year 4, but plateaued suddenly when facilities were shut down in March 2020 and only began to recover partially beginning in June 2020. The number of users began Year 6 at a lower level and have grown over the year at a slightly reduced pace and were unable to reach pre-pandemic totals. Recovery in usage hours appears more robust, although not complete. The cumulative usage in Year 6 is further dissected into internal and external users in Figure 18, where it is clear that recovery continues to be slower for external usage perhaps due to the burden of travel restrictions. This is further illustrated in Figure 19 which shows the percentage of cumulative external users by month for Years 4-6. It is clear that in Year 4 (and previous years) the fraction of external users increases throughout the year, with an enhanced rate during the summer months likely benefited by REU students and other summer researchers. During Year 5, of course, this summer effort was curtailed and the overall decrease in external usage is obvious.

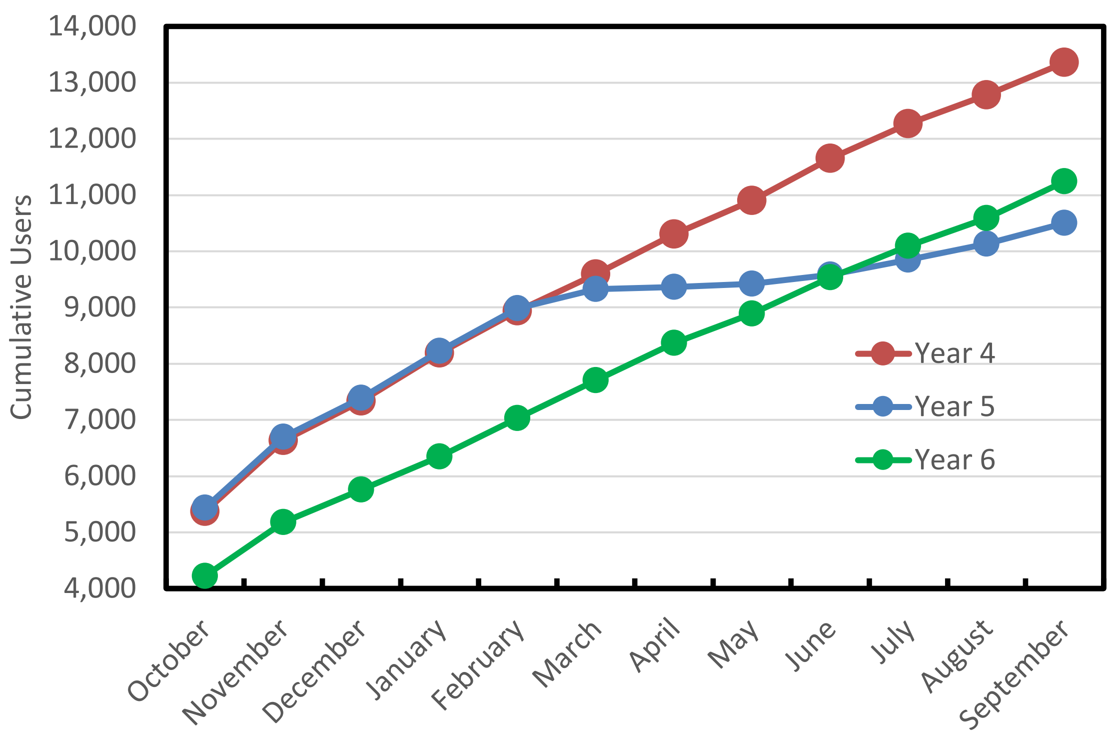


Figure 16: NNCI Cumulative Users by Month for Years 4-6

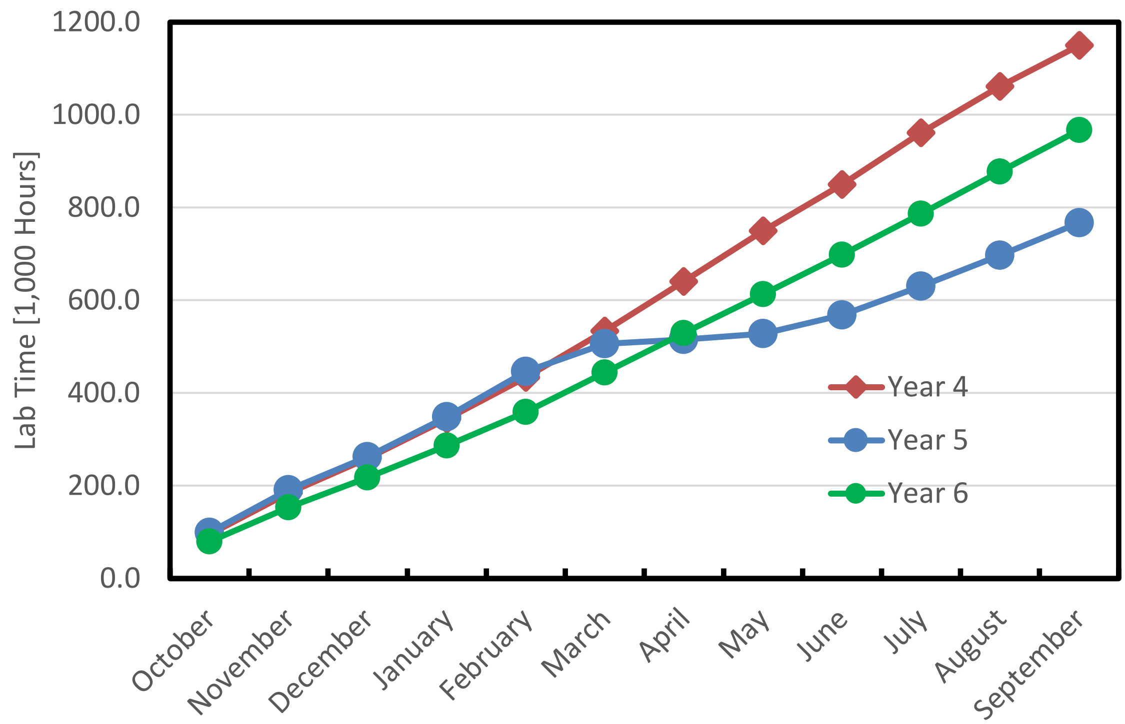


Figure 17: NNCI Lab Usage Time (1,000s of Hours) by Month for Years 4-6

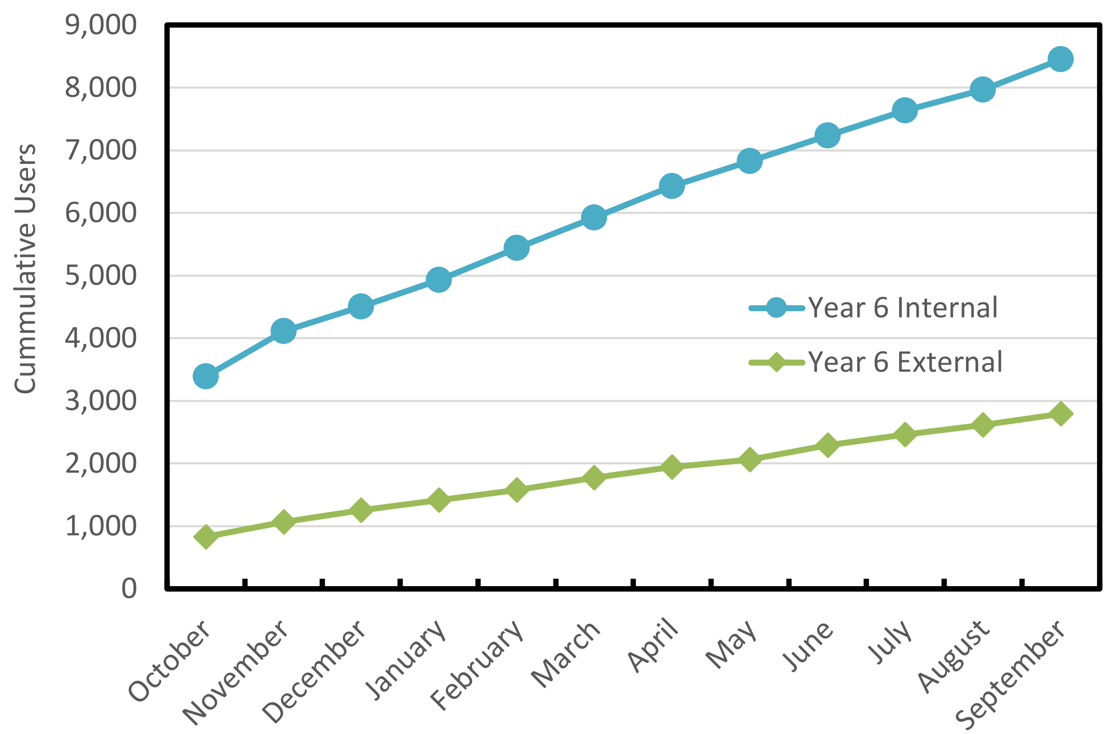


Figure 18: NNCI Cumulative Users, Internal and External, by Month for Year 6

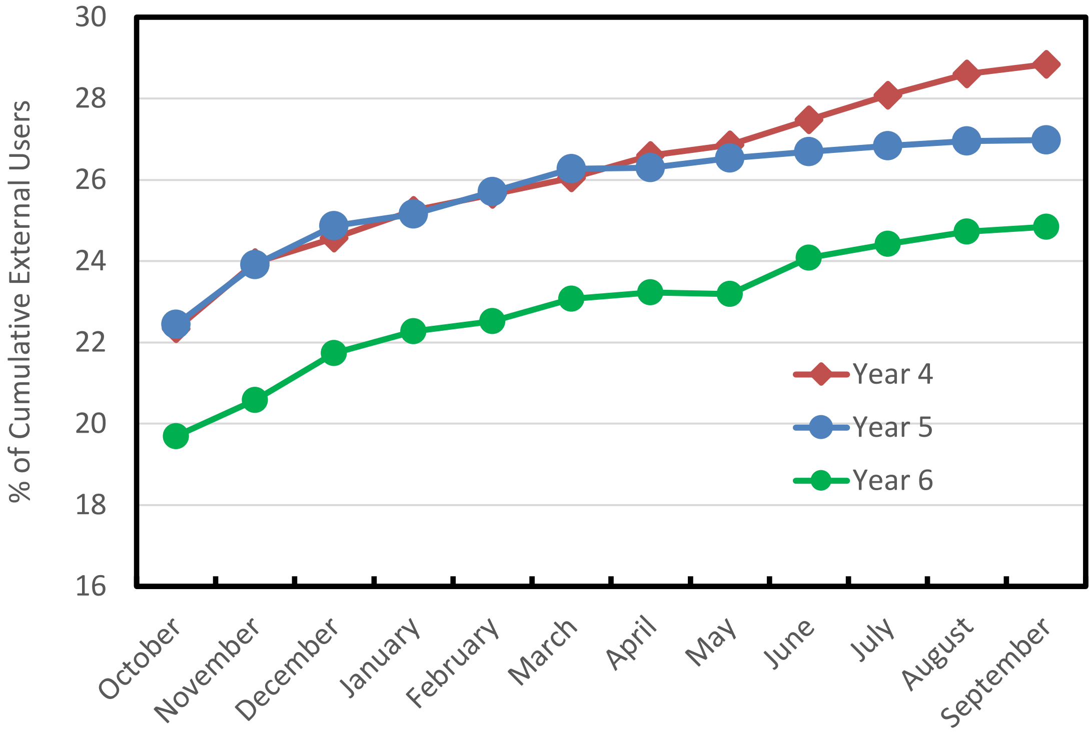
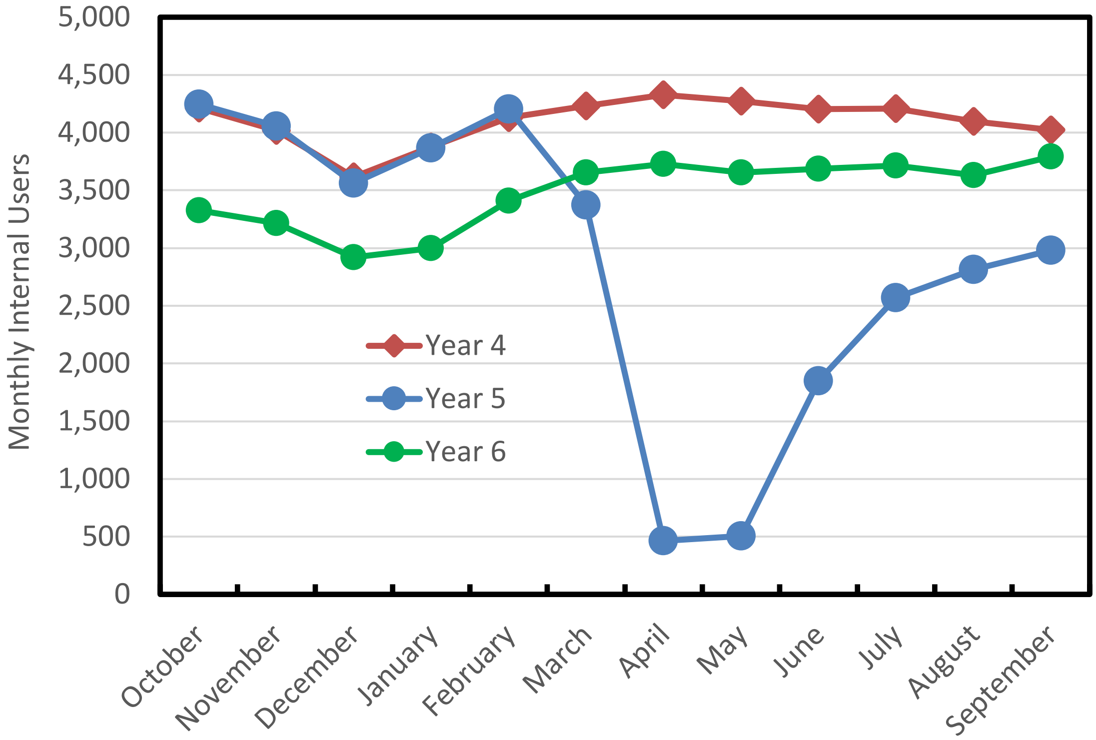


Figure 19: NNCI Cumulative External Users (%) by Month for Years 4-6

As indicated above, at the start of Year 6 the overall external usage started off 2% lower than pre-pandemic and failed to recover fully even with robust month-over-month increases. These pandemic effects on usage are amplified in Figure 20, which shows the number of monthly internal and external users across the NNCI, and indicates that, as of September 2021 (end of NNCI Year 6), monthly internal users have reached 92% of the number from February 2020 whereas monthly external users remain at 81% of pre-pandemic levels. Finally, the pandemic has accelerated a shift to remote usage as can be seen in Figures 21 and 22 for remote users and hours, respectively, as this mode of access, while more costly for users and labor intensive for facilities, avoids the hurdles associated with travel and training.



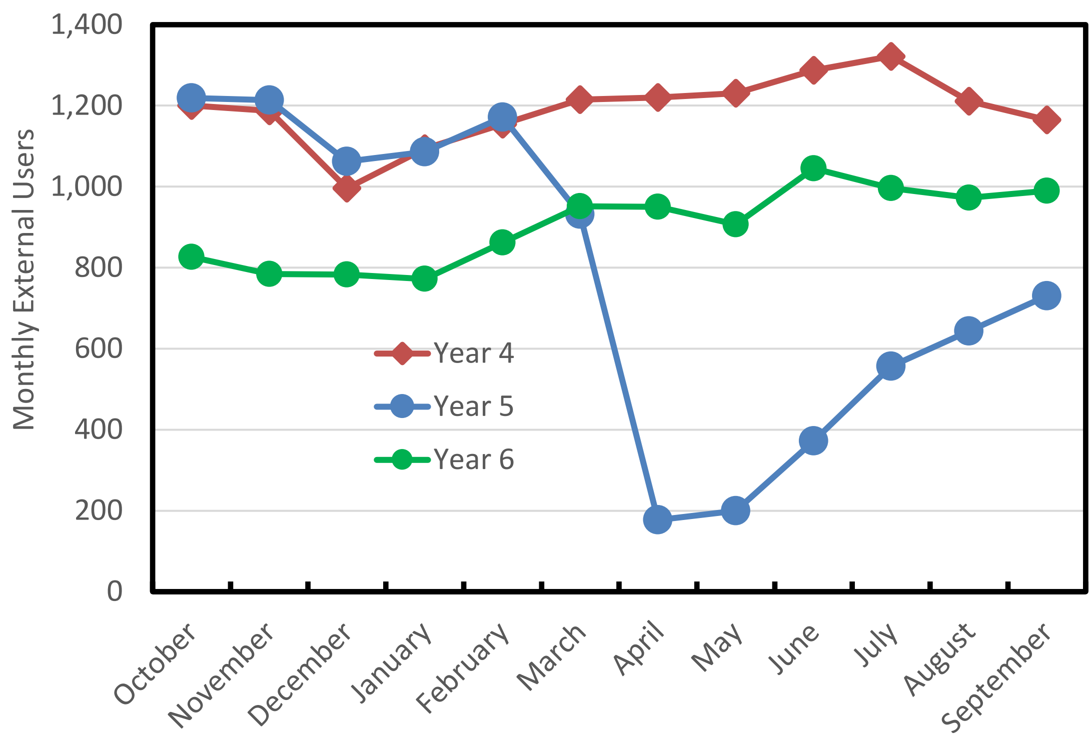


Figure 20: NNCI Total Monthly Internal (Top) and External (Bottom) Users for Years 4-6

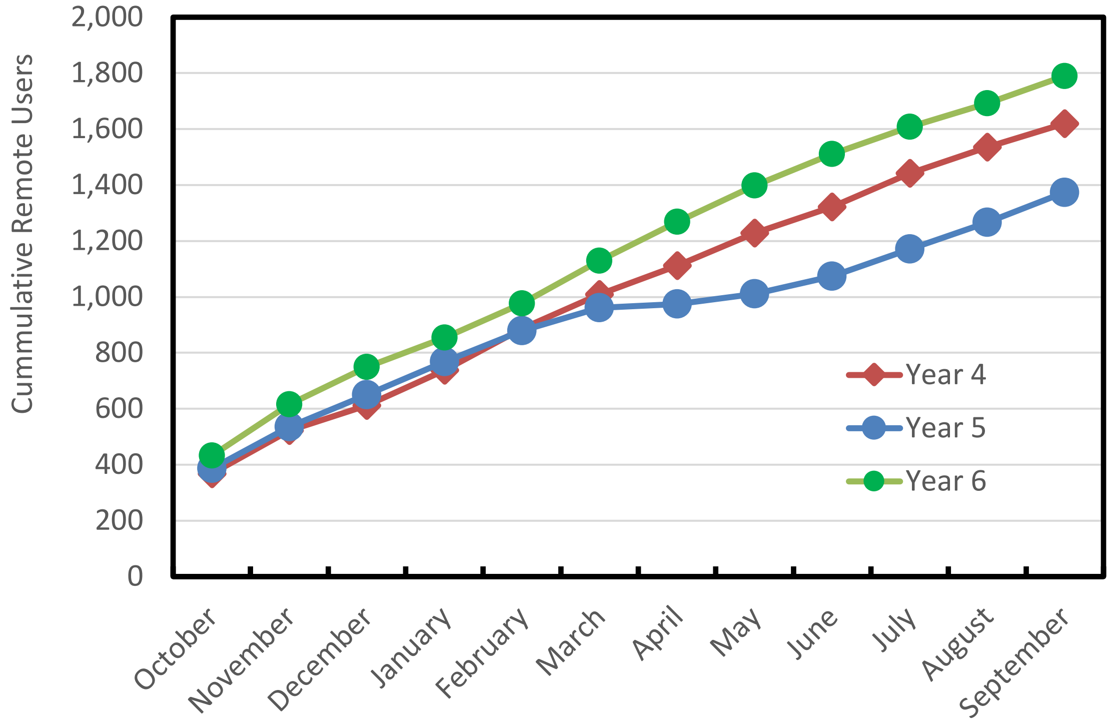


Figure 21: NNCI Cumulative Remote Users for Years 4-6

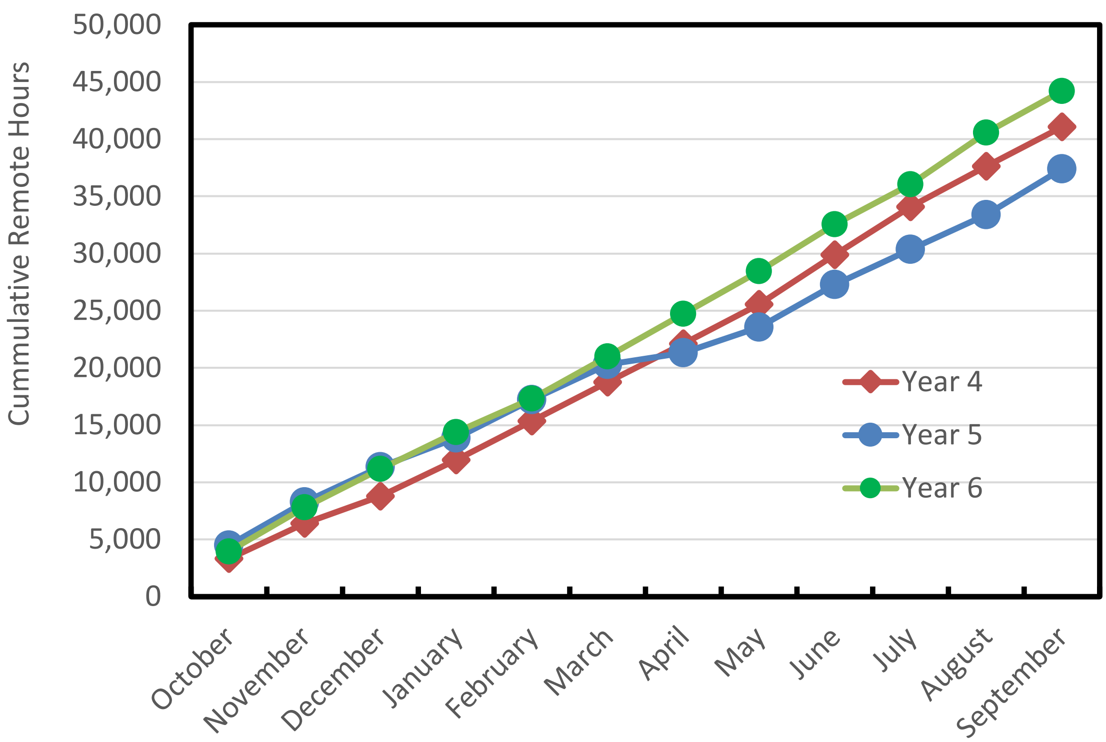


Figure 22: NNCI Cumulative Remote Hours for Years 4-6

The nearly 2,800 Year 6 external users come from 984 distinct external institutions (full list shown in Appendix 14.4), including 198 US academic institutions (Figure 23), 521 small companies, 184 large companies, 24 US local/federal government organizations, 39 international institutions (from Europe, Asia, North America, and Australia), and 18 other institutions (museums and non-profits, for example). This number does not include cases where an external institution (not necessarily the same PI or user) is working at multiple NNCI sites. It also does not include 99 companies, 5 government organizations, 3 foreign entities, and 1 other entity that remain anonymous due to contractual requirements with one of the NNCI sites and may or may not overlap with those listed in the appendix.

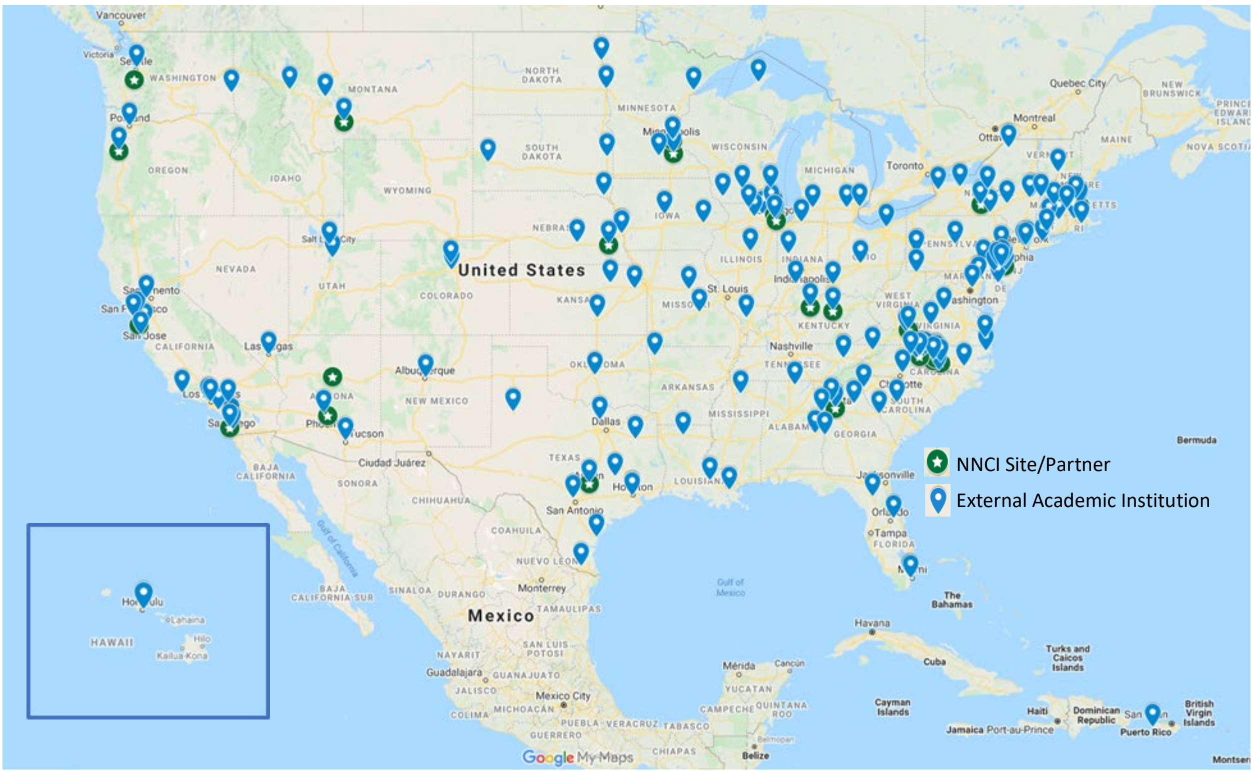
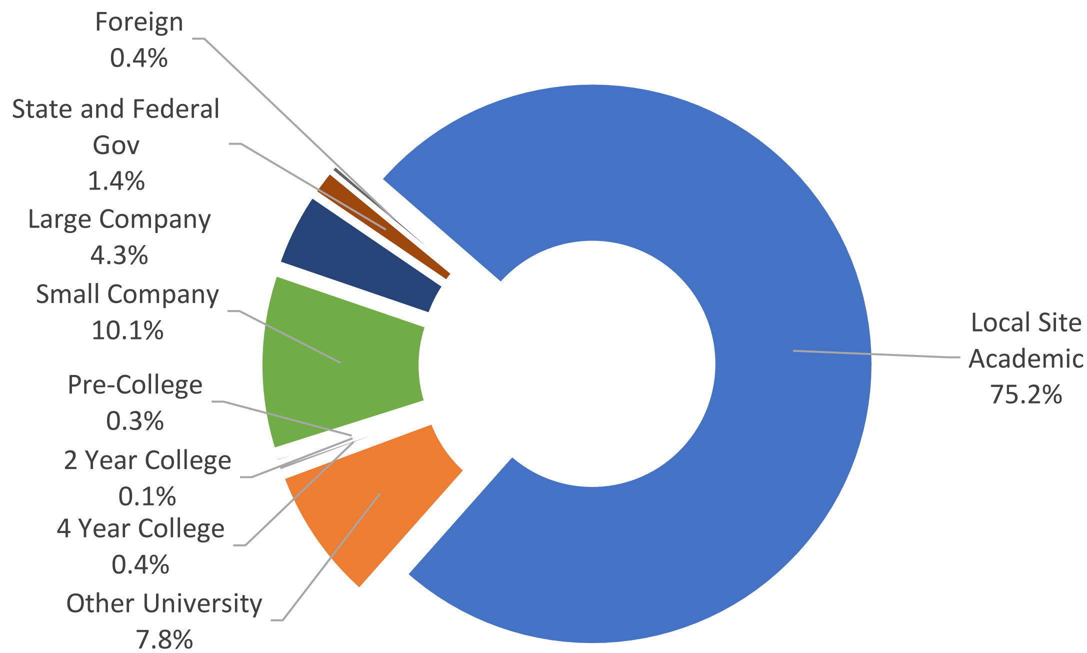


Figure 23: NNCI Year 6 US Academic Institutions (198 External)

Figure 24 shows the distribution of users and lab hours by affiliation for the entire network. Individual affiliation plots are shown for each site in the data of Section 12 below. External users make up 24.8% of total users and external hours are 25.1% of total hours. This represents the smallest discrepancy since the start of NNCI and the opposite of what has typically been observed. The greater fraction of external users compared to their hours has been ascribed as likely due to the proximity and ease of access of internal users to the facilities, which provides them opportunities for greater overall use. This difference between percentage of external users and external hours has been diminishing each year since the start of NNCI (see Table 15 above).



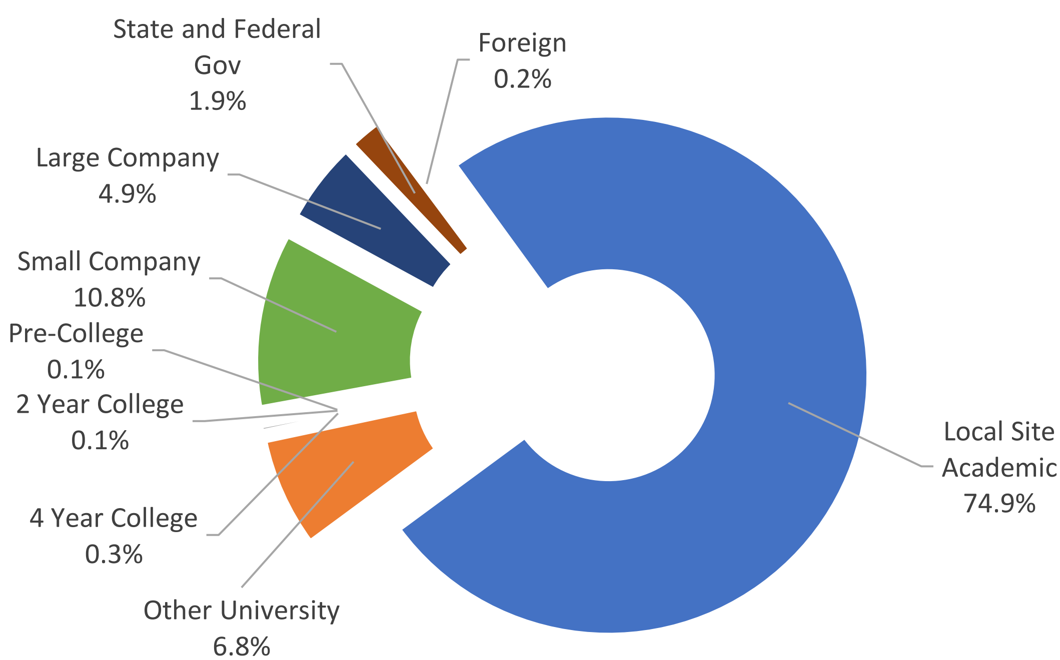


Figure 24: NNCI Users (top) and Usage Hours (bottom) by Affiliation (Year 6)

A comparison of Year 6 cumulative users (by affiliation) by site is provided in Figure 25 for all users and Figure 26 for external users only. Care should be taken when analyzing these data and particularly when comparing different sites. The NNCI sites are diverse: some are located in "nanotechnology" hub areas, others are not; some serve a general NSE user base with a broad tool set, others have a particular research focus; some were part of the NNIN program, others were not; some have a large number of facilities, tools, and staff, others do not. During Years 5 and 6, some universities imposed more restrictions than others on training and external facility usage due to pandemic precautions. Thus, it can be difficult to draw conclusions from a site-to-site statistical comparison.

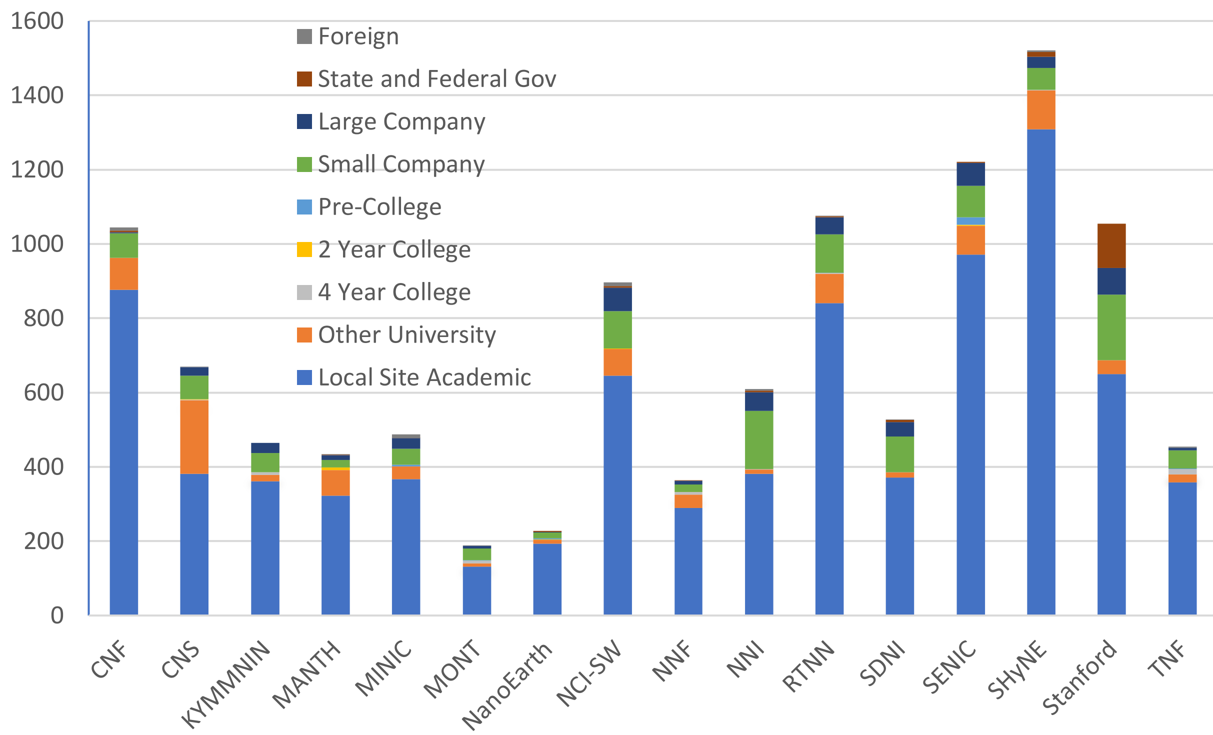


Figure 25: NNCI Cumulative Users by Site (Year 6)

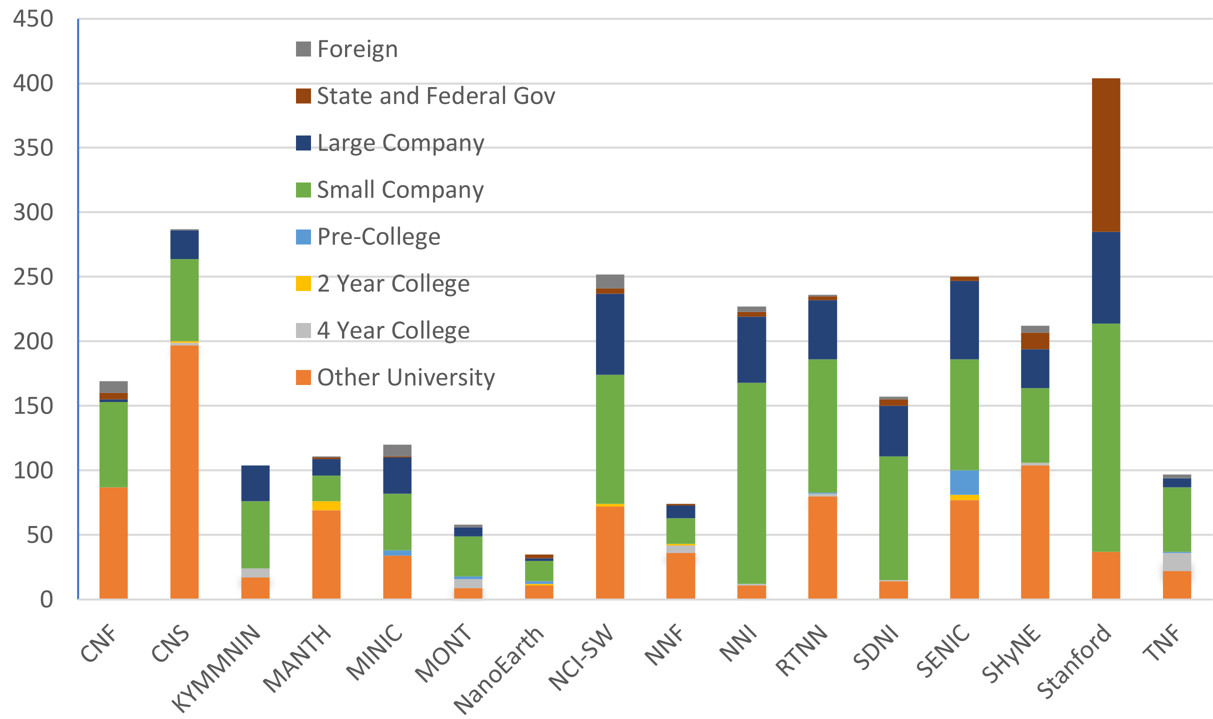


Figure 26: NNCI Cumulative External Users by Site (Year 6)

For academic institutions a network map showing the NNCI nodes and associated US colleges and universities (from 45 US states and Puerto Rico) is shown in Figure 27 below. The size of the NNCI node (blue circle) is proportional to the number of unique academic entities it has as users. Universities with projects at three or more NNCI sites (22 in Year 1 and 43 in Year 6) are labeled in Figure 27, including two institutions (Univ. of Michigan and Virginia Tech) with projects at 5 different NNCI sites and 4 (MIT, Penn State, UC-Berkeley, and Univ. of Washington) with projects at 4 sites. Year 1 had 296 linkages between institutions, and this increased each year reaching 395 in Year 4, but fell to 307 in Year 5 due to the pandemic-related decrease in usage and has risen a small amount to 314 in Year 6. In addition to the academic usage depicted by the figure, it was also observed that approximately 30 companies, government agencies, or foreign entities accessed facilities at multiple NNCI sites, although it cannot be determined if these resulted from the same or unique users or projects.

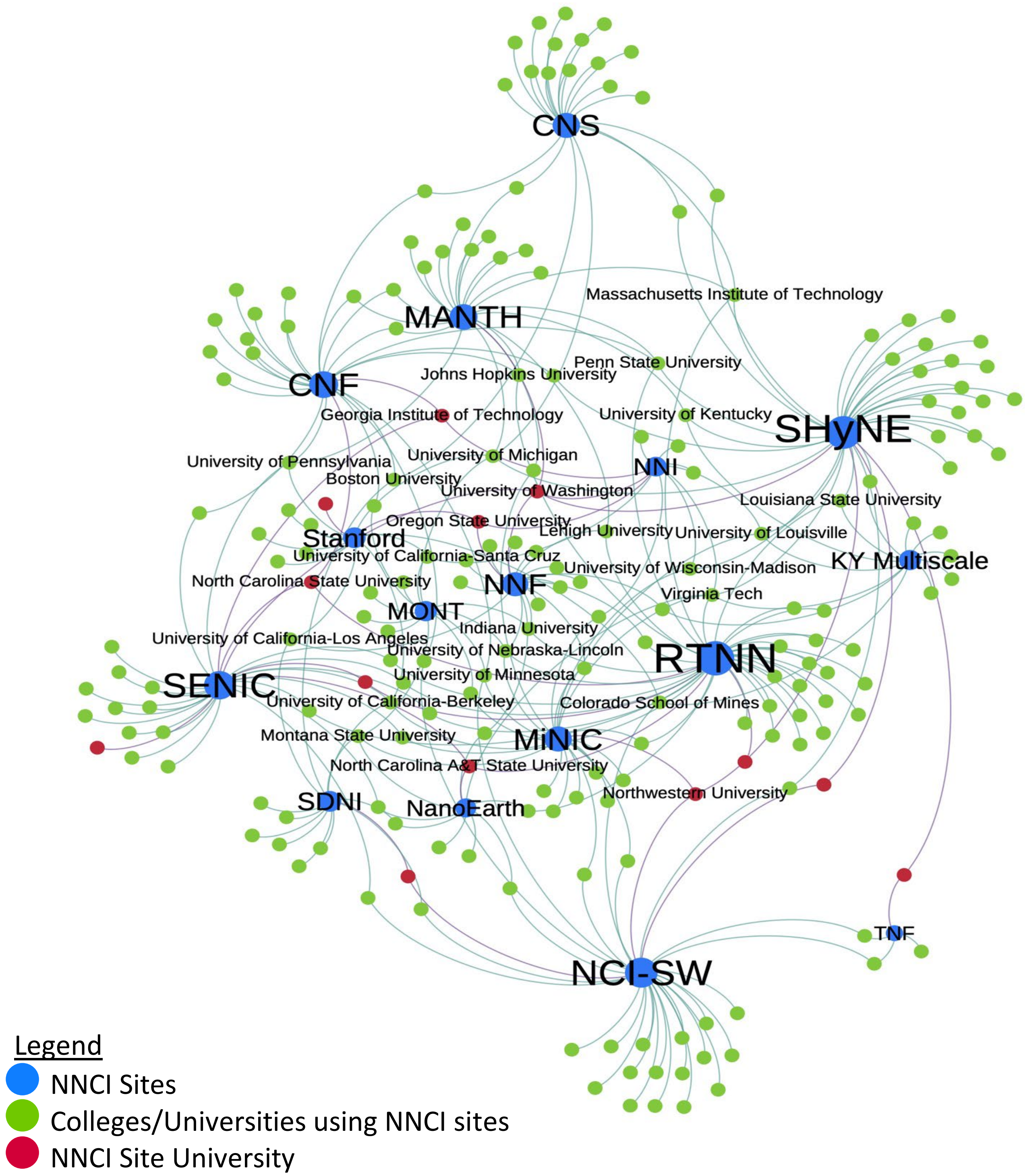


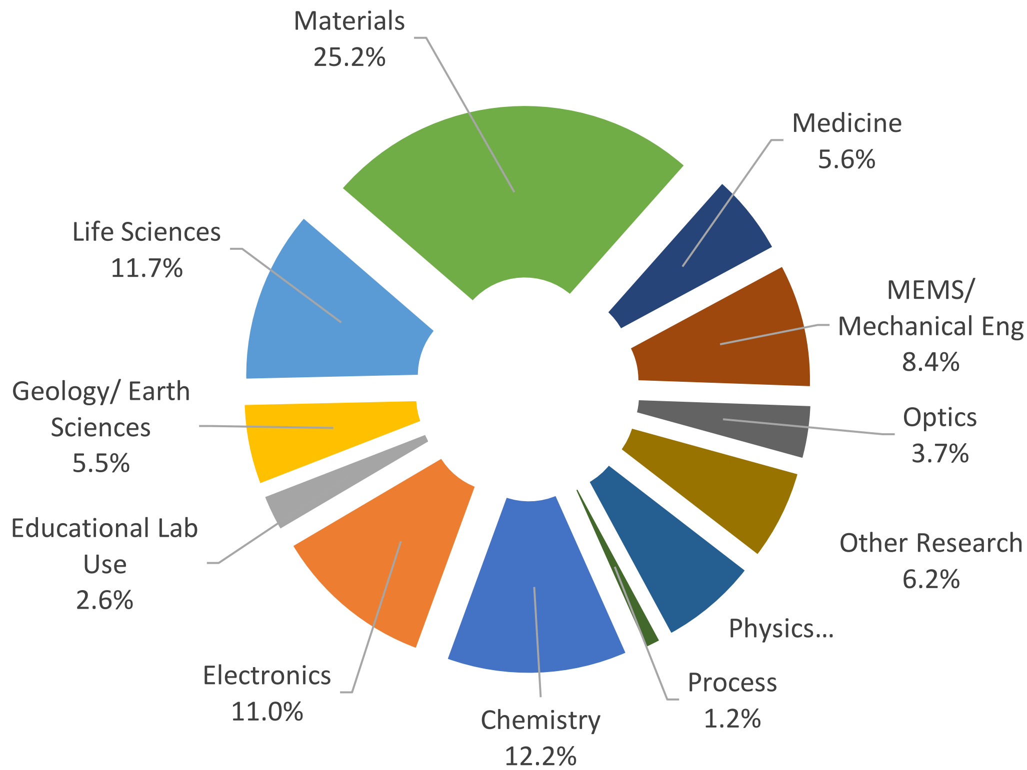
Figure 27: NNCI Academic User Network Map (Year 6)

11.2. Non-Traditional Users

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

1. Research areas that do not typically use nanotechnology facilities; these are identified using the disciplines described in more detail below.
2. Demographic groups, such as women and under-represented minorities; information on minority serving institutions is provided below.
3. Users from non-Research I educational institutions; data on 2-year and 4-year colleges are provided in the affiliation statistics above.
4. Small companies; data on small company users are provided in the affiliation statistics above.
5. K-12 students, community college students, and teachers; affiliation data is provided for pre-college users and more information about outreach to this category is provided in Section 4.1.

The charts below illustrate the usage of the NNCI network by users in specific disciplines (internal and external). It is worth noting that in many cases these disciplines are self-selected, may reflect the user's home department or their specific area of research, and these may be different from each other. Figure 28 illustrates the distribution by number of users and usage hours in specific disciplines. Furthermore, Figure 29 illustrates the average number of hours/user across the network based on the user's discipline, illustrating that the fabrication-heavy disciplines of electronics, MEMS, optics, physics, and process development tend to require more lab usage by researchers. These distributions are similar to previous years, continuing the rapid growth in Geology/Earth Sciences users (5.5% in Year 6 compared to 2.4% in Year 1) and usage hours (5.6% in Year 6 compared to 1.2% in Year 2), and this is also reflected in the hours/user for that discipline. Overall, users from Geology/Earth Sciences, Life Sciences, and Medicine now comprise 23% of all NNCI users. The annual changes in number of users in each discipline are graphically displayed in Figure 30 (with "Educational Lab Use", "Process", and "Other" removed for clarity).



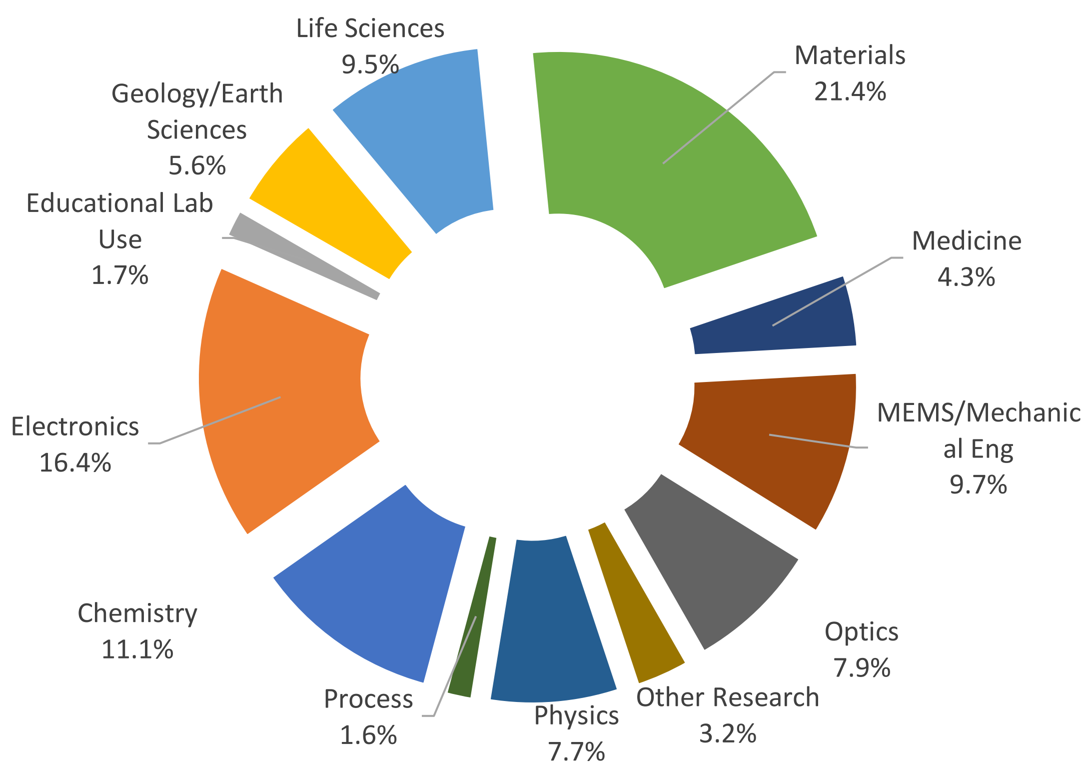


Figure 28: NNCI Users (top) and Usage Hours (bottom) by Discipline (Year 6)

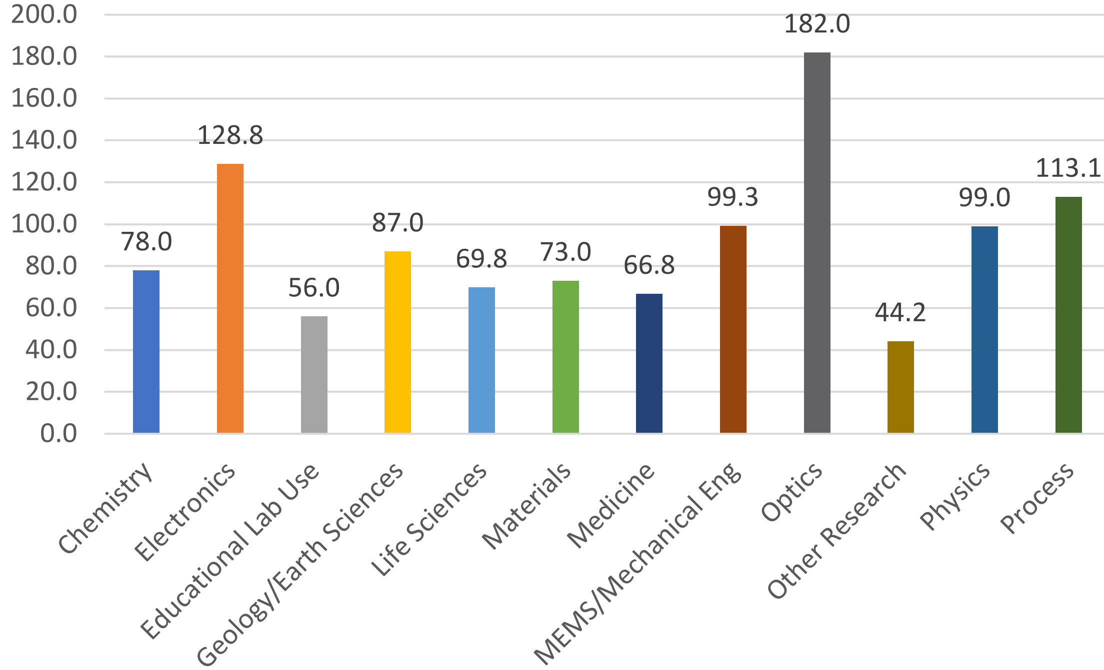


Figure 29: NNCI Hours/User by Discipline (Year 6)

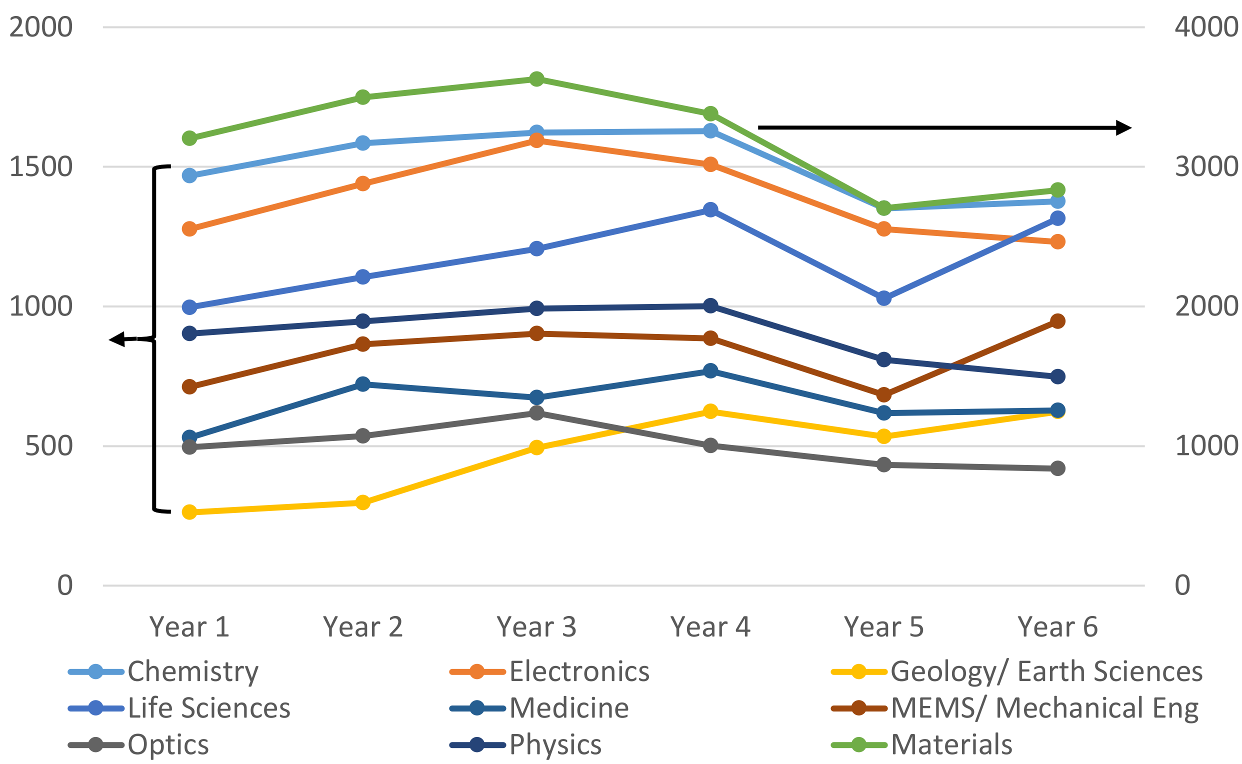


Figure 30: NNCI Yearly Users by Discipline ("Materials" indicated by the right Y-axis for comparison purposes.)

Beginning with the Year 1 annual report, and as a matter of convenience, we have defined “traditional” disciplines to include the engineering-related electronics, materials, MEMS, and process development disciplines, whereas “non-traditional” contains everything else (Educational Lab Use is excluded in this tabulation). Table 16 below compares the relative usage breakdown by number of users and hours for each year of NNCI. Using the above definition, the number of users was split evenly between traditional and non-traditional during the first three years, with a measurable shift in the usage hours from traditional to non-traditional during that same time period. However, during Year 4 usage by non-traditional users has increased significantly so that is now the dominant population of users, although the relatively proportion of non-traditional usage hours has decreased during Years 5 and 6.

Table 16: Usage by Traditional and Non-Traditional Disciplines

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

* 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 to examine the diversity of users’ home academic institutions, particularly those that serve under-represented minority populations as defined by the US Dept. of Education.

- As constituted, NNCI sites contain one *Historically Black College and University* (HBCU), North Carolina A&T State Univ. (SENIC), one *Minority-Serving Institution* (MSI), UNC-Greensboro (SENIC), one *Hispanic-Serving Institution* (HSI), Northern Arizona Univ. (NCI-SW), and one *Primarily Black Institution* (PBI), Community College of Philadelphia (MANTH).
- Four other primary sites are recognized as *Emerging Hispanic Serving Institutions* (EHSI, 15+% Hispanic undergraduate students): Univ. Texas-Austin (TNF), Arizona State Univ. (NCI-SW), Univ. California-San Diego (SDNI), and Stanford (nano@stanford).
- During Year 6, external academic users came from 19 *Hispanic Serving Institutions* (HSI, 25+% Hispanic undergraduate students), 11 EHSI, 6 HBCU, 4 *Asian-American and Native American Pacific Islander* institutions (AANAPI), and 1 *Native Hawaiian-Serving Institution* (ANNH). Thus, 41 of the 198 (21%) US academic institutions using NNCI facilities serve under-represented populations. This is a decrease from the 27% observed during Year 5.
- Examples of these institutions are: Alabama A&M University, Elgin Community College, Georgia State University, Morgan State University, Norfolk State University, San Jose

State University, University of California-Davis, University of Hawaii-Manoa, and University of Puerto Rico-Mayaguez.

More generally, the fraction of users from non-research academic institutions (4-year colleges, 2-year colleges, and pre-college) has remained steady through the first four years of 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 2020. Due to the difficulty in getting compliance from users for this requested information, this should only be considered a lower limit of the actual publications data. In addition, no attempt was made to remove duplicates, where authors might have been from multiple NNCI sites. The 4,293 publications collected for CY 2020 represent a significant 13% decrease in total publications compared to Year 5 (2019 publications), with most of the decline coming from fewer conference presentations (611 in Year 6 compared to 1,131 in Year 5). We ascribe this to conferences which were canceled in 2020 during the initial onset of the pandemic and even continued reluctance of researchers to present their work in virtual conference formats. Publications reported by each site range from 74 to 669. Patents/applications/invention disclosures remain at a high level for 2020, although at a slight decline from 2019. These trends can be observed in Figure 31. 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 32 below shows a significant improvement in this metric. Finally, a further detailed search reveals that the work carried out in the NNCI facilities heavily supports industries of tomorrow, as is highlighted by a keyword search among the more than 4,600 journal articles publications published between 2018-2020 that acknowledge the original NNCI award numbers from 2015 (Figure 33). “Quantum” is mentioned by 33% of these, “semiconductor” is found in 30%, and “biomedical” is included in 25% of these publications. This analysis has been featured in the *2021 National Nanotechnology Initiative Strategic Plan*.

Table 17: NNCI 2020 Publications

Publication Type (CY 2020)	
Internal User (Site) Papers	2,761
External User Papers	323
Internal User Conference Presentations	543
External User Conference Presentations	68
Books/Book Chapters	19
Patents/Applications/Invention Disclosures	626
Total	**4,293**

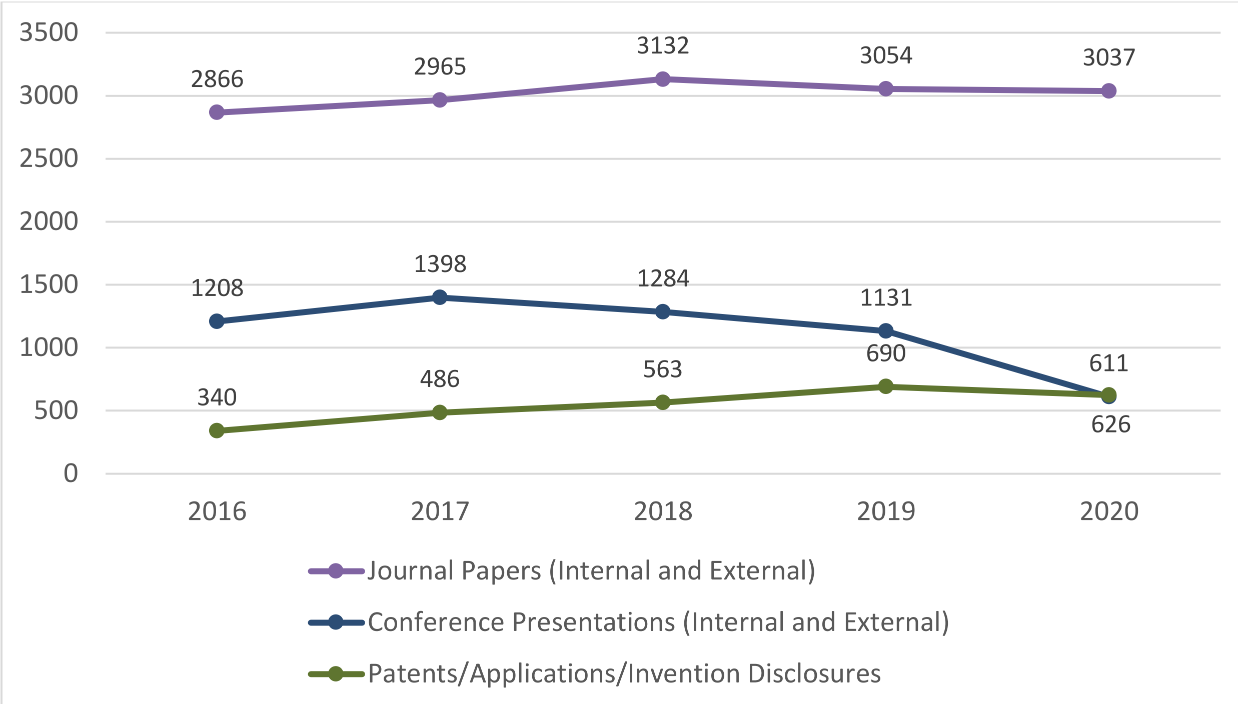


Figure 31 Number of NNCI-enabled Publications by CY.

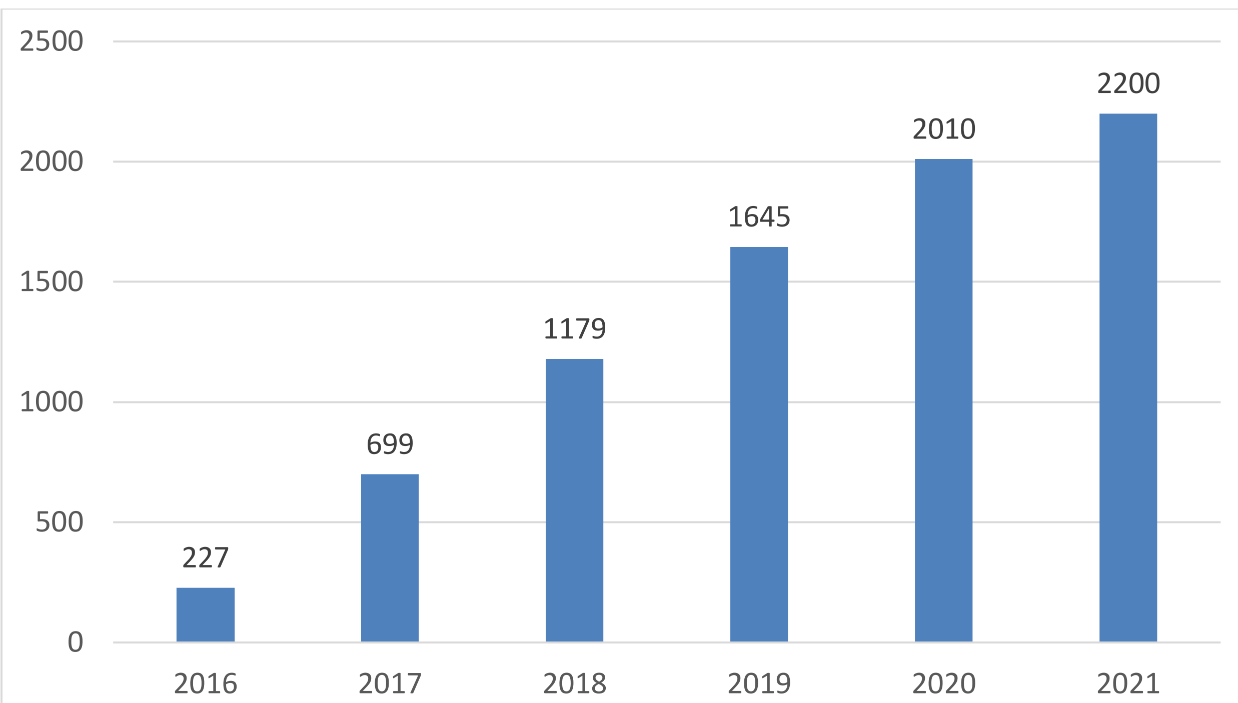


Figure 32: Number of Publications with NSF NNCI Award Numbers based on Google Scholar (NNCI-Award # or ECCS-Award #). Both 2015 and 2020 award #s were used. Search conducted 1/13/2022.

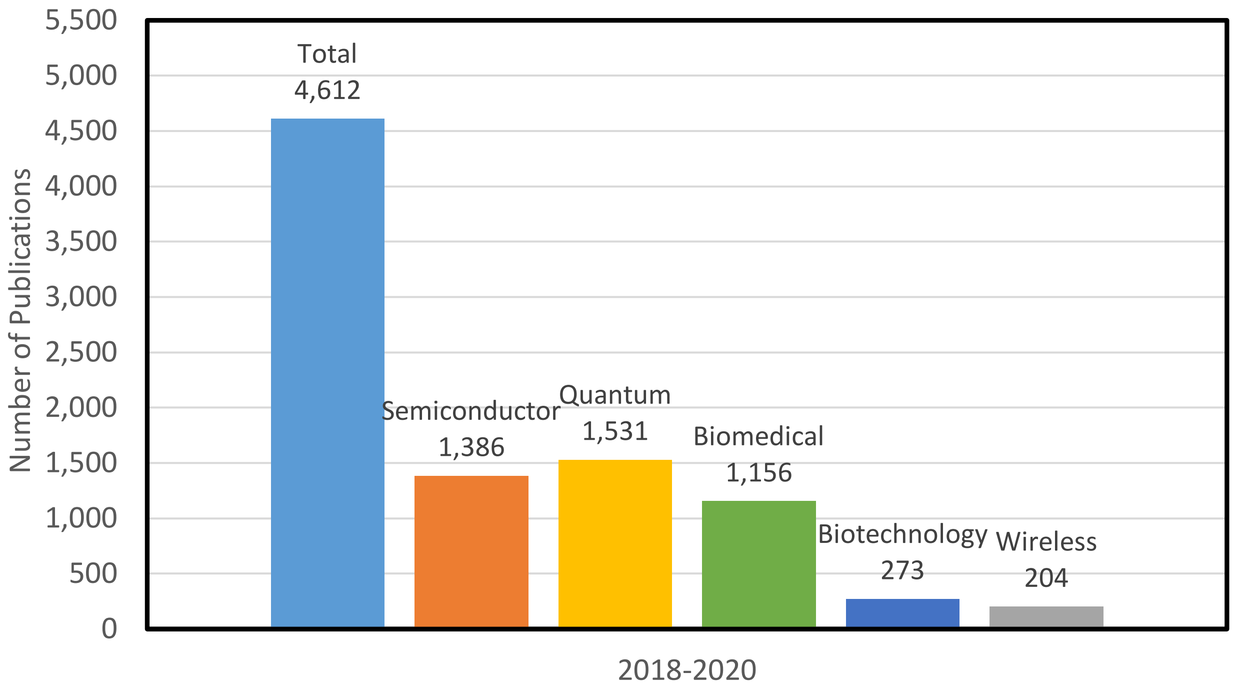


Figure 33: Number of NNCI publications (which cite the NSF award #s) on Google Scholar that also contain specific search terms (2018-2020)

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. Table 18 below provides an update, indicating 18 *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. In particular, the 2021 cohort of six new NSF Science and Technology Centers (STC) included three (bolded in the table) led by NNCI sites with additional partners from NNCI-affiliated universities.

Table 18: NNCI Supported Research Centers

Research Center	Supporting Site	Funding Source
Accelerating Quantum-Enabled Technologies	NNI	NSF NRT
Center for Hybrid Approaches in Solar Energy to Liquid Fuels (CHASE)	RTNN	DOE Energy Innovation Hub
Center for Integration of Modern Optoelectronic Materials on Demand	**NNI (partners Univ. Pennsylvania, Georgia Tech, Northwestern Univ., and Univ. Chicago.)**	**NSF STC**

Center for Research on Programmable Plant Systems (CROPPS)	**CNF**	**NSF STC**
Chip-Scale Integrated Multibeam Steering System for Cold-Atom Quantum Computing	NNI	NSF Convergence Accelerator
Cornell Visualization and Imaging Partnership (CVIP)	CNF	
Electronic-Photonic Integrated Circuits for Aerospace (EPICA)	SENIC	NSF IUCRC
Emergent Quantum Materials and Technologies (EQUATE)	NNF	NSF EPSCoR
Intel Center for Imag(in)ing New EUV Material Architectures (CINEMA)	CNF	Intel
Louisville Automation Robotics & Research Institute (LARRI)	KY Multiscale	
MonArk Quantum Foundry	MONT	NSF Q-AMASE-i
Querrey Simpson Institute for Bioelectronics	SHyNE	
Rapid Prototyping Laboratory (RPL)	CNF	
Science and Technologies for Phosphorus Sustainability (STEPS)	**RTNN (partners Arizona State Univ., North Carolina A&T State Univ., and UNC-Greensboro)**	**NSF STC**
Superconducting Quantum Materials and Systems Center (SQMS)	SHyNE	DOE (Fermi National Lab)
Supporting Micro and Nano Technicians through Hybrid Teaching Methods	NCI-SW	NSF ATE
The Internet of Things for Precision Agriculture (IoT4Ag)	MANTH	NSF ERC
UofL Industrial Assessment Center (IAC) for Manufacturing Technical Assistance and Energy Engineering Workforce Development	KY Multiscale	DOE IAC

11.5. Research Funding Sources

In 2019, at the request of NSF, the NNCI Metrics Subcommittee discussed the collection of data detailing the sources of funding used to support NNCI users and research. The first set of data (grants and users) was collected in 2019 from all 16 NNCI sites for usage during NNCI Year 3 (Oct. 2017 – Sept. 2018). Due to COVID-19, this data set was not collected in 2020. In 2021, a revised set of the data (grants information only) was collected for the time period of NNCI Year 5 (Oct. 2019 – Sept. 2020). A separate report of this data was provided to NSF and the highlights are presented below.

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

Research Funding

The number (not the funded dollar amount) of grants from each external funding source (NSF, DoD, etc.) which were used to pay for NNCI facility user fees and/or stipends for students performing the work in the facility were counted (Figure 34). To the best extent possible, data included both internal and external users (but not staff), although external user data is usually more difficult to collect.

In total, 2,416 Principal Investigators (PIs), internal and external faculty as well as industry researchers, were included in the counting with a total of 4,415 grants. This data (for NNCI Year 5) represents 85% and 81%, respectively, of the metrics collected in 2019 for NNCI Year 3 usage. Based on the facility closures during the initial stages of the 2020 COVID-19 pandemic, this is to be expected. An average PI used 1.8 grants/awards to fund research conducted at NNCI facilities, which is comparable to the previous Year 3 average (1.9).

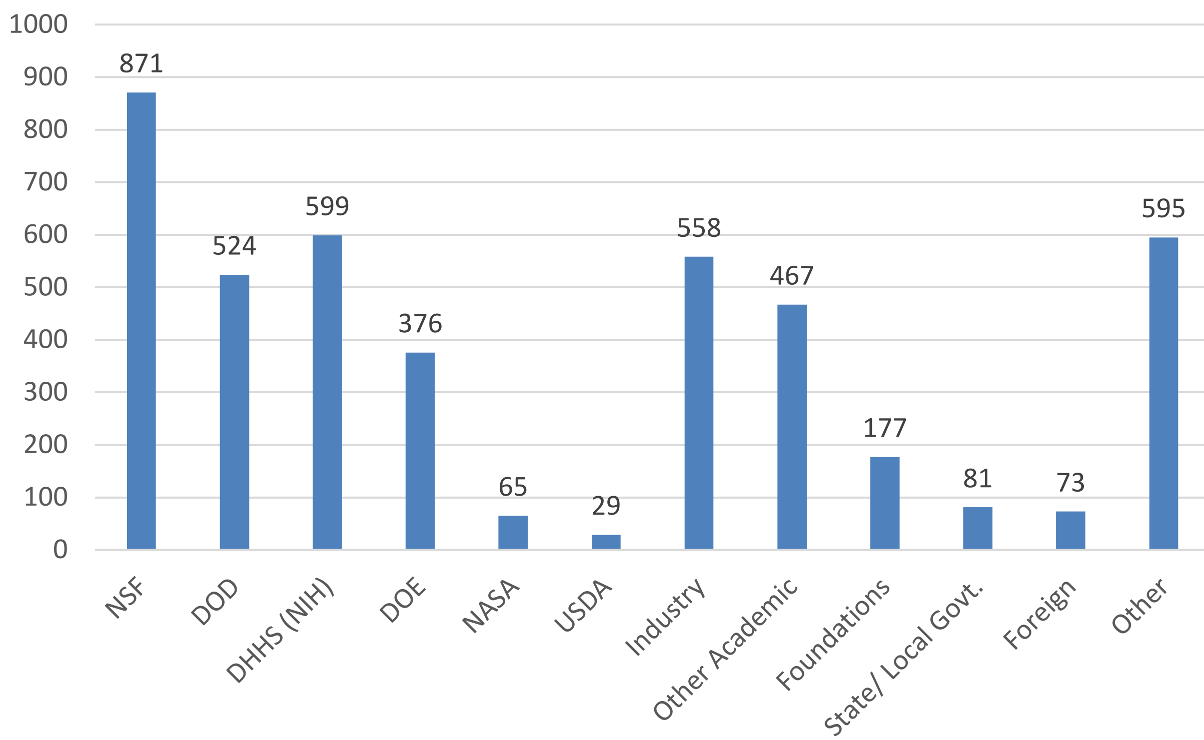


Figure 34: Number of grants by external funding source providing funding for NNCI facility access and research user support (Oct. 2019 – Sept. 2020).

NSF remains the largest single external funding source with 19.7% of awards, a slightly lower fraction than the 21.5% recorded in 2019. In addition, 28% of PIs had at least one NSF grant funding their research at NNCI-supported facilities. DoD, DHHS and DoE are the other federal funding agencies with a large number of awards that are supported by the NNCI with all showing increases in fraction of awards compared to the 2019 data collection. Industry accounts for 12.6% of grants and other academic sources account for 10.6%. Compared to the 2019 data collection, this represents a decrease in industry support and an increase in other academic support. In both of these cases, it is likely that some of the industry and academic sources include flow-through of federal funding, so the actual number of NSF (and other funding agency) awards is likely higher than indicated.

The distribution of NSF grants by directorate is shown in Figure 35. Within NSF, the Directorate for Engineering (ENG) provides the largest number of research grants (353) to NNCI researchers, with roughly equal distribution of grants from the Division of Electrical, Communications & Cyber Systems (ECCS, 116), the Division of Civil, Mechanical & Manufacturing Innovation (CMMI, 90), and the Division of Chemical, Bioengineering, Environmental and Transport Systems (CBET, 85). The Directorate for Mathematical & Physical Sciences (MPS) is the second largest source for grants (295), dominated by the Division of Materials Research (DMR) which provides 201 grants supporting NNCI research (the largest number of any NSF division) followed by the Division of Chemistry (CHE) with 77 grants. It should be noted that "Other NSF Program" also includes a large number of awards (108) that were not identified with a specific NSF program.

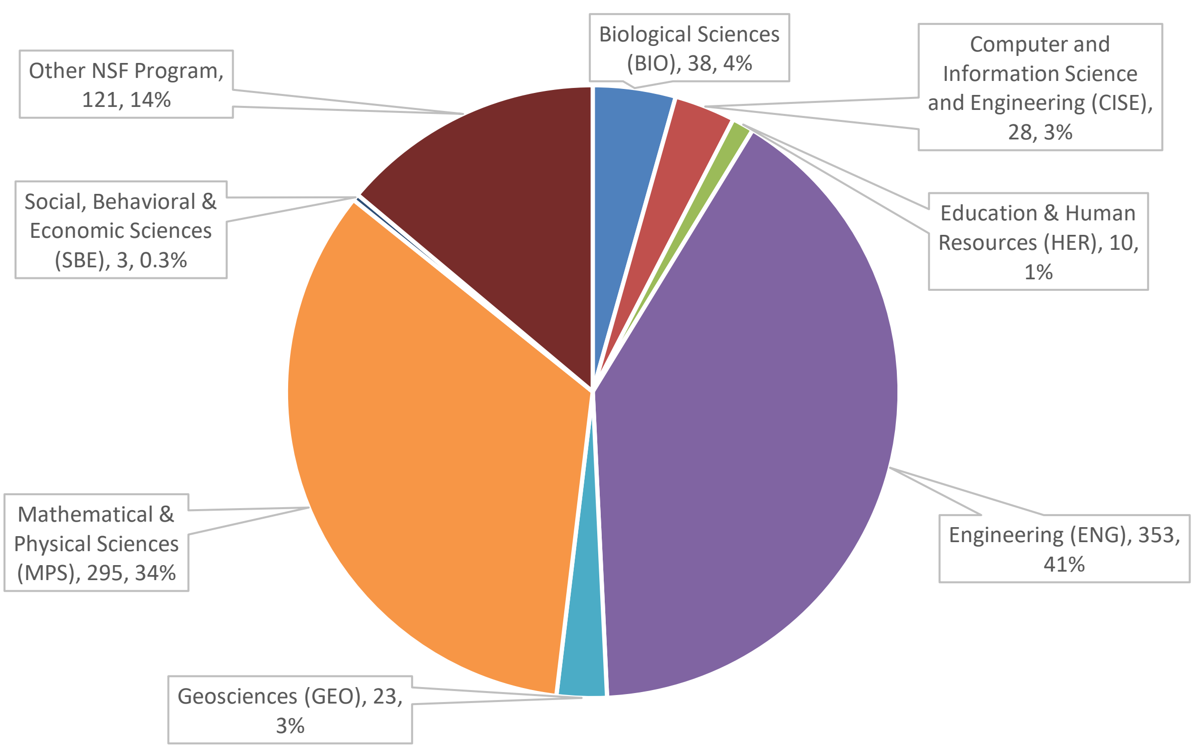


Figure 35: Number and % of reported NSF grants providing funding for NNCI facility access and research user support by NSF directorate (Oct. 2019 – Sept. 2020). The total number of NSF grants included in this chart is 871 (see also Figure 1).

Academic Disciplines

The 2021 data request combined the information on academic departments with the funding information by soliciting the primary departments of award PIs and assuming the resulting distribution to be indicative of users overall. All funded awards are distributed by their academic department as shown in Figure 36. Since industry users do not have an academic department, funding of those users is included in the "Other" category. By total number of awards, the top five academic departments (excluding "Other"), representing approximately 60% of awards, are:

1. Materials Science and Engineering
2. Electrical and Computer Engineering
3. Chemistry
4. Physics
5. Mechanical Engineering

These are also the top five departments for NSF awardees (representing 74% of awards), although "Materials Science and Engineering" and "Electrical and Computer Engineering" are reversed in the ordering.

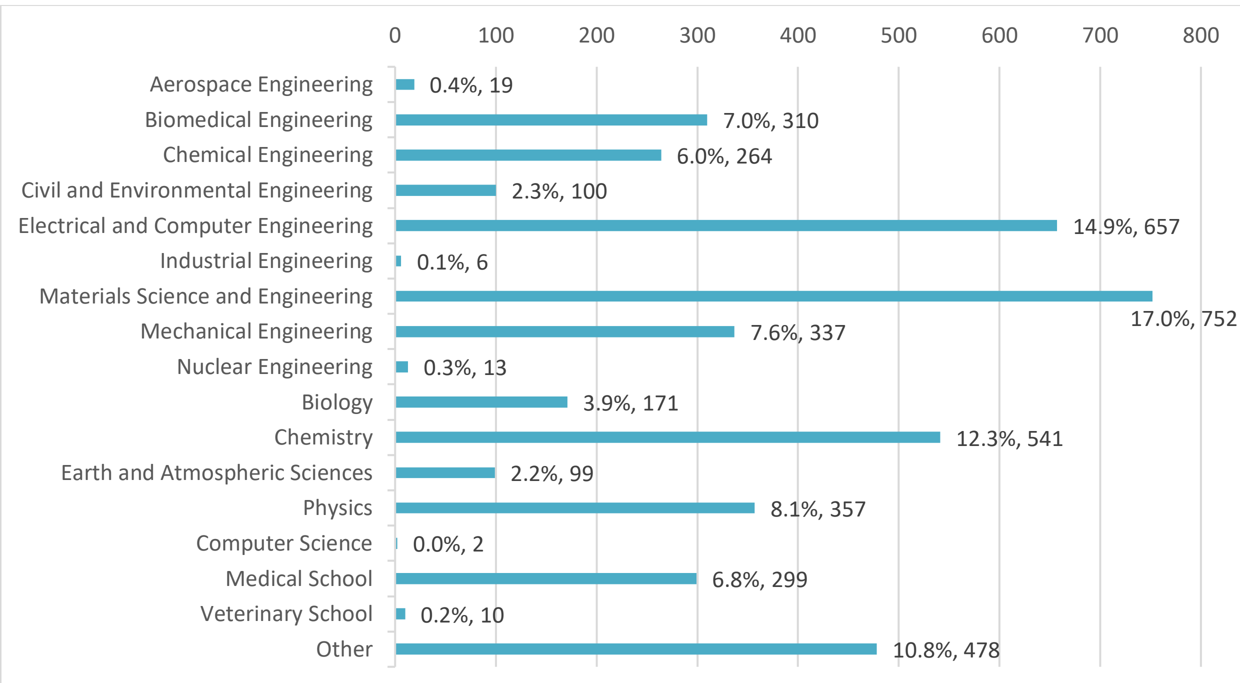


Figure 36: Academic departments of award PIs for grants summed across all funding sources, with funding provided for NNCI facility access and/or research user support (Oct. 2019 – Sept. 2020). The total number of awards included in this chart is 4,415.

Non-traditional users of NNCI facilities are supported by a variety of funding sources. Based on the number of research grants (not funded amounts), the largest number of awards to Earth Sciences or Environmental Engineering PIs (199) are provided by NSF (29%) with significant contributions from NASA (10%) and Other Academic sources (14%). Similarly, for those PIs in Biomedical Engineering or Biology departments or Medical Schools, awards (780 total) are primarily from DHHS (45%), as expected, with additional funding from Other Academic sources (8%), NSF (7%), and Other Sources (18%).

11.6. 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. Thirteen of the NNCI sites were able to obtain that data, and some only in a limited fashion, so this reporting should be considered a lower bound only for degrees granted. The degrees awarded for Fall 2020, Spring 2021, and Summer 2021 (corresponding to NNCI Year 6) are shown in Table 19.

Table 19: Degrees Awarded to NNCI Users (Fall 2020-Summer 2021)

Academic Department	BS Degrees	MS Degrees	PhD Degrees	Other Degrees	Total
Aerospace Engineering	3	3	3	0	**9**
Biomedical Engineering	24	27	33	3	**87**
Chemical Engineering	37	37	90	0	**164**
Civil and Environmental Engineering	6	14	21	0	**41**
Electrical and Computer Engineering	50	115	88	1	**254**
Industrial Engineering	3	0	1	0	**4**
Materials Science and Engineering	25	106	101	0	**232**
Mechanical Engineering	31	64	79	0	**174**
Nanoengineering	4	25	17	1	**47**
Nuclear Engineering	0	2	4	0	**6**
Biology	10	1	7	0	**18**
Chemistry and Biochemistry	17	19	78	2	**116**
Earth and Atmospheric Sciences	0	1	7	0	**8**
Physics	23	12	62	0	**97**
Nanoscience	0	5	7	0	**12**
Computer Science	4	12	1	0	**17**
Medical School	1	2	3	2	**8**
Other	22	26	39	11	**98**
Total	**260**	**471**	**641**	**20**	**1,392**

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

Overall, a total of 1,392 degrees were awarded by the 13 sites (mean=107, range=33-287). NNCI users were awarded 641 doctorates, 471 masters, 260 bachelors, and 20 other degrees (including MD or other graduate certificates) during this NNCI Year 6. 73% of all degrees (68% for PhD degrees) were awarded by engineering departments, with Materials Science and Engineering as the top PhD granting department, followed by Chemical, Electrical and Computer, and Mechanical Engineering, Chemistry/Biochemistry, and Physics. Electrical and Computer Engineering is the top discipline for masters and bachelors degrees. Disciplines in the "Other" category include: Mining Engineering, Robotics, Entomology, Pharmacy, Dentistry, Building Construction, Food Science and Technology, Oceanography, Applied Math, Textiles, and Dance among many others.

11.7. Industry Success Stories

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

Tunoptix, a Seattle-based optics startup co-founded by University of Washington electrical and computer engineering Professors Karl Böhringer (NNI site director) and Arka Majumdar, received two small business awards – a $1,500,000 Small Business Technology Transfer (STTR) Phase II award from the Defense Advanced Research Projects Agency (DARPA) and a Small Business Innovation Research (SBIR) Phase I award from NASA – to advance their meta-optics imaging systems.

Pacific Biosciences began as a startup in 2010 using CNF facilities and has now achieved a market capitalization of $5.2 billion (as of October 2021).

Micronic Technologies is a Virginia-based, woman-led early-stage clean technology company that has received a $3 million seed round investment from The Center for Innovative Technology (CIT) and The Pearl Fund, with participation from CAV Angels. NanoEarth was used to demonstrate the effectiveness of their core technology which resulted in an invention disclosure, multiple proposals, including SBIR, and support in securing private investment.

Monolith Materials works with NNF scientists in their building of a hydrogen burning power plant in Hallam, Nebraska. NNF's electron microscopy analysis of carbon nanoparticles is used by the company as they develop novel nanoparticle-based inks, paints, electronics and UV absorbers.

SDNI provides technical support for several startup companies for development of their disruptive technologies in biotech. **Isoplexis** issued its IPO in June 2021, while **Roswell Biotechnologies** and **NanoCellect Biomedical** each raised over $50M in venture capital funding and sold products internationally.

Inpria Corporation, an Oregon State University (NNI) spin-off whose metal oxide EUV photoresists are used in microchip fabrication has attracted investors, such as Intel and Samsung, was recently acquired by the Japanese firm JSR for $514 million.

A number of start-up companies began their existence using SENIC facilities and continue to do so even after they have recently achieved successful business exits. **MedShape, Inc.** develops medical implants based on shape memory alloys and was acquired by DJO in April 2021. **Nextinput** created a MEMS force sensor used in consumer, automotive, and medical applications and was acquired by Qorvo in May 2021. **Axion Biosystems** has pioneered microelectrode array technology for high-throughput assays and was acquired by Summa Equity in July 2021.

12. NNCI Site Reports

NNCI sites were asked to provide summary information as part of this Year 6 report. Specific information requested included:

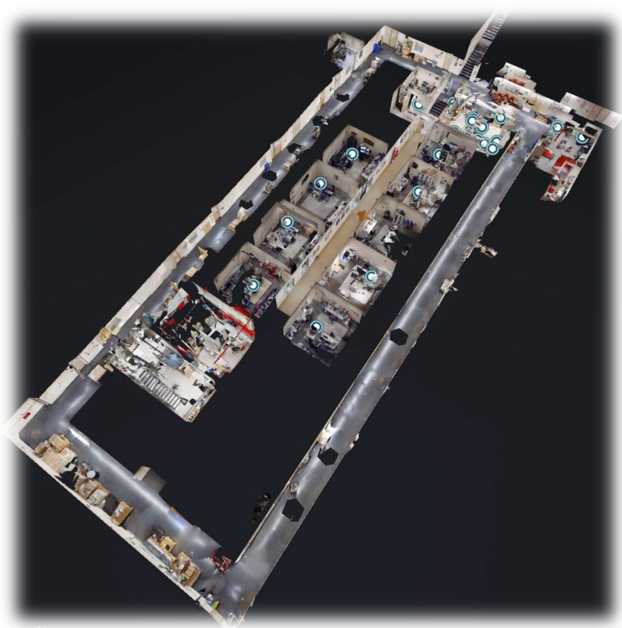
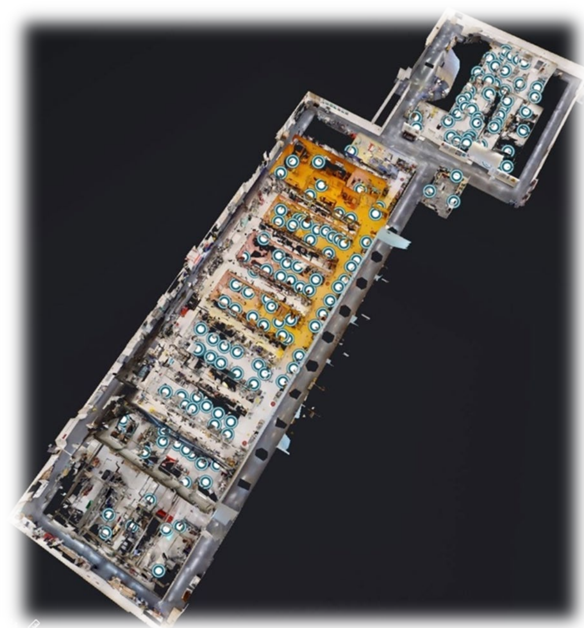
1. A brief narrative corresponding to the NNCI Year 6 (Oct. 1, 2020 - Sept. 30, 2021).
    a. Facilities, tools, staff updates during the year
    b. User base – marketing, outreach and support activities, including any specific research strengths or focus of the site
    c. Research highlights and impact – include brief mentions of any significant user accomplishments as well as scholarly and economic impact. Note: Research and education highlight slides are provided as a separate document.
    d. Education and outreach activities summary
    e. Societal and ethical implications activities (if applicable)
    f. Computation activities (if applicable)
2. A listing of all external user institutions for NNCI Year 6, separated as follows: Academic, Small company (<500 employees), Large company, Government, International, Other. See Appendix 14.4 for the complete listing. Due to disclosure limitations, some external users asked that their information not be shared, and the number of these are indicated in the appendix.
3. The number of publications in each category for calendar year 2020. The list of publications may have been part of each site's Year 6 report to NSF, but the data presented here (Section 11.3 above) are only aggregate numbers of publications for the NNCI network.
4. A list of site-site or network-wide activity, including proposals, facility operations, education/SEI programs, staff interactions, or other events. This is provided in Section 10 above.
5. User survey data, if the site did not participate in the common NNCI user survey for 2021. This data was added to the survey results presented in Section 8.3.
6. For this Year 6 report, all sites were asked to provide information that contribute to understanding the impact of NNCI. In particular, updates to the list of supported centers and degrees granted to users, along with the funding sources collected during 2021, are presented above (Sections 11.4-11.6).

In addition, the user statistics for NNCI Year 6 (Oct. 2020-Sept. 2021) were collected from the sites and used by the Coordinating Office to generate both the aggregate network user activity described in Sections 11.1 and 11.2 above, as well as the individual site usage information shown after each site narrative below.

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

12.1. Center for Nanoscale Systems (CNS)

This has been a very challenging year for the Center for Nanoscale Systems as it has continued to be for the nation. While we have been getting used to our new normal, Covid-19 still has impacted all research operations during this period from October 2020 – October 2021. Our labs are not back to full capacity and we expect to be in this reduced mode at least until the fall of 2022. In spite of this, PI Westervelt and co-PI Wilson, the Operational Director of the center, have been continuing the assessment, revamping, and augmentation of the tools and instrumentation available at CNS for advancing transformative Nano and Quantum science. Our staff have adapted to protocol changes that have allowed us to safely re-open our labs. As noted in our end year report last year, we were allowed to use user experience as our trigger for access. This allowed us to remain open for both *internal and external* users. We stressed to the University that admission of external users was of paramount importance. We believed that it was really important to strongly support our start-up user-base, as many of these small companies depend on our resources for their survival, and for many survival was in question. During the last year we have widened the door for more inexperienced users but our operations in Cambridge have been recovering slowly. We did use some of our research bandwidth to develop a VR model that allows us to give virtual tours of the lab, (now accessible from our website.) In addition, we opened satellite facilities, (with staff support), on the new Harvard Engineering Campus.

Virtual maps of Harvard CNS. (left) Imaging level. (right) Cleanroom Level. The markers are links to information for specific tools and instruments. They direct the visitor to the relevant pages on the CNS website.

Specific tool examples. (left) Cleanroom SEM, (right) The Atom Probe. Note, the marker links direct the tour to the tool information.

The VR tool allows for a quite detailed look at CNS tools. Throughout the map there are link tags that directly connect to website information on the tool/instrument on the map. To access the VR map the link is https://my.matterport.com/show/?m=hcTD1ZqpsKu and is now operational.

Facility, Tools, and Staff Updates

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

CNS Allston Spaces:

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

New Harvard Science and Engineering Center (SEC)

New CNS Tools/ Instruments: This year we have added one new permanent staff to support the Allston satellite and have modestly expanded our instrumental research capabilities. A list of modest new instruments is listed below, and we note essentially that we have experienced a 6 month vendor shutdown which is just getting lifted now. As noted above during the pandemic we have expanded the capabilities available to remote train the user-base, both in the nanofab and the other instrumentation focused areas of the lab. Our team has developed training materials using "StoryLine" a course development software platform. The new tools and/or instrumentation include a new Jupiter AFM, (which will be located in our cleanroom), which will be used to measure large format samples and will enable "tip driven nanostructuring of 2D materials. In addition, we have acquired a number of replacement processing tools.

Instrumentation/Tool additions:

- Asylum Jupiter AFM (Added to Fab for measurements and re-structuring inside cleanroom.)

Other Nanofabrication additions:

- Xactix XeF_2 Etcher
- Samco Oxygen Plasma Etcher

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

Advanced Electron Microscopy:

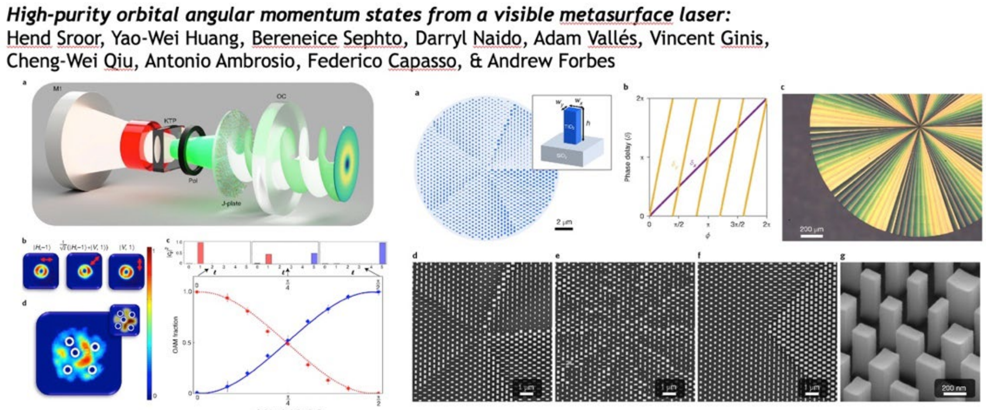
We have also finalized the delivery of the "Harvard Quantum Imager" a Hitachi 300keV aberration corrected electron microscope, which has an ultra-high-resolution energy filter and the capability of imaging magnetic materials with atomic-resolution. (*This was quite an accomplishment given delays driven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

<u>User Base</u>

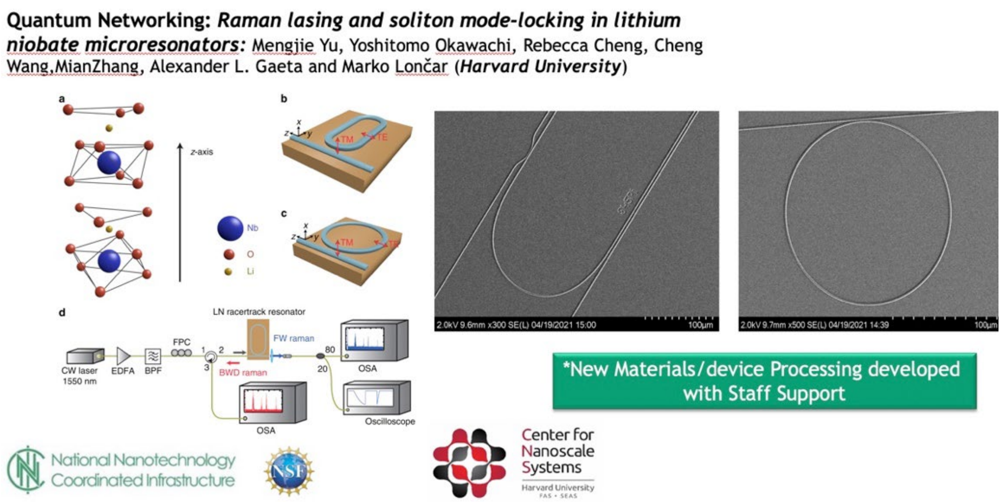
This year, even with our continued Covid-19 restrictions our accumulated user-base topped 669 active users (as of 9/30/2021). (Note: active users are users that have accessed CNS resources during the reported grant period.). Importantly ~43% of our user base is non-Harvard, 30% being external academic users and ~13% industrial users, (~60% of which are from small companies). Overall consistently of order 11% of our user-base over the last 6 years are small businesses.

<u>Research Highlights and Impact</u>

This past calendar year (2021) there were 112 publications. Some highlights of the work include advances in photonics, quantum science and technology, and quantum networking. Examples of some of this work are detailed in the panels below.



MetaSurface Photonics

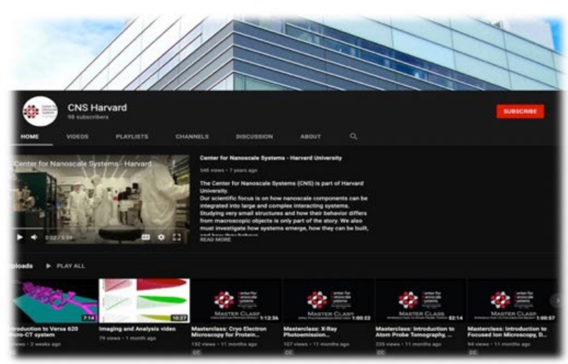


Integrated $LiNBO_3$ Photonics

Education and Outreach Activities

Outreach activities focused on remote activities. We ran a remote REU and continued to augment our Master Class series shown in the figure below.

- **Cryo-Electron Microscopy for Protein Structure**, Svetla Stoilova-McPhie (113 views) https://youtu.be/YRJ8Ts_8Hic
- **X-Ray Photoemission Spectroscopy**; Greg Lin (94 views) https://youtu.be/Je_KeUQIrdk
- **Introduction to Atom Probe Tomography**, Dr. Austin Akey (216 views) https://youtu.be/K4AQQZP06C8
- **Introduction to Focused Ion Microscopy**, Dr. Stephan Kraemer (87 views) https://youtu.be/b_AcT4aBIP0
- **Intro to 3D Printing with FormLabs**, Sandra Nakasone (71 views) https://youtu.be/_wNfHZX5cdg
- **Biological EM sample preparation**, Nicki Watson (64 views) https://youtu.be/YRW3w9k4eRQ
- **Energy Dispersive X-ray Spectroscopy**, Jules Gardener (82 views) https://youtu.be/02jtzq4Zf5k
- **Optical Spectroscopy**, Dr. Arthur McClelland (277 views) https://youtu.be/A501lKr1XZ4



Master Class Series

We also began "re-connection" with our CNS scholars so they could plan the "spin-up" of their research activities.


*Prof. K. Dorsey – Smith College


Prof. T. Searles – Howard University


Prof. R. Horton – Miss State University


Dr. Pia Sorenson – SEAS


Prof. K. Aidala – Mount Holyoke


Prof. T. Brower-Thomas – Howard University

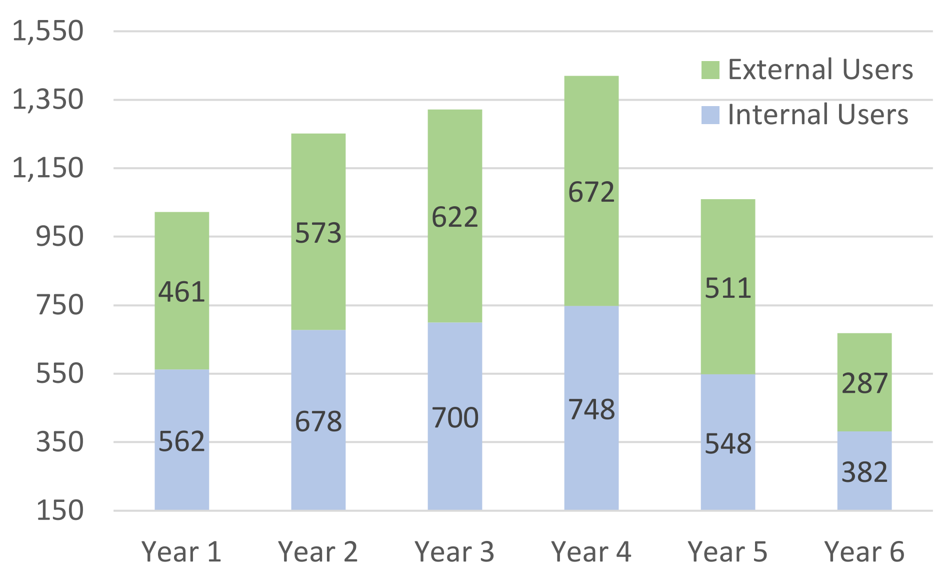

Prof. D. Simien – UAB

Reconnecting *Post-Covid*

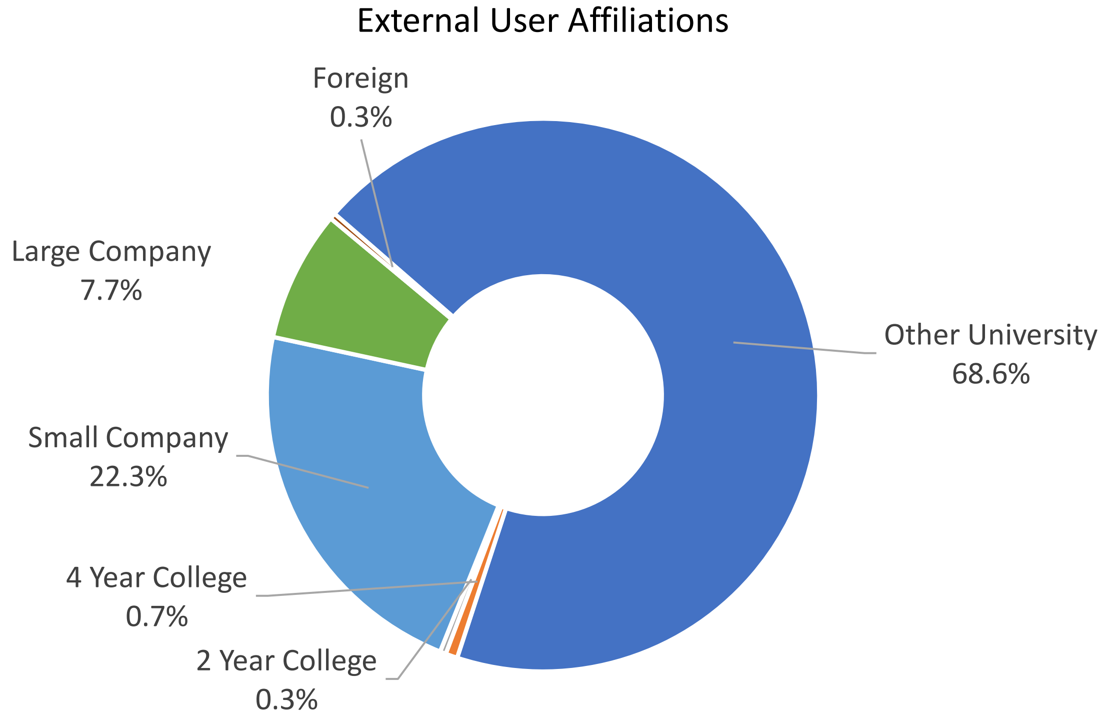
*NSF Career Awardee

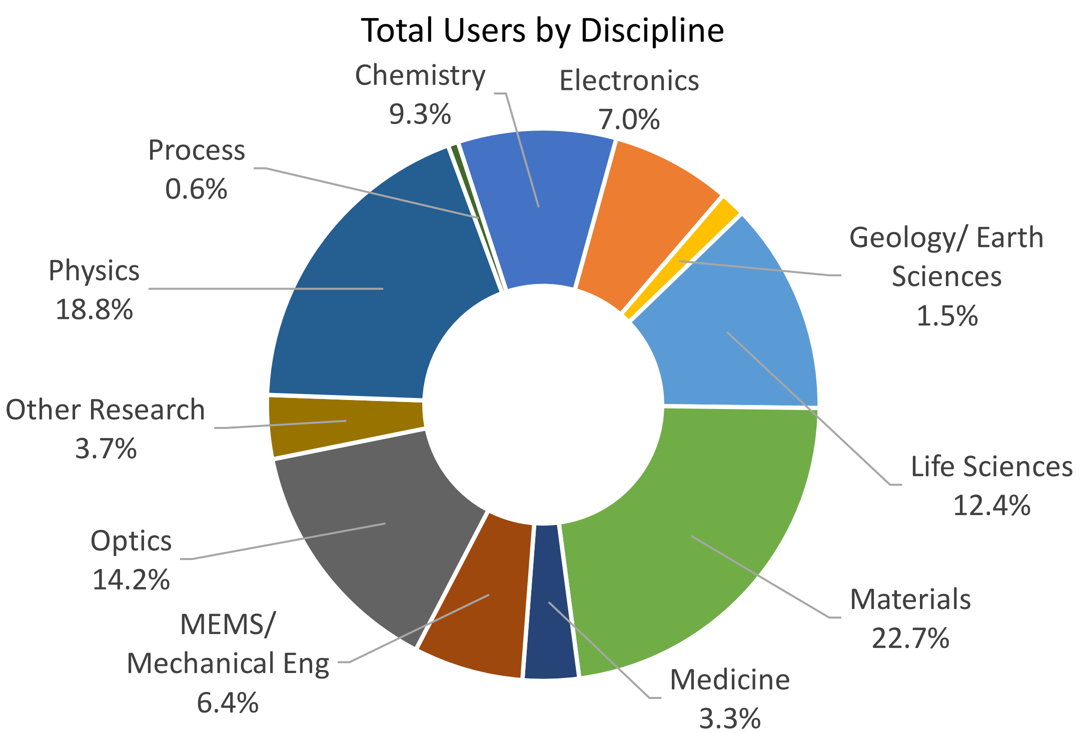
CNS Site Statistics

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



CNS Year 6 User Distribution





12.2. Cornell Nanoscale Science and Technology Facility (CNF)

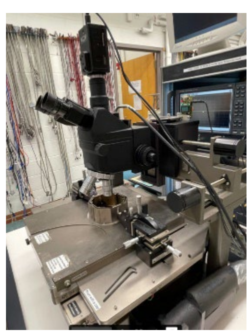
Facility, Tools, and Staff Updates

The **Cornell Nanoscale Science and Technology Facility** (CNF) is a uniquely capable, open-access user nanofabrication center offering outstanding tools and capabilities for both research and prototyping. Recognized as one of the largest and most comprehensive sites in the **National Nanotechnology Coordinated Infrastructure (NNCI**), CNF has consistently demonstrated the ability to bridge disciplinary boundaries; providing innovative solutions to challenging, multi-step, micro- and nanofabrication processes.

The CNF employs a highly skilled staff to meet the demands of a diverse user base. Proficient at assisting users at all levels the CNF team can focus on the individual needs of the research community. The CNF maintains a full complement of processing and characterization equipment (i.e., over 180 state-of-the-art lab instruments) with emphasis on electron beam lithography at the smallest dimensions, advanced stepper-based photolithography, and a wide array of software, characterization, imaging, testing, packaging, printing, deposition and etching resources. Its diverse toolset enables processing of the widest spectrum of materials in NNCI. The CNF prides itself on being a broad-based, interdisciplinary facility with initiatives spanning the physical sciences, engineering, and life sciences. CNF actively strives to remain at the forefront of technology while exhibiting responsiveness to new user requests and research trends.

CNF regularly updates and expands its equipment base to maintain a broad set of state-of-the-art equipment and to address areas of growing interest. To remain at the forefront of nanotechnology research new and more advanced capabilities must be constantly added to the suite of available CNF tools. The following tools have been acquired or installed/qualified during the past year:

New CNF Tools	
Plasma Therm (ALE) Atomic Layer Etching System	Plasma Therm HD PECVD
Veeco Savannah Atomic Layer Deposition System (ALD)	200 mm Hardware for OEM Endeavor AlN Sputtering System
Brucker Dektak XT-A	DC Probe Station and Electronics
Angstrom Engineering UHV Load Locked Evaporator	Microwave Small Signal Probe Station and Electronics
mm-wave Vector Network Analyzer and Probe Station	Microwave Large Signal Test System-Load Pull System

UHV Load Locked Evaporator, Microwave small signal test system, Veeco ALD system, Plasma-Therm HDP PECVD

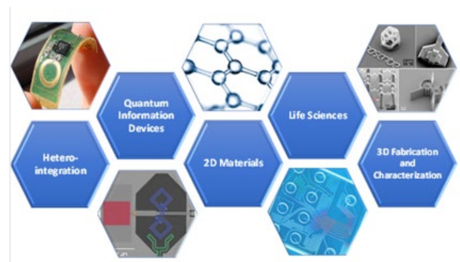
CNF and the Cornell Institute of Biotechnology (Biotech) have partnered to further advance Cornell’s excellence in Life Science characterization and imaging capabilities. Now CNF users have access to 18 additional 3-D characterization tools including a variety of confocal microscopes, super-resolution microscopes, and micro/nano-x-ray-CT scanning.

CNF has also partnered with the Cornell Mechanical and Aerospace Engineering Department's Rapid Prototyping Lab (RPL) to make a broad range of 3-D printing technologies available. The CNF users now have access to 2 additional laser cutters and 10 additional multiscale, 3D printing resources. CNF and RPL staff will serve as a gateway to these new 3-D printers, providing consultation, software services, design help, billing, and user support.

CNF employs a team comprised of technical management (2 FTE+faculty directors), administrative staff (2.75 FTE), and a laboratory technical staff of 18 (17 FTE) responsible for equipment maintenance, user instruction, and process and user support. The primary function of the CNF is supporting the user program. The expertise and experience of these team members is critical to CNF's operation; the median tenure of staff at CNF is currently 20 years. During this year a new Program Assistant was hired to further support team initiatives. The new Program Assistant dedicates 75% of her time assisting with new user onboarding for the CNF and 25% supporting another Cornell resource. The CNF also hired a new technician to assist with facilities, maintenance and equipment installation. One member of the academic staff was promoted to fulltime status while another left to pursue a career in industry.

<u>User Base</u>

Historically, the CNF has encouraged the application of nanotechnology across broad fields. This effort continues and is reflected in the diversity of the current user base; many hailing from non-traditional fields of nanoscience. CNF has exhibited continued strength in support of applications in the life sciences area. As part of its strategic plan CNF has highlighted several areas as Strategic Initiatives over the next decade. These include:



CNF Strategic Areas

- **Heterointegration:** The evolution of nanoscience will require increasingly more complex systems. We envision integrated systems where traditional electronic chips including stacked chips, are integrated with photonics, polymer materials, or even biological materials, for novel applications. CNF will continue to acquire equipment and expertise to serve this evolving area.
- **Quantum Materials and Devices:** Fabricating and understanding a broad array of new materials provides the basis for advances in quantum materials and devices supporting a national imperative. CNF has joined with 3 other NNCI sites to form the Global Quantum Leap, an NSF AccelNet (network of networks) program to impact international information exchange and human resources.
- **2D Materials:** Thin film 2D materials are enabling both electronic structures with dramatic new electron, photon, and polariton properties. Cornell faculty provide significant support for 2-D materials research. CNF fully supports the activity of PARADIM, an NSF Materials Innovation Platform (MIP) with significant activities in materials discovery.
- **Life Sciences:** CNF has a long history (30+ years) of actively supporting projects involving biological applications of nanotechnology. Current CNF projects include extensive work in bio-sensors and microfluidics. The tools of nanotechnology also enable advances in

bioengineering and medicine; an area where CNF has excelled for many years. CNF leads NNCI facilities with percentage of users in the life sciences.

- **3D Fabrication and Characterization:** As part of its renewal proposal, CNF has established a partnership with an existing imaging facility within the Cornell Institute of Biotechnology and an existing 3D printing facility in Mechanical Engineering. These new capabilities are needed to meet the demand of the electronics, photonics and life sciences communities.

CNF will continue to invest in and promote these strategic areas while supporting users from all areas of nanotechnology.

Research Highlights and Impact

CNF exists to enable cutting edge research across the nanotechnology spectrum. Naturally, this includes significant contributions from Cornell research groups. We are, however, particularly proud of our support for non-Cornell research groups. These groups utilize CNF by choice, even when similar facilities exist closer to home or at their own universities.

Each year CNF collects technical research reports for projects utilizing CNF resources. These summary reports highlight accomplishments by each user and are compiled and published as the **CNF Research Accomplishments**. The **CNF Research Accomplishments** are readily available in print and electronic form on the CNF web site https://cnf.cornell.edu/publications/research_accomplishments/2020-2021. This annual publication includes details of CNF user nanofabrication discoveries, use of CNF technologies and tool capabilities and patents, presentations, and publications related to user research.

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

The CNF provides critical support for research within NSF's 10 Big Ideas, including Understanding the Rules of Life, Quantum Leap, and Convergence.

The research conducted by CNF users yields a large number of publications, presentations, and patents; too many to itemize via the report module. CNF collects publications, presentations, and patents from its users on a calendar year basis. We make a diligent efforts to encourage all publications to properly acknowledge the CNF and the NSF award number. Users are also encouraged to report their publications to CNF; however, there is room for improvement in reporting. Nontheless, these numbers should be considered as the minimum, documented impact of CNF research.

The user research collected during the 2020 calendar year resulted in at least:

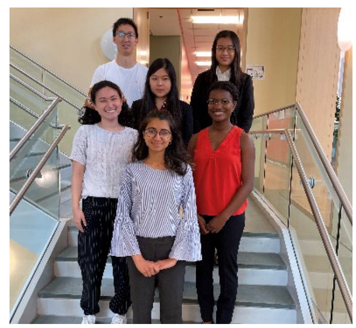
- 228 Publications
- 44 Presentations
- 91 Patents and Patent Applications

In addition, over 41 citations have been collected from 2021 to date.

CNF remains an effective resource for the commercialization of nanotechnology. One hundred twenty-nine different companies (95 small/startup and 34 large) have utilized CNF for major research and development/prototyping under NNCI. In addition, CNF continues to serve as an engine for small business economic development. Since the inception of the NNCI CNF has averaged three, new startup company launches per year based on CNF developed technology including; Xallent, Esper Biosciences, Logrus, FloraPulse, Ultramend, Jan BioTech, Heat Inverse, JR2J, White Light Power, Odyssey Semiconductor, Inso Bio, Halo Labs, GeeGah, CyteQuest Soctera and OWIC Technologies. Beyond CNF inspired startups, CNF provides access to critical nanotechnology supporting an extensive group of small and large companies involved in the commercialization of nanotechnology. During the recent year this included 31 small U.S. companies and 12 large U.S. companies. The flexibility of CNF's tool set and low barriers to entry (legal, technological, and financial) provide an ideal environment for rapid technology development.

Education and Outreach Activities

The CNF supports a broad range of education and outreach activities at all levels spanning from K-12, post-secondary, professional and general public access. Unfortunately, due to COVID restrictions, essentially all in-person outreach activities had to be cancelled, postponed, or reformulated. However, in 2021, CNF hosted or participated in 65 events for a total of 2055 participants including an in-person, summer internship for Cornell undergraduates, two virtual short courses, an NNCI workshop on Quantum Engineering Infrastructure, hands on nanotechnology experiments with local Cub Scouts, a virtual CNF Annual Meeting, and a very successful virtual cleanroom tour for Cornell alumni. Since 1997 the widely successful, REU program remains the premier education and outreach program offered by the CNF. The CNF REU program is conducted in coordination with programs at other participating NNCI sites. Despite COVID restrictions in 2021 the CNF was pleased to offer an in-person REU program exclusively to six currently enrolled Cornell students (image right). *Kareena Dash, Niaa Jenkins-Johnston, Elisabeth Wang, and Zhangqi Zheng* from the undergraduate College Of Engineering, *Micah Chen* from the Cornell Center for Transportation, Environment, and Community Health's (CTECH) REU Program and *Francesca Bard*, a summer undergraduate student and CNF user, all benefited from participation in the program.



CNF REU summer interns

For the second year since the start of the COVID-19 pandemic, the Cornell NanoScale Science and Technology Facility (CNF) held a virtual annual meeting allowing for the opportunity to showcase excellence in research demonstrated by users and research groups utilizing the plethora of resources offered at the CNF.

The themes for the user meeting focused on quantum information devices, life sciences, and Artificial Intelligence (AI). Presenting the keynote addresses were Professor Debdeep Jena (DJ) from the Cornell Electrical and Computer Engineering and Materials Science and Engineering Departments and Professor George Malliaras from the University of Cambridge and former CNF Director. CNF users were also invited to provide highlights of their accomplishments over the last year. The proceedings and released presentation videos of the meeting can be found at https://www.cnf.cornell.edu/publications/research_accomplishments/2020-2021

Richa Agrawal 2021 Whetten Award winner

Annually the CNF presents the Whetten Memorial Award in recognition of young women scientists whose work and professional lives exemplify a commitment to scientific excellence, interdisciplinary collaboration, professional and personal courtesy, and exuberance for life. The 2021 award was presented to Richa Agrawal (Figure 4) of the Meinig School of Biomedical Engineering, Cornell University.

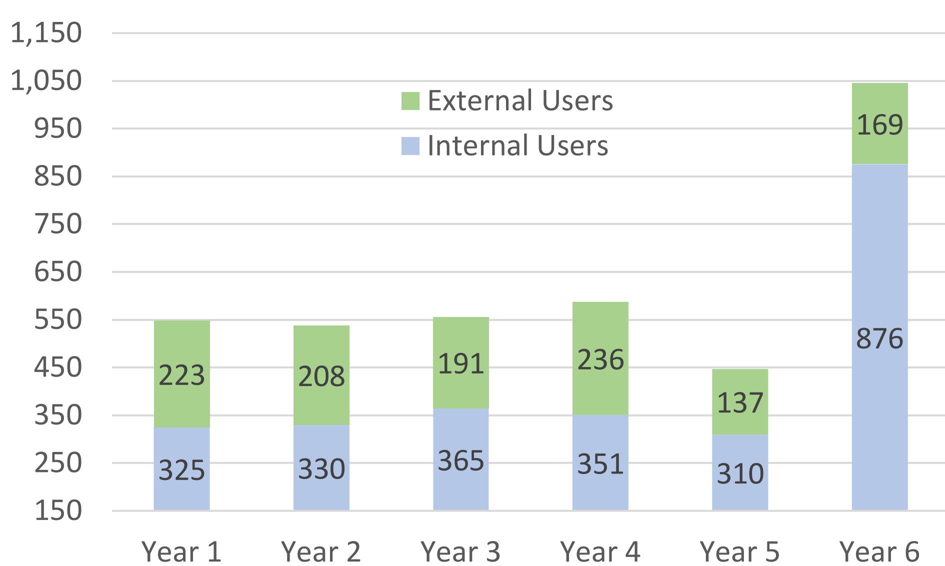
Under NNCI, CNF has continued to partner with NY 4-H to assist with STEM-based content for young students. 4-H provides an extensive network at state and national levels for platforms, logistics, and outreach for students ages 8–18. This summer CNF hosted 4-H students from across NY State at the Cornell Annual Career Explorations. In the fall, the CNF also participated in a weekend long, National 4H summit educating students about nanotechnology and how it relates to interplanetary and interstellar space exploration.

Tom Pennell, the CNF Outreach Coordinator also created five, new at-home nanoscience experiments based on photolithography, materials science and nano-robotics. He has provided nearly 300 experimental material packets for distribution to youth groups interested in learning more about the field. Tom has also been working with BOCES New Visions Engineering groups from Tompkins and Onondaga Counties to introduce young scientists to the CNF and the innovative technologies being developed.

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

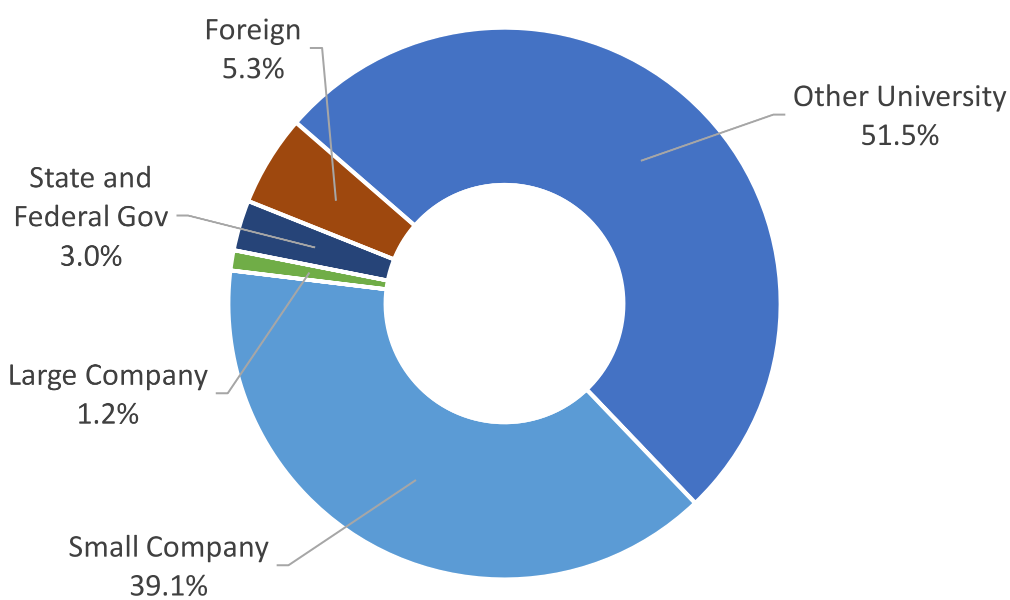
CNF Site Statistics

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

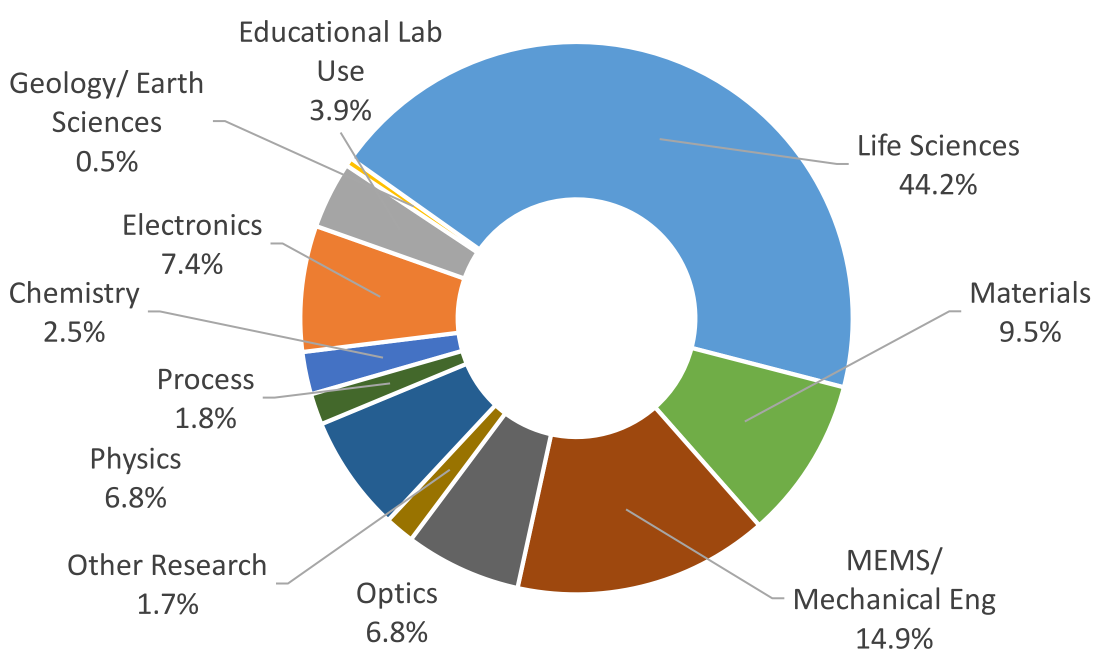


CNF Year 6 User Distribution

External User Affiliations



Total Users by Discipline



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

Facility, Tools, and Staff Updates

Despite the unfortunate COVID challenges, our KY Multiscale NNCI site remained both busy and productive during this reporting period. While we had to shut down most of our core facilities for up to 3 months and cancel many of our face-to-face activities, the pandemic created some interesting opportunities for our cores and staff to help our community as they struggled with the virus. For example, several of our core facilities donated personal protection equipment (PPE) to the COVID cause. Our AMIST additive manufacturing facility took the lead on a regional effort to 3D print protection faceshields and swabs for Coronavirus testing. At UK, Prof. Dibakar Bhattacharyya, director of the UK Center of Membrane Sciences, lead a team of scientist in the development of a membrane that will not only effectively filter out the novel coronavirus, like the N95 mask does, but deactivate the virus completely. They have pending proposals into various funding agencies. At UofL, a startup company, AdhviQ, was established to mass produce both disposable and washable N95 masks using newly developed technology from the Conn Center. This activity was supported by our new Seed Funding Program for new users.

The COVID pandemic made it a challenging year for new equipment purchases. However, our site was still able to make a few very critical acquisitions during this reporting period. A new **Fisher Scientific Apreo Scanning Electron Microscope (SEM)** was purchased for the UofL Micro/Nano Technology Center (MNTC). The tool features two in-lens detectors useful for topography and z-contrast, a scanning transmission detector for high resolution imaging, and a low vacuum detector to image nonconductive materials. The tool is also capable of performing energy dispersive X-ray spectroscopy. During this period, we devoted efforts to fully characterize the tool, create training videos, and offer virtual instructional workshops.

In Year 6, the MNTC was asked by the UofL VPR Office to take over the operations of the university **Hitachi HT7700 Tunneling Electron Microscope TEM** located at the School of Medicine. The addition of the TEM is a strong complement to the existing electron microscopy capabilities of the MNTC. This instrument is specifically used to image biological specimens and operates at 80kV.

Our NNCI site recently won a large $1.5M NSF MRI award to UofL Endowed Professor Dan Popa entitled "MRI: Development of a Multiscale Additive Manufacturing Instrument with Integrated 3D Printing and Robotic Assembly". In this project, Professor Popa and his team of co-PIs are developing a custom tool called ***Nexus***, which is an autonomous advanced manufacturing robotic system that integrates several fabrication modules, including 3D printing, aerosol jet direct write printing, intense pulse light curing, and fiber weaving.

New DRIE System - One of the workhorse and most popular tools of our KY Multiscale NNCI site is our Deep Reactive Ion Etcher (DRIE). Our current system is over 25 years old, having been purchase in the 1990's from a winning NSF MRI award. It is literally on its last leg and needs to be replaced as soon as possible. Therefore, during this reporting period, we successfully solicited support through a combination of the Executive Vice President of Research, the Engineering Dean, the MNTC center, and the NNCI grant. In total we secured over $900K of funding. Our team evaluated competitive bids and placed an order for a new DRIE system from Oxford Instruments. This system will be installed in early 2022.

Micro CT System, Ion Polisher, and X-ray Diffractometer – The KY Multiscale UK cores added a Thermo Scientific HeliScan Mk2 X-ray micro-computed tomography system. The system offers high-throughput 3D imaging of sub-micron structures and also enables dynamic in-situ experiments. The system is housed in the University of Kentucky Electron Microscopy Center (EMC). We have also placed an order for a new JEOL IB-1952OOCP cryogenic, broad-beam ion polisher. The ion polisher is intended for creating damage-free cross sections for electron microscopy and microanalysis with a particular emphasis on hard to prepare mixed-materials, biological, and larger area samples for with FIB is not well-suited. We have placed an additional order for a new ARL Equinox 100 X-RAY Diffractometer. This compact, high-throughput, user friendly system, will offer users rapid access to x-ray diffraction for applications ranging from pharmaceutical science to additive manufacturing.

3D Printing Upgrades - The UofL Additive Manufacturing Institute for Science and Technology (AMIST) core facility started a new initiative during this reporting period called the "**Print Farm**". The Print Farm is a collection of about a dozen benchtop and tabletop 3D printers that is used to quickly and efficiently produce parts for students, staff and faculty. The 3D printers fabricate parts via Fused Filament Fabrication (FFF) and Vat Photopolymerization (SLA).

As discussed in the original KY MMNIN proposal, both UofL and UK agreed to target several faculty and staff hires during the course of the award in areas related to our NNCI theme. These hires are critical as they bring additional users and recognition to our NNCI core facilities. Below is a summary of the new hires which occurred during this reporting period.

Name	Appointment	Research Expertise
Dr. Alexandra Paterson (UK)	Assist. Prof. Mat. Science & Eng/ ECE	Organic Mat/flexible electronics/printed sensors
Dr. Paul Rottman (UK)	Assist. Prof. of Mat. Science and Eng.	Nanoscale materials. Additive manufacturing alloys and thin films.
Dr. Caigan Yu (UK)	Assist. Prof. of Biomedical Eng.	Bio-photonics.
Dr. Chris Fry (UK)	Assoc. Prof. Clinical Nutrition	Muscle Biology/electron microscopy.
Dr. William Gannon (UK)	Assist. Prof. of Physics	Quantum and Magnetic Materials.
Dr. Joseph Chen (UofL)	Assist. Prof. of Bioengineering	Biomaterials & Biomechanics
Dr. Bikram Bhatia (UofL)	Assist. Prof. of Mechanical Eng.	Nanotechnology, Advanced Materials, and Energy.
Dr. David Eaton (UK)	CAER Facilities Manager	Fuels, batteries, and environmental material recovery.

Kentucky Multiscale is currently conducting a **national search** for an experienced Faculty member who will serve as the **Director of the UofL Micro/Nano Technology Center (MNTC)**. Candidates are expected to have outstanding academic credentials; a demonstrated commitment to excellence in research in the field of nanotechnology, microtechnology, MEMS, electronics or other closely-related discipline; excellent teaching, communication and team skills; and the interest, experience and ability to serve as faculty director of our $30M Micro/Nano Technology

Center (MNTC), which is part of the prestigious NSF NNCI national nanotechnology network. The successful candidate will also serve as associate director of our NSF KY Multiscale NNCI site, with the expectation to lead the University's proposal for renewal in 2025.

User Base

Figure 1. 2019 KY NANO + AM Symposium

KY Multiscale's signature outreach event is our annual *KY Nano + AM Symposium*, which focuses on the intersection of nanotechnology and additive/advanced manufacturing (AM). The two-day event consists of parallel technical and business sessions, several joint keynote presentations by national renowned speakers, poster presentations, sponsorship opportunities, food and refreshments, core facility tours, and a valuable evening networking reception (see Figure 1). Local dignitaries includes the mayor of Louisville and the president of UofL. The annual conference includes an Industry Outreach Day where potential industrial users are invited to tour our core facilities. The goal of our annual Nano+AM Symposium is to bring together researchers in the Nano+AM space to discuss new findings, share results, discuss applications, debate the future, and network with one another. After two very successful events in 2019 and 2020 with approximately 200 participants each year, we had to postpone the 2021 symposium due to the state's and University's in-person event restrictions due to the pandemic. Instead, we spent the time planning for our next in-person event which will be held August 9-10 this summer.

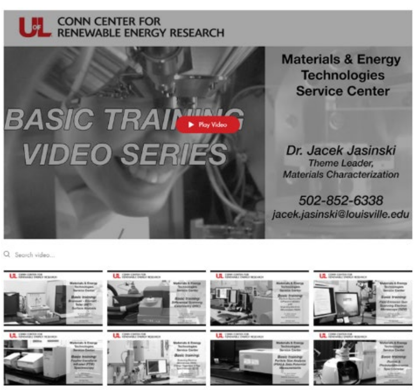


Figure 2. Training Video Series

With regard to other outreach and marketing activities, we devoted a great deal of time producing online materials and planning virtual events and activities. The KY Multiscale Core Facilities created videos highlighting our new labs and centers. These were distributed via email campaigns, virtual conferences, and our kymultiscale.org website. Our staff took advantage of virtual opportunities to expand our library of short training and educational videos on social media (YouTube, Facebook, Instagram and LinkedIn). Training videos were shared with current and new users who needed an introduction to the facilities and their unique capabilities. Educational videos were included in our KY Multiscale Newsletter which reaches an expanding audience of over **8,000 recipients** across the nation. Of particular success was our Halloween themed Nano Materials Video featuring spider webs, which we called **"Nano-ween".** Our MNTC core facility initiated a *capital campaign* with help from the UofL Advancement Office. The campaign named **"Make a Gift"** was distributed to potential donors, such as alumni, former users, investors, and local companies. In addition to this campaign, our staff took this opportunity to greatly expand our list of regional academic and

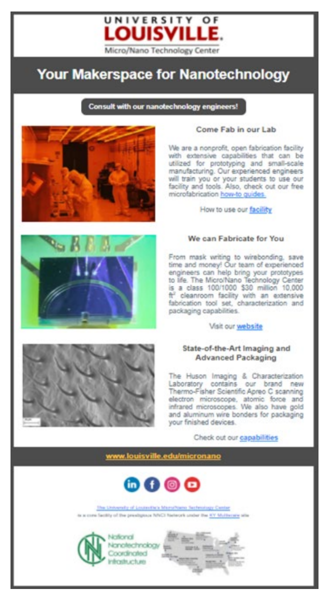


Figure 3. MNTC Regional Campaign

industrial contacts, a time-consuming activity requiring countless hours searching the web. As a follow-on, custom newsletters were produced to target these groups, such as the example shown in Figure 3 targeting **"Inorganic Sciences Users".**

As soon as in-person interactions were allowed, KY Multiscale personnel arranged a visit to meet the **Funai Corporation** regional team in Lexington, KY. We visited their cleanroom facility and discussed projects and the possibility of sharing resources. As a result, Funai now sits on our our Advisory Board and on our Symposium Organizing Committee. Very recently, **Ford** announced that they will be building a **Battery Factory in KY** to support their electric vehicles. We are meeting with Ford to explore a possible collaboration.

Figure 4. KY Multiscale Visit to Funai Lexington

Finally, in Year 6, KY Multiscale started a **Seed Program** to promote our core facilities to new users and increase their use among non-traditional users. This program provides members from both the internal and external scientific communities limited free access to our cores. Funding is limited to $1000 and must be used within a 6-month period. The application process is relatively simple and a final report is required at the end. The Table below lists our awardees during this reporting period.

Recipient Name	**Industry/Academia**	**Project Title**
Hans Mayer	Academia – California Polytechnic State University, San Luis Obispo	Development of New Microelectronics/Microfluidics/MEMS Mask Set for Cal Poly SLO Microfabrication Laboratory
Josh Hood	Academic – UofL Department of Pharmacology and Toxicology	A Microfluidic Device to Fractionate Colloidal Suspensions of Nanoparticles and Nanovesicles
Kalyan Kakarala	Industry – AdhviQ Technologies LLC	Facemasks with Nanowire Technology
Michael Merchant	Academia – UofL School of Medicine	Lab-on-a-chip approach for the study of archived tissue multi-omics studies
Zain A Malik	Industry – Kentucky Advanced Materials Manufacturing	Growth Condition Optimization of Single Crystal Diamonds
Daniel Moore	Academic – UK Department of Ophthalmology	Nanoplastics in the Human Eye (previous seed award that received additional follow on funding from the Center for Appalachian Research in Environmental Sciences Early Career program)

Research Highlights and Impact

Lead and Copper Removal from Water Using Carbon Electrodes in an Electrochemical Filter - Lead concentrations in drinking water are nationwide concerns in the United States. Likewise, metals removal from industrial waste water is critical for many industries. The company PowerTech Water used the KY Multiscale core facilities at the University of Kentucky to perform research that demonstrated that carbon electrodes in an electrochemical filter can target certain metals for removal or recovery. The device uses activated carbon electrodes and a small applied voltage to precipitate metals from solution and trap them in the porous electrode matrix (see Figure 5). This system achieved >90% lead removal, while leaving other species (eg. Na^+ and Ca^{2+}) in solution. Targeted Cu removal was also demonstrated. The results of these studies show the promise of electrochemical treatment for both public water supplies and industrial waste streams. This research was performed by L. Boehme, J. Landon, A. Rassoolkhani, J. Rentschler, and C. Lippert of PowerTech Water Inc. Funding was provided by DOE DE-SC0021567 and NIH R44ES028171. This research was presented by L. Boehme et al. at the *ECS Meetings Abstracts MA2021-02, 1771 (2021).*

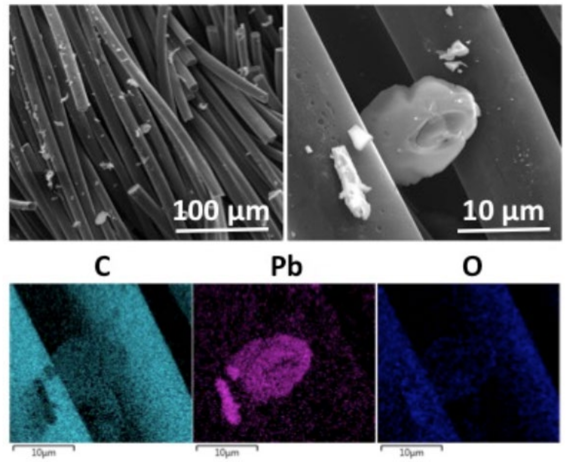


Figure 5 - Electron micrographs (upper panels) and energy dispersive X-ray spectroscopy maps (lower panels) of lead immobilized on a carbon electrode

Aerosol Jet Printing Conductive Traces and Sensors on Flexible Surface - Aerosol Jet Printing is a maskless, direct-write, additive manufacturing solution that reduces the overall size of electronic systems by using nanomaterials to produce fine features and embedded components. The resulting functional electronics can have line widths and pattern features from 10 microns to several millimeters. KY Multiscale has designed an autonomous robotic system that integrates aerosol jet printing along with several other advanced manufacturing modules. Using this system, one can directly deposit a wide range of materials, including conductive metals and nonconductive polymers, onto essentially any substrate and orientation. Our system enables a wide range of applications that include flexible electronics and sensors which can be manipulated to meet the user's specific requirements. A 6-DOF (degree of freedom) positioner is integrated with the aerosol jet print engine and is capable of printing different geometric structures such as pads, traces, strain gauges and interdigitated fingers. NovaCentrix JS-A426 silver ink was used as the conductive material and the process recipes were optimized/tuned by changing the sheath flow rate, atomizer flow rate, substrate material, stand-off distance and stage speed to change the morphology of the printed lines. Using this system, we successfully printed miniature strain gauges on a variety of flexible surfaces, as shown in Figure 6. This

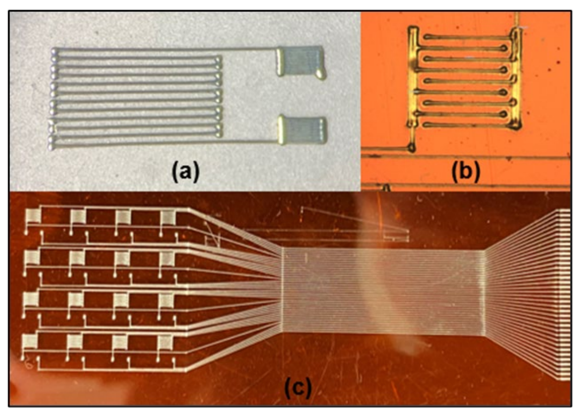


Figure 6 - (a) a strain gauge with pads printed on a glass slide, (b) interdigitated fingers on Kapton, (c) a skin sensor array printed on Kapton

research was performed by Dilan Ratnayake, Alexander Curry and Kevin Walsh of the University of Louisville using the KY Multiscale Micro/Nano Technology Center (MNTC). It was supported by NSF NNCI Award 2025075 and NSF MRI Award 1828355. Resulting publications included: 1) Ratnayake, D., Curry, A., Qu, C., Usher, J., and Walsh, K., "Characterizing the conductivity of aerosol jet printed silver features on glass ," *ASME 2021 15th International Manufacturing Science and Engineering Conference*, and 2) Ratnayake, D., Curry, A. and Walsh, K., "Demonstrating a new ink material for aerosol printing conductive traces and custom strain gauges on flexible surfaces", *2021 IEEE International Conference on Flexible and Printable Sensors and Systems (FLEPS)*.

<u>Education and Outreach Activities</u>

The KY Multiscale NNCI site remained actively involved in many educational and outreach activities this past year. While we had to cancel a few activities due to COVID, we still engaged in numerous impactful E&O initiatives, as highlighted below:

Solve Climate by 2030: Kentucky Climate Solutions Dialog. The "Green Recovery and Climate Solutions Initiative" was a worldwide virtual initiative held during the month of April (2021) that consisted of 136 events held by universities in every state in the USA and in 50 countries around the world. The UofL Conn Center for Renewable Energy Research (CCRER) took the lead for this initiative for the state of Kentucky with a public virtual webinar held on April 7, 2021 via YouTube.

Solar Decathlon Middle East Competition. The Conn Center also led a team for the Solar Decathlon Middle East competition, which took place in Dubai UAE in October 2021. Faculty members and students from the University of Louisville competed in the second Solar Decathlon Middle East (SDME) as part of an international team that included members from the American University of Sharjah (AUS), Higher Colleges of Technology (HCT) and American University in Dubai (AUD).

User Training & Intro Videos. As mentioned above, we transitioned most of our training workshops to a virtual format due to the pandemic. Here we highlight one that was especially successful and well-attended - our training workshop for our new **APREO Low Vac SEM.** The Webex introductory workshop was attended by approximately 30 staff and users. Basic image operation and the science behind Scanning Electron Microscopy Imaging were covered in a 2 hour long virtual session. Due to this activity, today the MNTC staff is able to *train users both in person and remotely*.

New Graduate Program in Materials and Energy. UofL introduced a new degree into their graduate program with the start of the MS MESE (Master of Science in Materials and Energy Science & Engineering) graduate program. This program offers advanced level training to provide students with in-depth knowledge of materials and energy science & engineering in areas such as materials science and engineering, materials chemistry and physics, processing, energy conversion and storage devices, and systems-level engineering.

Undergraduate Nanoscience Course with Transylvania University. KY Multiscale staff members Jillian Cramer and Brian Wajdyk provided instruction on two-photon lithography, assisted students with fabricating nanoscale 3D structures using the UK CeNSE Nanoscribe system, and helped students characterize these structures in the Electron Microscopy Center (EMC).

Advanced 3D Printing and Manufacturing Summer Camp. Hosted by the Additive Manufacturing Institute of Science of Technology (AMIST) core facility of KY Multiscale, this camp was offered to students from 7th-12th grade interested in using various 3D printers and related manufacturing equipment. The three-day course included lab tours and hands on project based learning with various 3D printing technologies.

Summer REU Program in Micro/Nano/Additive Manufacturing Technology. The KY Multiscale Site was able to offer our Research Experience for Undergraduates (REU) Program at the University of Louisville *in person* again in the summer of 2021. Our program trained a diverse cohort of interdisciplinary STEM students in the field of Advanced Manufacturing, with a special emphasis on micro/nano-manufacturing and additive manufacturing (i.e. 3D printing). We welcomed 13 students this past summer and they participated in the virtual 2021 REU Convocation. ***Our site will host the NNCI REU Convocation during the summer of 2022*.**

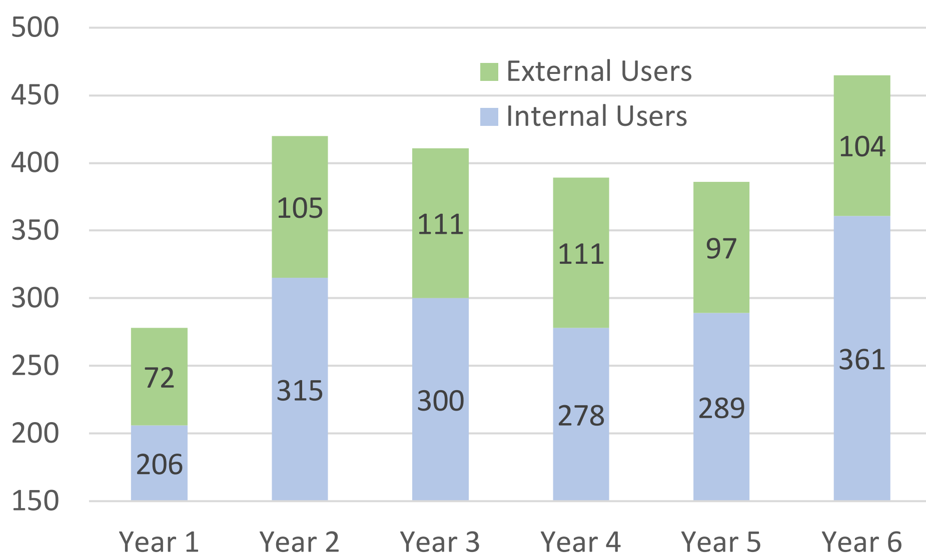
Engineered Bioactive Interfaces and Devices REU Program. The KY Multiscale Site continued to support UK's REU site program in Engineered Bioactive Interfaces and Devices. This program focused on creating device architectures engineered to interact with biological systems for applications in sensing, drug delivery, and tissue engineering. All student participants received an introduction to the Center for Nanoscale Science and Engineering (CeNSE) and the Electron Microscopy Center (EMC) core facilities.

Nanodays Celebration. In honor of National Nanotechnology Day (October 9), KY Multiscale joined the National Nanotechnology Coordinated Infrastructure (NNCI) Network in celebrating nanotechnology with a series of outreach and educational activities that engaged the general public and promoted STEM to a broad audience. This activity was done with our partner, the KY Science Center.

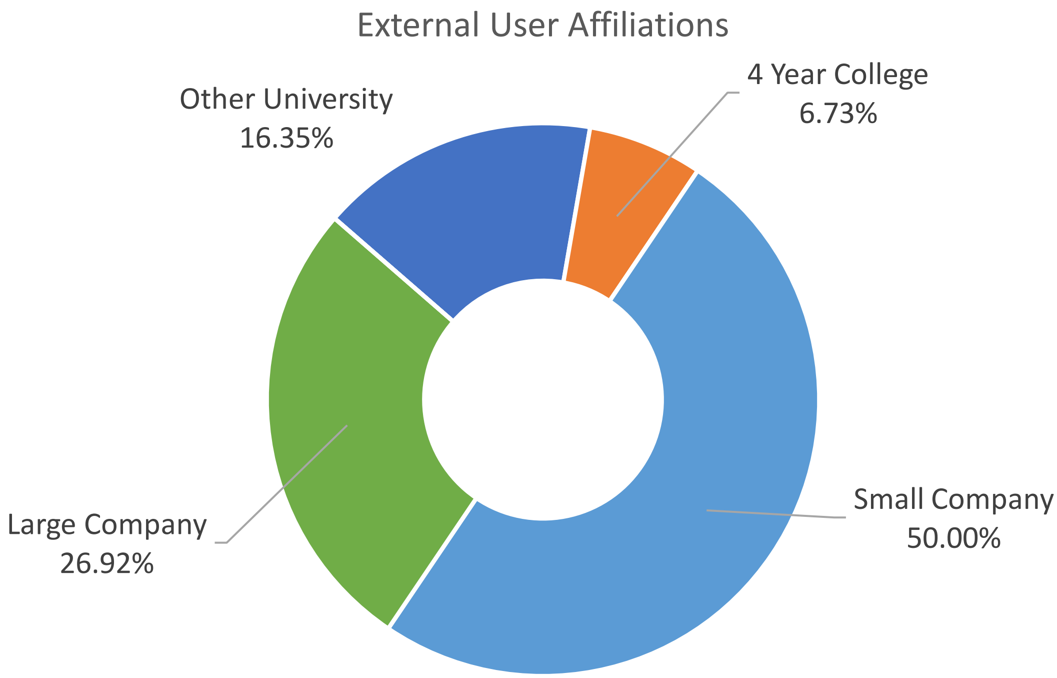
Nano Image Competition. KY Multiscale participated in this year's "Plenty of Beauty at the Bottom" Nano Image competition organized by the NNCI Coordinating Office. The winners from our local competition were forwarded to compete nationally. All of the images from our local competition were printed and permanently displayed on our own "Nano Gallery" on-site on the UofL campus.

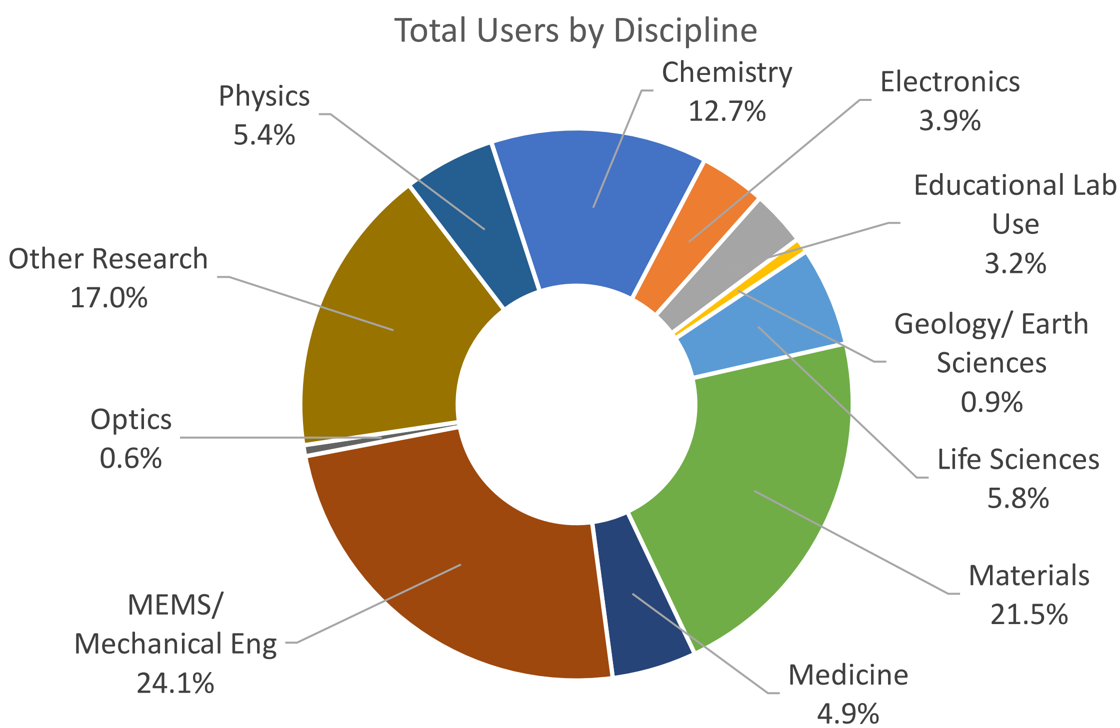
KY Multiscale Site Statistics

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



KY Multiscale Year 6 User Distribution





12.4. Mid-Atlantic Nanotechnology Hub (MANTH)

The Mid-Atlantic Nanotechnology Hub (MANTH) is based at the Singh Center for Nanotechnology at the University of Pennsylvania and has partnered with the Community College of Philadelphia (CCP) to develop workforce opportunities and nano-related curricula for 2-year college students. MANTH provides open access to leading-edge R&D facilities and expertise for academic, government, and industry researchers who work within all disciplines of nanoscale science, engineering, and technology.

In spite of continuing obstacles caused by the pandemic, researchers at MANTH made important contributions to nanoscience and nanotechnology. Surprisingly, although the number of users is lower than the pre-COVID count – both internal and external – the number of user hours exceeded previous years. Small company use of our labs was particularly strong; the share of equipment use hours for startups was significantly larger than that of other external users.

MANTH staff have implemented new ways to train researchers, including filming videos about equipment operation and requiring new users to present their projects in detail so that the staff may streamline training efforts. MANTH staff and faculty have also found innovative ways to deliver remote nanotechnology-related education outreach to high school and external college students in the past year.

The collaboration between Penn and CCP on workforce and curriculum for community college students has progressed in spite of COVID related setbacks. In particular, a nanotechnology technician internship program for CCP students has been formulated.

Facility, Tools, and Staff Updates

New Nanocharacterization Staff Member: Dr. Stephan Steimle. He joined the Beckman Center as Core Director, overseeing the MANTH Krios Cryo-transmission electron microscope, in September 2020.

New Nanofabrication Staff Member: Dr. David Barth joined the QNF staff on November 2021 as a Senior Manager - Lithography & Advanced Processing. He brings with him expertise in electron beam lithography and materials deposition.

New Equipment: Staff installed 3 new tools in the Quattrone Nanofabrication Facility (QNF) last year:

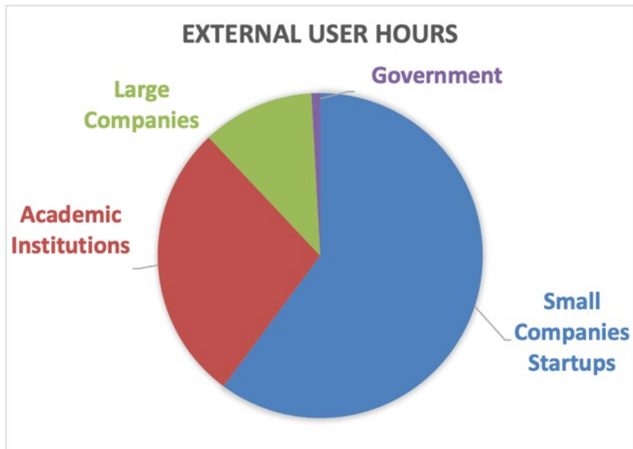
- MPT RTP-600s tabletop rapid thermal annealing system (RTA). This system supports back-end dopant diffusion/activation and metallurgical contact formation. The RTA can handle wafers and pieces up to 150 mm substrates. It is currently plumbed with Nitrogen and Argon and can reach temperatures up to 1200 C.
- Jandel 4-point probe station. This manually operated system, complements the new RTA by providing conductivity measurements after metal contact formation or dopant activation; it incorporates a constant current source capable of providing 10 nA to 99 mA and a digital voltmeter capable of reading 0.001 mV to 1 V. It can accommodate samples ranging from pieces up to 150 mm substrates. An accuracy of 0.1% is achieved across the measurement range from 1 milli-Ohms to 100 Mega-Ohms per square.
- Genesis oven for HMDS vapor prime Newly refurbished Genesis vacuum oven with updated touch screen and PLC control for performing HMDS vapor priming to support

lithography. Capable of processing samples ranging from pieces to multiple cassettes of 150 mm wafers.

Besides this new equipment, MANTH invested in OEM-supported Windows 10 upgrades for several key tools in order to extend their usable service life. The Suss Microtec MA/BA-6 upgrade included new backside alignment cameras and full PLC replacement. The SPTS DRIE Windows 10 upgrade included a replacement CTC (main) computer and a replacement for the embedded process control computer. The K&S Dicing saw upgraded included a new control computer and full PLC replacement. The Xactix XeF2 dry etch system upgrade included a replacement control computer.

User Base

434 unique researchers used the equipment and laboratories at MANTH in the period October 2020-September 2021. Data show a robust return of internal users, but the numbers of external users are significantly lower than that over the same time period before the pandemic.



In spite of this decrease in user *numbers*, it is interesting to observe that user *hours* were at an all-time high. The total number of user hours in Year 4 was 57,000, while in Year 6, researchers logged nearly 64,000 hours. The smaller number of users - yet greater number of hours - phenomenon we attribute to a more concentrated use paradigm: as the number of people allowed in the facility was restricted for many reasons, research groups and small companies funneled their efforts through a smaller number of designated researchers in order to continue their work. As the pandemic eases, MANTH expects to return to the path of robust user growth.

The number of external users dropped substantially to 111 in year 6, likely due to governmental travel restrictions and restrictions placed on researchers by their own employers/universities. It is interesting to note that pre-pandemic, external use hours were split about equally between small companies, large companies, and academic institutions. During COVID-affected times, academic and large company use hours were greatly reduced, but small companies made up approximately 2/3 of external hours. We attribute this to the critical need of small companies to maintain momentum and we were pleased that MANTH was able to provide nano access to them even during the pandemic.

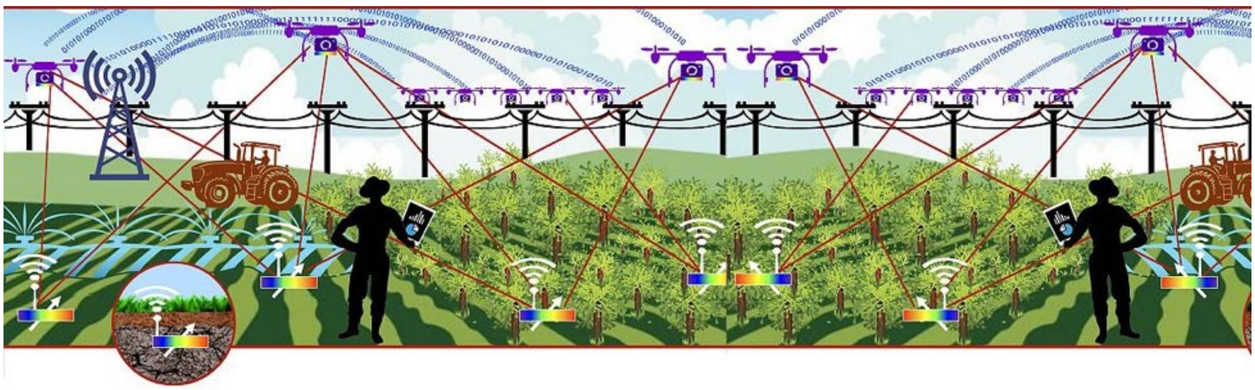
MANTH users conducted research in a wide range of fields; approximately 19% of the users were involved in life science or medicine, similar to previous years. Materials research comprised 31% of users, and 49% identified as working in the physical sciences or engineering. There was a notable increase in those who identify as electronic device researchers this year.

Research Highlights and Impact

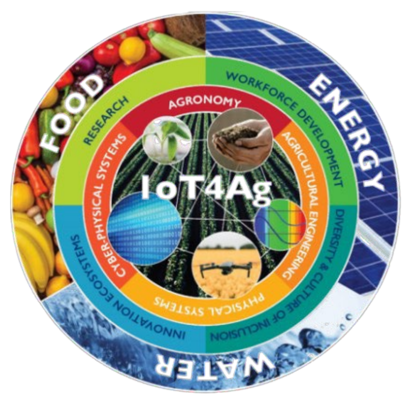
MANTH researchers published over 300 journal articles, book chapters, and conference proceedings in 2020. Their work was published in prestigious, nano-centric journals such as *Science*, *Nanoletters*, *ACS Nano*, and *Nature Nanotechnology*. Other MANTH-enabled publications contributed to our understanding in fields that are encompassed by several of the NSF 10 Big Ideas:

- Understanding the Rules of Life, in *Biomicrofluidics*, *Langmuir*, and *Lab on a Chip*;
- Quantum Leap in *Nature Photonics*, *JAP*, and *Physical Review*;
- and in MANTH's specialty field – the Nano-Internet of Things - that includes the Future of Work, Growing Convergence, and Harnessing the Data Revolution in *IEEE Sensors*, *ACS Energy*, and *JMEMS*.

Researchers at Penn, Purdue, the University of California Merced, and the University of Florida have been recently awarded an NSF ERC grant to pursue the convergence of the Internet-of-Things and agriculture, or **IoT4Ag**. IoT4Ag Center Leadership includes the following PIs that are also users of the MANTH site: Program Director Prof. Cherie Kagan; Site Director Prof. Kevin Turner; and University Education Director Prof. Sue Ann Bidstrup Allen.



The mission of IoT4Ag is to Transform the Future of Agriculture by creating and translating to practice Internet of Things (IoT) technologies for precision agriculture and to train and educate a diverse workforce that will address the societal grand challenge of food, energy, and water security for decades to come. *Nano-scale IoT* will play critical roles in the three thrusts of the center:

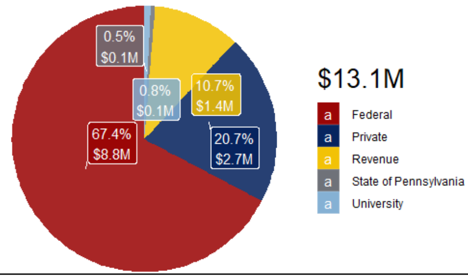


Thrust 1: Agricultural sensor systems will design and manufacture resilient, networked, intelligent sensor-robotic systems that monitor the state of plant and soil health over extended areas.

Thrust 2: Communication and energy systems will enable advanced approaches for powering IoT devices and robots in the field and for data communication from heterogeneous platforms of sensors, robots, and farming equipment.

Thrust 3: Agricultural response systems will create and deploy smart response systems that are driven by machine learning and decision-based models for precision agriculture.

To date, MANTH has supported dozens of startup companies and corporate initiatives. These companies have subsequently raised more than $13 million in revenue, venture capital, grants, and awards. More than 67% of their funding comes from Federal grants such as SBIR/STTRs from various government agencies, demonstrating the ability of MANTH startups to attract both private and public funding.



Above: Pie Chart showing the sources of revenue of the MANTH-based startups. Below: InnaMed's blood testing device.

Recent innovations conceived by startups work in MANTH laboratories include: *AAPlasma*, which has developed plasma systems to clean hard-to-fabricate SiN membrane nanopores for re-use; *Qbos*, which fabricates microfluidic devices that efficiently assess immune response in ICU patients; and *InnaMed*, which is developing a smartphone-based, at-home blood testing device and has recently raised $2M in funding.

<u>Education and Outreach Activities</u>

MANTH hosts highly motivated and talented high school students to attend the **Engineering Summer Academy at Penn (ESAP)**. MANTH developed a hands-on opportunity for them to fabricate and characterize micro and nano-scale structures using the tools in the MANTH cleanroom facility. The pandemic forced us to create a new, remote learning ESAP experience. Staff designed and shipped lab kits for at-home use and conducted a series of online demonstrations. There were 34 participants in summer 2021 (male: 17, female: 17).

Above: Graduate Student preparing kits for the ESAP Program. Below: Some components for the kits, including an Arduino.

The lab modules include an example of "microletters" photolithography patterning, quantum dot synthesis and characterization, microfluidic device fabrication and characterization, and a 2-photon lithography demonstration, all to teach both conventional and non-conventional applications of nanotechnology. Students handled wafers and operated simple tools on their own so that they could acquire some real-world nanofabrication experience. A total of 12 hands-on processing lab @ home modules and 10 virtual demo lab modules were provided.

The lab @ home modules include: characteristics of light; nanofabrication with pre-sensitized PCB; gelatin microfluidics syringe pump assembly and characterization of actual microfluidic devices; characterization of solar cells, LEDs and MEMS devices using an Arduino microcontroller; and computer coding. Three of 12 lab @ home modules were inspired by content in the NNIN education database (https://www.nnin.org/education-training/k-12-teachers/nanotechnology-curriculum-materials/search?key)

Each year, several Penn research labs present aspects of their work to visiting high school students at the Singh Center at MANTH on **Nanoday@Penn**. This year, six groups developed and led several *online* presentations instead for over 100 students at local schools. A total of 17 presentations were delivered. Some students joined from in-person classrooms with their teachers while other students joined from their own homes.

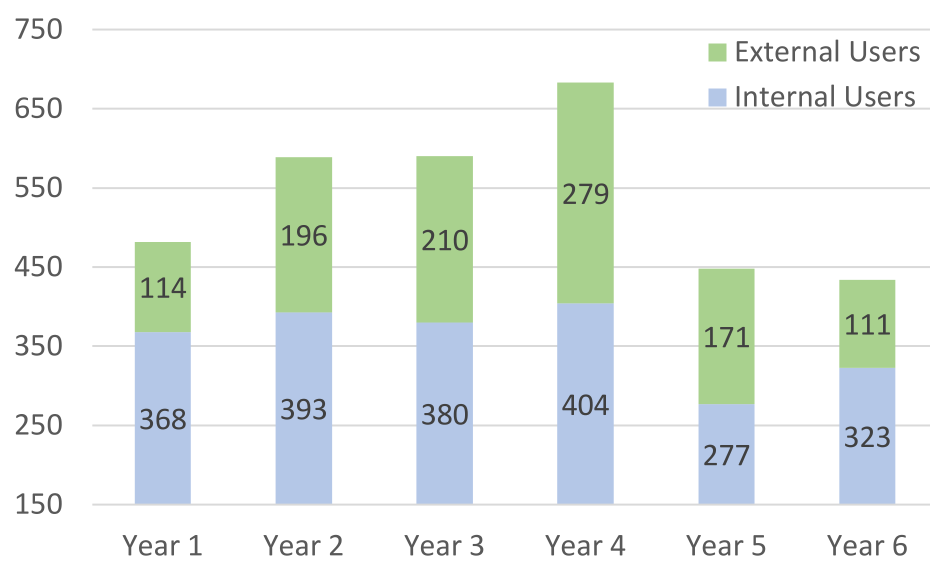
With our CCP partners, we have developed a **Nano-technician internship** program for community college students. The first cohort of CCP students (N=3) will start summer 2022 with a 20-hour/week, 14-week, paid internship at the MANTH QNF cleanroom. Multiple CCP-Penn discussions have and continue to address internship goals and outcomes, CCP student preparation for the internship, MANTH preparation for hosting, promotion of the program, selection of the students, and internship structure and assessment. Program promotion began in the Fall 2021 semester. Following and guided by the assessment of the Summer 2022 program, CCP and Penn will develop a plan to make any necessary modifications, expand funding sources and recruit local industry hosts for future internships.

The CCP **"Intro to Nano" course** community college students, was delayed until summer 2021 to allow the students to have a more hands-on, meaningful experience than would have been possible in the Spring. This is the second time this course was offered and CCP-PENN continue to discuss and develop curriculum that leverages MANTH's facilities and staff expertise. This past summer, MANTH hosted the CCP class for a 3-h cleanroom laboratory session that focused on deposition, lithography and etching. COVID-19 safety protocols required groups of 4 students or fewer in a given session; accordingly, the CCP class visited MANTH in small groups over three different days.

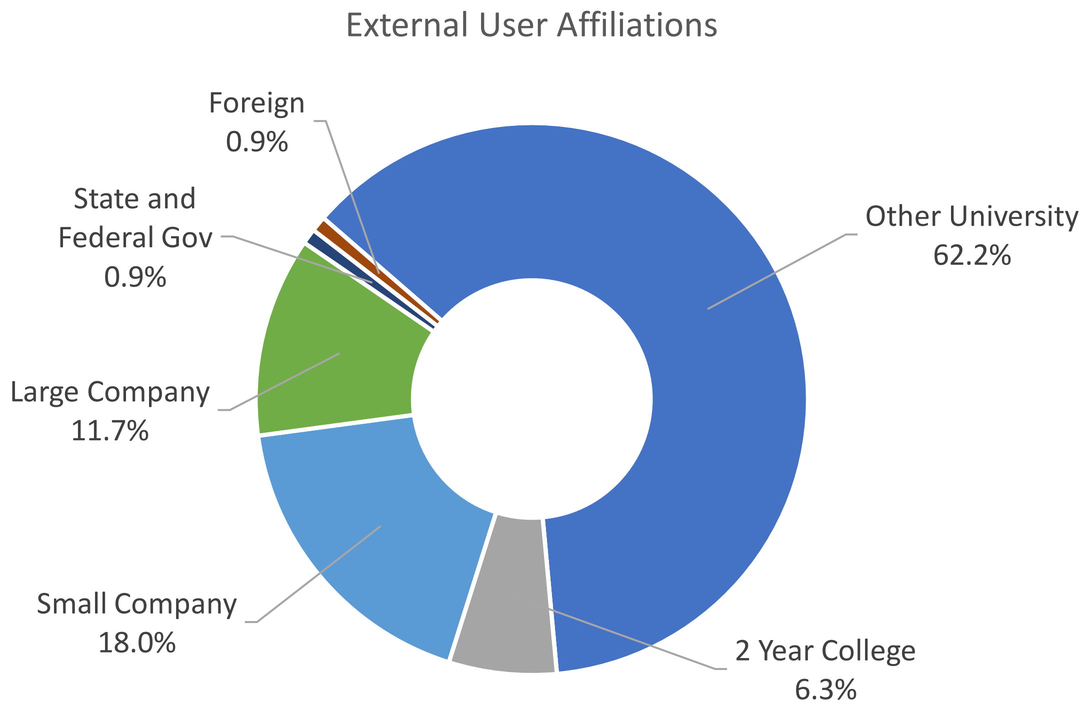
The 2020 **REU** program was canceled after Penn and Philadelphia went into a lockdown in response to COVID-19. In 2021, the Singh Center and other Penn Engineering undergraduate summer research programs were given permission to have students conduct research onsite in their host labs and 4 REU students were again invited to campus. Programming that has historically supplemented the research, such as faculty research talks, workshops, final presentations, was provided remotely. Fieldtrips and social events were not held in 2021. The NNCI REU Convocation, hosted by Georgia Tech, was held remotely; all MANTH REU students participated in the NNCI REU Convocation.

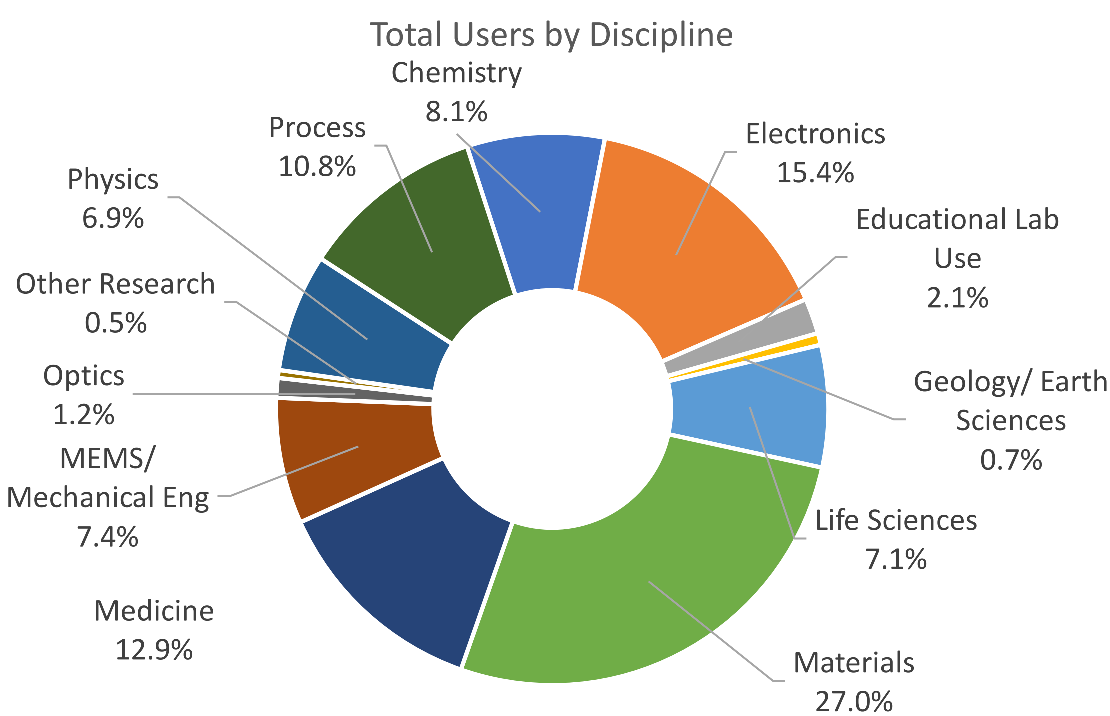
MANTH Site Statistics

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



MANTH Year 6 User Distribution





12.5. Midwest Nanotechnology Infrastructure Corridor (MiNIC)

Facility, Tools, and Staff Updates

Facilities and Tools: New tools on order or recently installed during this period exceed $4M, 90% of which has been internally funded. These acquisitions have been targeted toward our NNCI Research Communities areas: Quantum Leap and Rules of Life. A new SPTS Rapier deep silicon etch tool has been installed and is now accepting new users. This new etcher greatly improves our deep silicon etching capability by providing faster, more controlled silicon etching. It is targeted toward MEMS work generally, but will have significant impact on our users in the BioMEMS community. The second major addition to the cleanroom is an ultra-high vacuum (UHV) deposition capable of producing extremely high purity films and interfaces required for quantum devices. The system integrates four discrete process capabilities in a single UHV load-locked tool: a six-pocket e-beam evaporator, a four-target sputtering system, an ion mill, and a dedicated Nb sputtering station. The system includes a fully rotatable stage and a base vacuum below 10^{-9} Torr. Packaging these capabilities in a single UHV chamber means that multiple steps can be run in sequence without air exposure, overcoming significant obstacles in leading-edge materials and device research.

Other additions/improvements to the cleanroom tool set this year include:

- Upgraded 2D material transfer system and nitrogen glove box for use in manipulating 2D flakes onto device wafers. The new system has motorized control capabilities and improved optics over our current system,
- New endpoint detection system for our argon ion milling system. The SIMS-based detector will provide real time analysis of etching byproducts, thus allowing improved etch control on devices with multiple layers of different thin films.
- Upgrades to the Keller Hall cleanroom ultrapure water system, including modifications to the dichlorination process and the system controller.

MiNIC has also upgraded its BioNano lab facilities. In February, we installed a new $0.4M Beckman Optima analytical ultracentrifuge (AUC) using funds from NIH. Analytical ultracentrifugation is a technique that monitors the behavior of nanoscale materials as they sediment under the large settling forces developed in a specialized high speed centrifuge. The sedimentation velocity measured by the AUC provides information on the size, shape, and molecular weight of macromolecules, as well as the interactions between them, making it of great utility in molecular biology. The Optima AUC is the only instrument of its kind at the University of Minnesota, and was obtained with major funding from the National Institutes of Health. We are now training new users, which include several external academic and industrial researchers.

MiNIC's Characterization Facility (Charfac) added two major acquisitions during this period. A new Talos F200X FEG-TEM has been installed in Charfac's Shepherd Labs location. The system's cost, $1.65M, was internally funded. This microscope offers high-resolution (HR), broad-application TEM and STEM capabilities, with reduced environmental sensitivity and expanded capabilities for remote operation. In addition to HRTEM, the microscope brings several new capabilities, including fast 3D elemental mapping using energy dispersive X-ray spectroscopy (EDS) and EDS tomography; micro electron diffraction for crystallographic analysis of nanoscale single crystals; and a 30+ fps CMOS camera for *in-situ* sample imaging.

Charfac also added a K2 camera for the existing TEM ($0.38M, internally funded). The K2 is a single-electron counting camera added to resolve tertiary structure (e.g., beta sheets and alpha helices) in biological matter in cryo-TEM images including 3D reconstruction. The K2 is also a boon to materials research. Minnesota Ph.D. student Zezhou Li (PI Nathan Mara) used this system to image Cu/Nb nanocomposites and 3D interfaces (mixed with crystalline and amorphous phases) and showed that these are stable until 600°C is reached. The high-resolution K2 imaging also showed the Kurdjumov-Sachs (K–S) and Nishiyama-Wasserman (N-W) relationship of Cu and Nb interfaces after annealing. The formation of nanotwins was also observed and confirmed by fast Fourier transform (FFT) pattern analysis.

Staff Updates: July 1, 2021 saw a leadership transition at MiNIC. Longtime director Prof. Stephen Campbell retired and was replaced by new center director Prof. Steven Koester of the Electrical and Computer Engineering Department. Prof. Koester brings a broad background in device fabrication to MiNIC, with particular strengths in semiconductor devices and 2D materials. In January 2021 two longtime members of the technical staff retired, Mark Fisher (senior process staff) and Rich Macy (senior maintenance staff). In August 2021, Emma Jore was hired as a junior member of the process staff. Plans are in place to hire a new maintenance staff member soon.

User Base

Marketing and new user outreach over the past year included the following activities:

- MiNIC established a new LinkedIn page to publicize new tools, capabilities, and staff changes, as well as to highlight cutting edge research at our facilities. We are now working to attract followers to the page.
- MiNIC sent an annual "What's New at the Nano Center" New Year's email update to our potential client contact list (about 1100 unique names). MiNIC also produces a quarterly newsletter on activities at the Nano Center and related facilities, distributed to all current users.
- The Northern NanoLab Alliance continued to build a mutual support network for nanotechnology labs in the upper Midwest. While pandemic conditions have limited large group meetings, the NNLA has facilitated peer-to-peer communication on cleanroom technical and management issues.
- The annual Nanomedicine Workshop, originally scheduled for June 2020, was successfully reworked into a remote webinar held in November 2020.
- In May, MiNIC relaunched its incentive program for new users called *Explore Nano*. The program awards a $2000 credit against lab fees and training charges for new users or those returning after an absence of two or more years. The Program reached its capacity of 12 users in a couple of months, and plans are being made to continue the program in year 7.

Since its inception, MINIC has emphasized growing its user base by cultivating three research focus areas. During NNCI 1, one focus was in 2-D materials: synthesizing samples of graphene, MoS_2, WSe_2, and other such materials and exploring their applications. During NNCI 2, this materials infrastructure has been redirected to support the development of quantum information sciences and engineering. The second focus area addresses the biological applications of nanotechnology, specifically making and analyzing nanoparticles and applying these materials to drug delivery and cell analysis. MiNIC has seen increasing numbers of bio-related researchers use our facility, and we see this focus area as a major avenue to attract industrial involvement from the area's large and vibrant biomedical device community.

Research Highlights and Impact

MiNIC had numerous impacts from our external academic user base. One particular highlight was from external users at Michigan Tech who used the EBPG 5000+ electron-beam lithography system in the Minnesota Nano Center (MNC) cleanroom to create structures that can launch and control magnons using laser pulses. The structure consisted of a 1D grating of trenches in magnetic media which enables the possibility for the selective spin manipulation, a key issue for further progress of magnonics, spintronics, and quantum technologies. The work was published in *Nano Letters* in 2020.

MiNIC also supported numerous breakthroughs in quantum technology in this period. For instance, studies from researchers at the University of Minnesota, in collaboration with Cornell University, found that $NbSe_2$, a so-called "Ising" superconductor, has a two-fold rotational symmetry of the superconducting state under in-plane magnetic fields, in contrast to the three-fold symmetry of the lattice. The work was published in *Nature Physics*. In addition, the group of Vlad Pribiag at the University of Minnesota, in collaboration with Chris Palmstrøm at UCSB, found that transport in three-terminal Josephson junctions based InAs quantum wells, in proximity to an epitaxial Al superconductor, could be tuned between superconducting and diffusive transport states as a function of top gate voltage. Both of these studies could be important for understanding topological superconductivity, and could ultimately have important impacts for fault-tolerant quantum computing based upon Majorana zero modes.

MiNIC has enabled bio-related start-up activities. Dynation, LLC is a startup company based in St. Paul, MN that is developing new topical treatments for osteoarthritis. In this period, Dynation used the bionano lab in MNC and the cryo-TEM in Charfac to help develop micellular nanoparticles for improved transdermal delivery of therapeutics such as ibuprofen and paclitaxel based upon dense nanolipid fluids (DNLFs). This work is a key step towards development of a commercially viable, FDA-approvable topical ibuprofen medicine. In another highlight, Agitated Solutions, LLC is an early-stage medical technology company developing a system to generate microbubbles of various biocompatible gases and deliver them intravenously for diagnostic and therapeutic benefit. The company's first product is a syringe that automatically produces agitated saline for use as a contrast agent in ultrasound imaging procedures. Agitated Solutions is working with MiNIC bionano staff to quantitatively test its bubble generators using our particle analysis tools.

MiNIC has also played an important role in supporting the Spintronic Materials for Advanced Information Technologies (SMART) center, which is a center funded through nCORE, a consortium organized by SRC with funding from the microelectronics industry and NIST. In this work, researchers from MIT and the University of Minnesota found that magnetic order in ferri-magnetic structures can be reversibly controlled using only an electric field. This work has broad implications for the use of magnetic and spintronic materials for non-volatile logic and memory applications. The work was published in *Nature Nanotechnology*.

Finally, a collaboration between the University of Delaware (UD) College of Earth, Ocean, and the Environment and University of Minnesota's Institute for Rock Magnetism (IRM, PI Josh Feinberg) was recently initiated. In this work, a UD graduate student visited the Charfac in November 2020 to begin collaborative work in person, interfacing with Dr. Nick Seaton of CharFac on scanning electron microscopy (SEM) methods. The work examined rock samples to find magnetic minerals and determine the chemistry of the magnetic domains.

Education and Outreach Activities

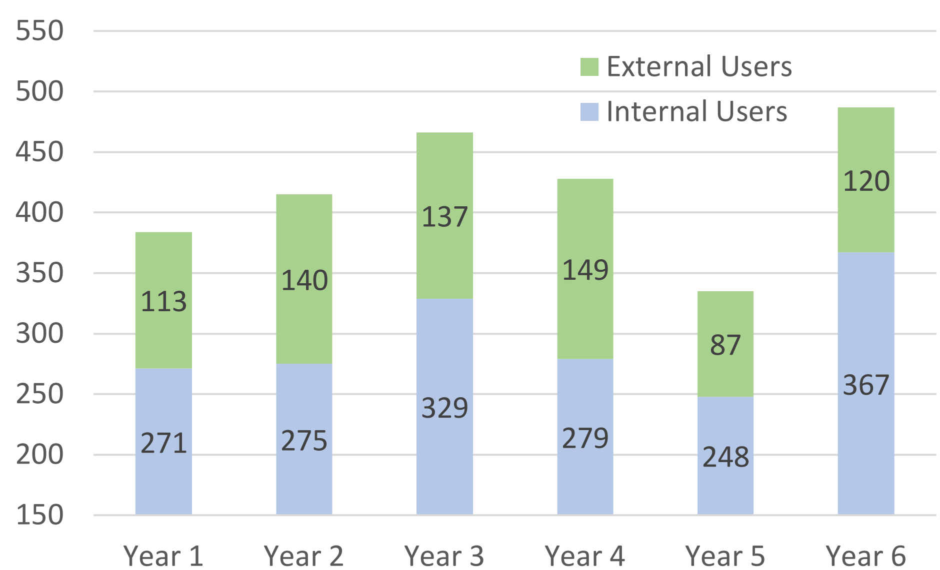
Nanomedicine Workshop: The third annual Nanomedicine workshop was held November 10-11, 2020. The workshop was delivered via Zoom to an audience of students, faculty at Minnesota and other universities, and industry researchers. Speakers included Profs. Zhenpeng Qin (University of Texas—Dallas), Stefan Wilhelm (University of Oklahoma), Jennifer Andrew (University of Florida), and Rick Wagner (University of Minnesota). The workshop covered several topics in the areas of nanotechnology-based diagnostics, nanomaterials with biomedical applications, and controlling cell interactions with nanoscale devices. Workshop talks were recorded and will be available on the MiNIC website.

Research Experience for Teachers (RET) Program: In 2019 MiNIC partnered with three other NNCI sites to apply for and win an RET grant. The grant supports five high school or community college teachers for a summer research experience, as well as developing new classroom activities to introduce students to nanoscience and technology. The RET program, scheduled to start in summer 2020, was postponed due to the pandemic, and was formally inaugurated in June of 2021 with a mix of in-person lab work and remote webinars. MiNIC staff recruited five high school teachers for the program, recruited research faculty to host the teachers, and identified senior lab personnel to work with and mentor the RET teacher attached to their lab. The RET teachers reported high satisfaction with their research experiences, and successfully developed classroom lessons on thin films, forces at the microscale, and careers in nanoscience. Yearly program assessments will be completed by an outside consultant, with a full evaluation report for year one expected shortly.

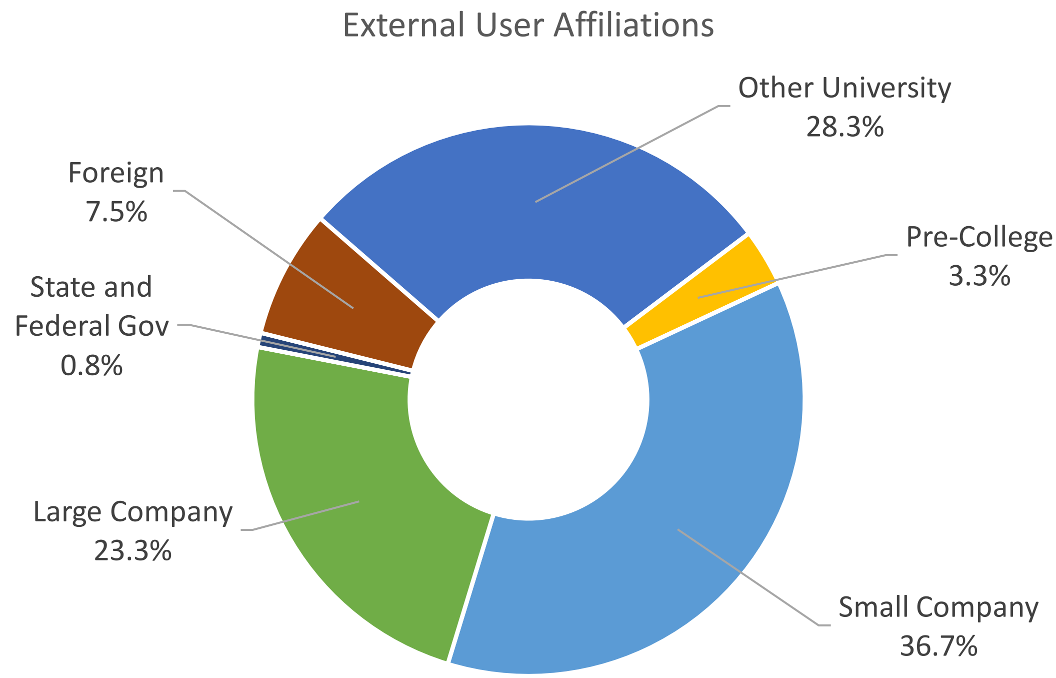
Tours and Classes: Like other NNCI sites, MiNIC was able to offer only limited education and outreach programs due to the continuing COVID pandemic which forced cancellations of in-person classes and tours over the reporting year. However, some progress was made on adapting to the new post-COVID world. Four remote programs were developed and offered to students in grades 8 to 12 during the summer of 2021, featuring virtual versions of our popular Intro to Nano class, as well as presentations on careers in nanotechnology. A special five-day course on nanomaterials safety was developed and presented by MiNIC staff in partnership with the university's School of Public Health and the NSF-funded Micro Nano Technology Education Center (MNT-EC). MiNIC also began the process of developing new video facility tours for use in education and for recruiting new faculty and grad students. Overall, MiNIC's outreach efforts reached 70 K-12 students, 275 post-secondary students, and 244 teachers.

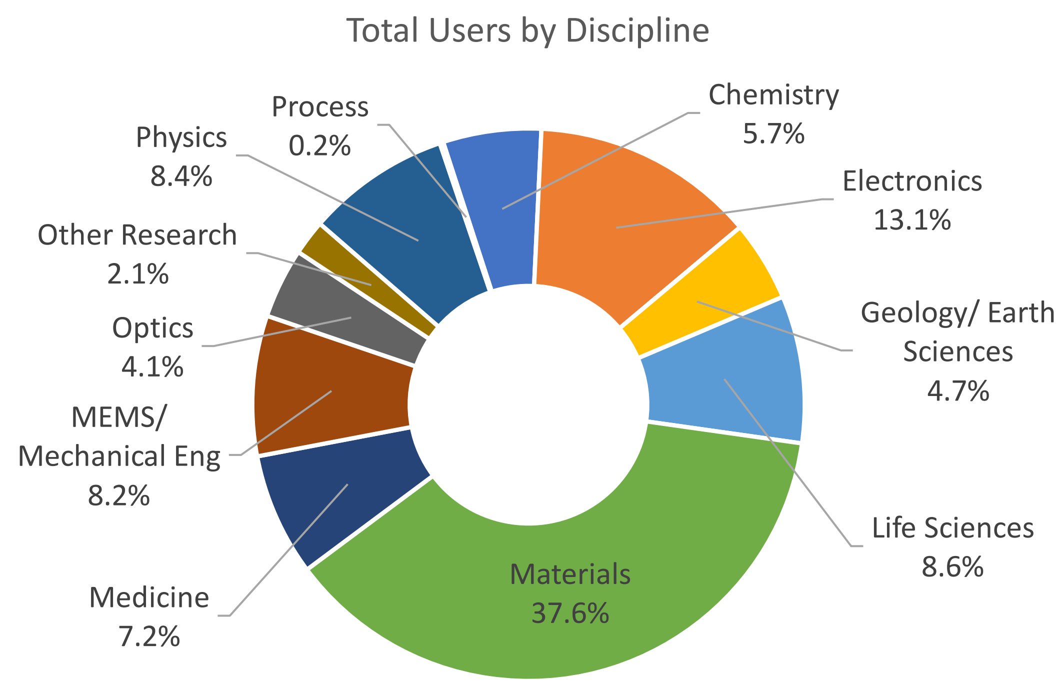
MiNIC Site Statistics

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



MiNIC Year 6 User Distribution





12.6. Montana Nanotechnology Facility (MONT)

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

Facility, Tools, and Staff Updates

MONT facilities have been greatly enhanced with several new tools. **The Imaging and Chemical Analysis Laboratory (ICAL)** installed a new Bruker D8 Advance powder X-Ray Diffractometer, a Cameca Time-of-Flight Secondary Ion Mass Spectrometer,and a Pella Carbon Coater. **The Center for Biofilm Engineering (CBE)** has a new Multi-Modality Multi-Photon Digital Light Sheet Fluorescence Microscope, a $1.5M custom made scope, and a Leica THUNDER Live Cell epifluorescence widefield microscope. **The Montana Microfabrication Facility (MMF)** added a new Disco DAD 323 Dicing Saw, a Flacktek DAC 330-100 SE Model Mixer**,** and a Filmetrics Profilm 3D optical profilometer that uses cutting-edge white light interferometry. **The Mass Spectrometry Facility** acquired an Agilent 6490 QQQ MS, an Agilent 7800 ICP-MS with ESL 193 nm Laser Ablation System, and a Waters Synapt-XS Q-IMS-TOF with Ion Mobility. Our new **2D Quantum Materials and Nanooptics Characterization Lab** includes tools for sample prep, fab & growth, an ultrafast laser system, a cryogenic quantum-optical microscope, and a nano-optical microscope. Our **TEM facility** expanded capabilities with a Talos Arctica cryo-EM, a Tecnai Spirit TEM, and a Vitrobot Mark IV System specimen preparation unit.

MONT's goal of enhancing our facilities (with a 5 year goal of $3-5M in new tools) has already been met with $5.5M in new acquisitions during this reporting period. All these tools have been purchased outside of NNCI funds and are very exciting to our local academic users and will help expand our external user base.

In staff updates, Dr. Sara Zacher is the new ICAL manager. She began her scientific career as an undergraduate physics student in ICAL and went on to earn her PhD in Applied Physics and Engineering from Cornell University. All other positions remained stable.

User Base

We are pleased that the Year 6 user count has returned to pre-pandemic status. MONT served 189 users in Year 6, compared to 169 users in Year 5, 188 users in Year 4. MONT served 58 external users who made up 30% of our user base. **This is the largest number of external users to date and right at our 30% external user target mark**. In Year 5 MONT served 48 external users, who made up 28% of our user base, and 27% (50 users) in Year 4.

MONT substantially upgraded and reorganized our website. Important updates included tools pages, ease of use for user registration, outreach resources, and more intuitive navigation throughout the pages.

MONT awarded 5 **user grants to seed new projects** in Year 6. Five internal grants were awarded to:

Joseph Stage, graduate student, under the direction of PI Nick Borys, *Dynamic Creation of Quantum Emitters in 2D Semiconductors with Optical Forces*. This project includes acquiring preliminary results to develop a competitive proposal to build an optomechanical nanodevice to dynamically generate highly localized strain in 2D semiconductors and quantum light emitters.

Dr. Yoafa Li, *Qualifying the Microscale Dynamics of Multiphase Flow in 2D Porous Micromodels*. This project will fabricate microfluidic devices to study the pore-scale flow interactions of water and oil in porous media. The focus of this work is to generate preliminary results as well as fostering collaborations for successful proposal submission.

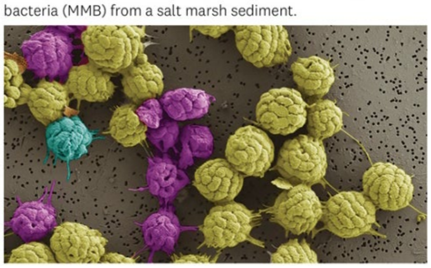
Dr. Stephan Warant received funding for two projects:

1) *Integrated Biofilm Control Strategies for Water Systems during Extended Space Flight*. A group of CBE faculty was selected to submit a NASA EPSCoR proposal (limited submission) to advance biofilm control strategies for mitigating biofouling in water systems. This user grant enabled the CBE research team to fabricate sensors to collect additional preliminary data.

2) The Glass to *Glass Wafer Bonding* project aims to make a microfluidic device existing of two glass wafers bonded through an intermediate layer. This process will bring the Warnat research group in the position to establish fluidic chips that are transparent from both sides. This brings a significant advantage regarding microscopy techniques as required in several projects.

McKenna Landis, graduate student, received funding for her project, *PDMS Microwell Arrays for Neurite and Protein Tracking*, under the direction of PI Anja Kunze. This project will create a device that contains microfluidically connected microwells in which neurons will be cultured. Landis will test the effects on drug uptake in cells, neurite growth, and protein dynamics. The aim of this support is to secure follow-on NIH funding.

Correlative fluorescence and electron microscopy reveals distinct populations of obligate multicellular magnetotactic bacteria (MMB) from a salt marsh sediment.



The user grant program has had a significant impact for MONT researchers. One former recipient, graduate student George Schaible (who last year won the NASA FINESST award) had his image (left) selected as cover art for the *The ISME Journal* for the full calendar year 2022.

MONT is working with NNI to coordinate the Northwest Nanotechnology Laboratory Alliance (NWNLA). The newly created NWNLA serves as a platform for exchange on laboratory experiences and best practices. NWNLA will offer biennial workshops, alternating with the UGIM symposium, for facility staff in Idaho, Montana, Oregon, Washington, Wyoming, Alberta, and British Columbia. The agenda is set for the inaugural meeting (virtual), November 8-9, 2021. About 80 people have registered representing academia, industry, and government.

The NNCI Nanoscience Earth and Environmental Science Research Community Virtual Workshop was held May 24-26, 2021. MONT coordinated this successful workshop with NanoEarth, NCI-SW and nano@stanford. The workshop included invited presentations and group discussions to explore modern advances of nanoscience as applied to the Earth and Environmental Sciences. The meeting was well attended with 136 participants and was reviewed positively. Post workshop assessment found an average rating score for questions targeting workshop facilitation, communication, design, and active learning at 3.84 out of a high score of 4. The average rating for survey questions targeting new opportunities, data, implications, collaborations, and outreach scored a 3.8 out of 4.

Usability studies of the Teaching Nanotechnology Across the STEM Curriculum, https://serc.carleton.edu/msu_nanotech/index.html, conducted by SERC, lead to redesigned and augmented content. The added information and new organization provide more context and a more accurate representation of what to expect in the module.

The **CBE** Montana Biofilm Science & Technology meeting was presented in a virtual format again this year. MONT researchers presented in various sessions. MONT did not hold its traditional in-house workshop due to pandemic constraints.

The MONT Annual Users meeting was held virtually in October 2020. Invited speaker Dr. Michael Hochella (nanoEarth) kicked off the meeting. Participants discussed the renewed MONT NSF funding, facilities updates and how the facilities should prepare for future research directions.

Research Highlights and Impact

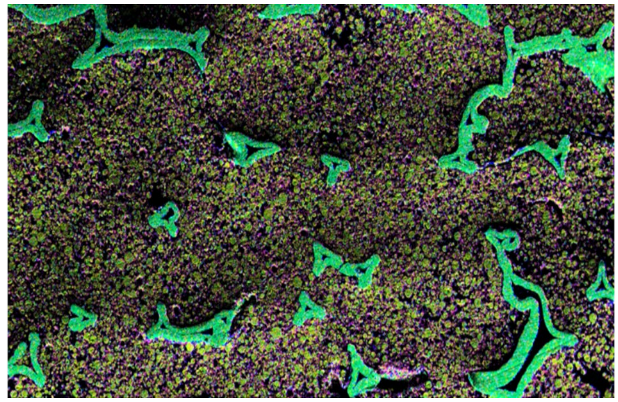
Scholarly impact: During 2020, MONT researchers produced 50 journal papers, 27 other products, and 6 patents.

MONT users had several outstanding accomplishments during the reporting period including research that was funded in-part by **MONT Empower undergraduate support**. Undergraduate Michael Espinal is a part of the research team that found that plastic treated with certain bacteria could be added to concrete in significant quantities without compromising the structural material's strength. The paper "Biomineralization of Plastic Waste to Improve the Strength of Plastic-Reinforced Cement Mortar" was authored by several MONT users and was published in the journal *Materials* in April 2021.

MONT faculty users Adrienne Phillips, Cecily Ryan and Chelsea Heveran, along with student users, doctorate student Seth and senior Michael Espinal, show samples related to a study on recycling microbe-treated plastic into concrete.

MONT faculty user Eric Boyd and team (which includes MONT PI Dave Mogk) received **a $3.4M DOE EPSCoR** award to fund continuing research into microorganisms that display the ability to extract important metals, like nickel and cobalt, from pyrite. This work has significant implication in the renewable energy sector along with eliminating harmful by-products of historical mining methods. This award includes tool funding that will be utilized by MONT.

Virtual press conference on this funding featuring US Senators Jon Tester (top left) and Steve Daines (top right), US Secretary of Energy, Jennifer M. Granholm (bottom left), and Prof. Eric Boyd (bottom right).



Energy dispersive X-ray spectroscopy (EDX) elemental mapping of a Ni-Zn cathode.

External user Æsir Technologies was recently awarded a $2.5M DOD subcontract. Æsir specializes in the development and commercialization of next-generation Nickel-Zinc (Ni-Zn) and zinc-based battery technologies that utilize sustainable materials that can be safely and easily recycled. These technological advancements require combining in-house electrochemical performance testing with compositional and structural analysis of our synthesized materials and electrodes. The use of analysis equipment at MONT helps lead to further optimization of our current Ni-Zn electrodes and accelerate R&D on experimental zinc-based chemistries.

Education and Outreach Activities

The newly launched MONT Empower Scholars program, which provides support to place underrepresented undergraduate students with MONT researchers for a research experience and tool training, awarded 7 scholarships in Y6 (as per budget). Demographics include 1 Native American student, 3 Hispanic/Latinx students, and 3 female students. Projects included:

- Chemical Engineering student investigating novel biosurfactants in our mass spectrometry facility
- Mechanical Engineering student working in both ICAL and MMF on carbon-based energy storage materials
- Physics student doing materials characterization on the nanoAuger in ICAL
- Biological Engineering student involved in microfabricated sensor technology in MMF
- Mechanical Engineering student working with novel experimental studies of thermal-fluid problems at small scales in MFF
- Environmental Engineering student studying biomineralized plastic fibers in CBE
- Mechanical Engineering student conducting research on unrecyclable plastic treated with bacteria and added to concrete (paper published) in ICAL

MONT hosted 30+ students in our labs during the 4-H Summer Congress. The lessons included live demonstrations in ICAL and MMF. As a follow-up to Congress, we have created videos and lessons that 4-H clubs can work on with a MONT mentor. We expect this program to be running across the state this spring.

We have been working with the Salish Kootenai College (SKC) middle/high school programs to incorporate nanoscience/technology education on the Flathead Reservation in northwestern Montana. The SKC programs ran in a very limited capacity this summer and fall. SKC requested asynchronous lessons for their camps. We complied and organized a series of videos and lessons from web resources, other NNCI sites, and MONT. The lessons are accessed on the MONT website and students can work through each lesson independently. Lesson units include: What is Nano?, Size and Scale, How do We See Nano?, The Clean Room, Applications, and Quantum Introduction. Students take a short quiz at the end of each unit that allows the admin at SKC to know a student has completed a unit. The quiz is also a survey that gives MONT feedback and assessment about the student’s experience with the lesson. To date, about 20 students have completed one or more of the nanoscience units and all report a positive experience and a better understanding of nanoscience and technology.

MONT sponsored and participated in Montana State University's Science Summer Institute (SSI), an annual STEM teacher professional development conference. PI Mogk led a session on nanoscience in geoscience and MONT users gave sessions on nanoscience in materials science and nanoscience in water shed research. The SSI was hosted virtually on August 11-13 and served teachers and non-formal educators from schools and organizations throughout the state. Attendees represented a typical Montana demographic: multi-grade educators from one-and two-room schoolhouses to elementary, middle and high school teachers from Montana's largest districts to informal educators from organizations such as Yellowstone National Park and the American Prairie Reserve.

MONT graduate student Evan Scherer participated in 2021 Science Outside the Lab (SOtL) led by NCI-SW. Scherer has spoken about his SOtL experience with several MSU/MONT student groups and will talk about SOtL at the Annual MONT Users meeting.

Our REU program was an on-campus, in-person program this year. We hosted 10 REU students in our facilities and three participated in the NNCI REU Convocation.

The Solar Cells for Teachers course resumed this summer. MONT hosted 6 teachers from around the US in the summer of 2021. The post-course survey suggested that overall, teachers would use the lessons learned in their own classrooms.

MONT hosted two RET participants studying materials science in our ICAL facility. Both teachers are from rural Montana schools, one a high school and one K-12 school.

In April, MMF and ICAL hosted hands-on tour and demonstration for 12 members of the university's Society for Biological Engineers.

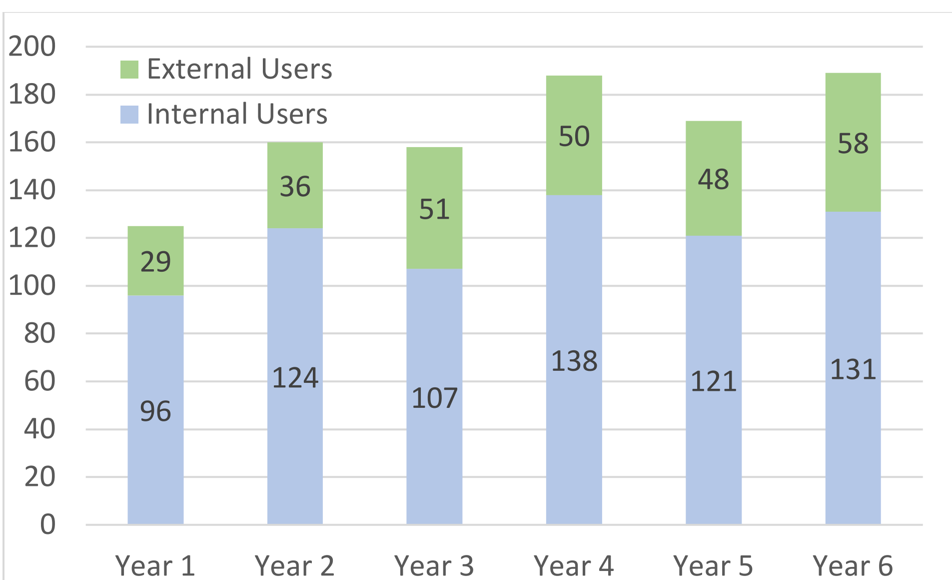
A materials characterization class from Montana Technological University in Butte, MT visited the MONT facilities for demonstration and instruction on the AFM and FEM instruments. The day of instruction included 3 visiting faculty and 12 undergraduate students.

Societal and Ethical Implications Activities

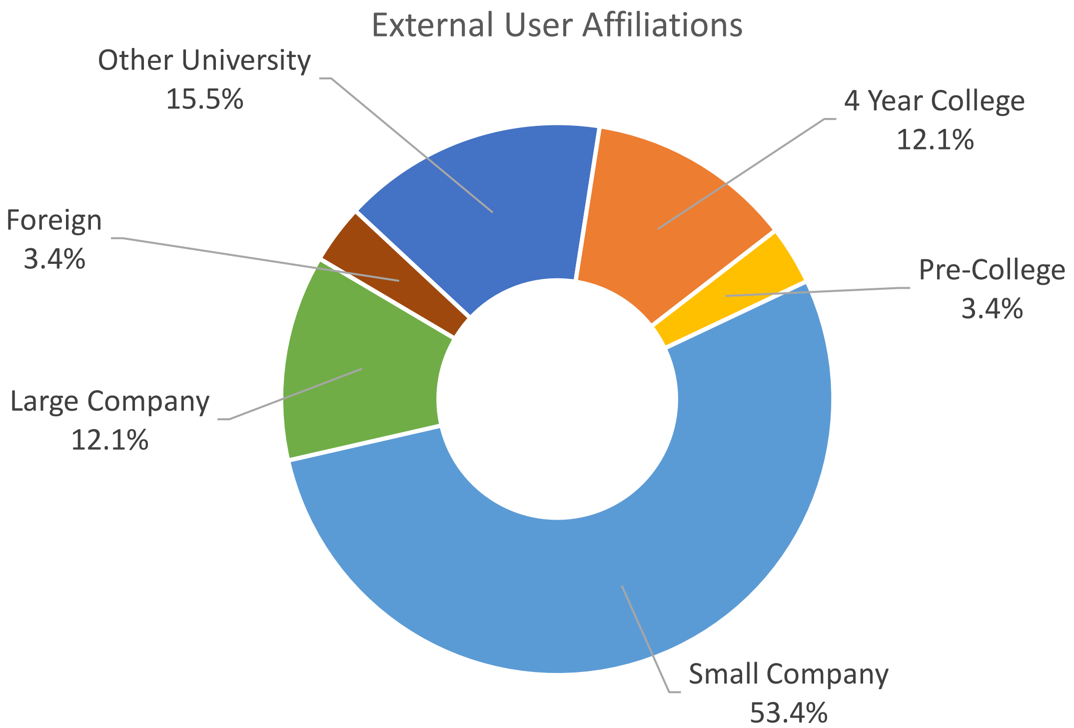
Co-PI Mogk continues to regularly participate with the NNCI/SEI committee chaired by Jamie Wetmore. Continued website development includes an expanded resource collection of journal articles and books related to ethics and nanotechnology/science, and societal issues related to nanoscience. These references can be accessed at: https://serc.carleton.edu/msu_nanotech/ethics.html

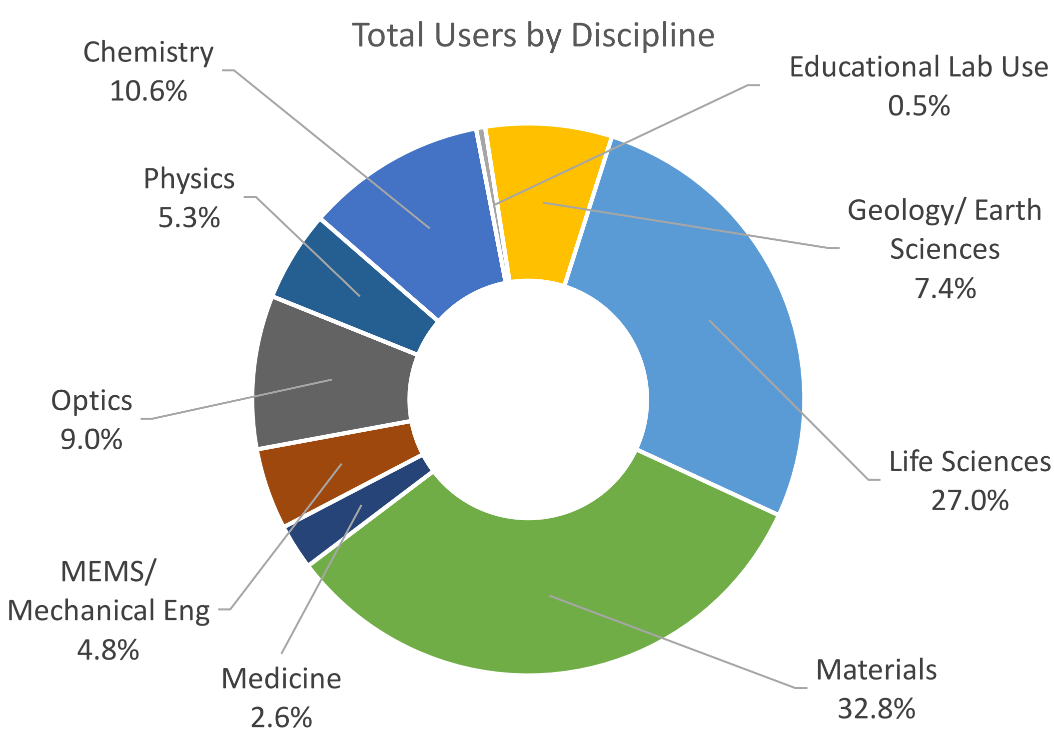
MONT Site Statistics

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



MONT Year 6 User Distribution

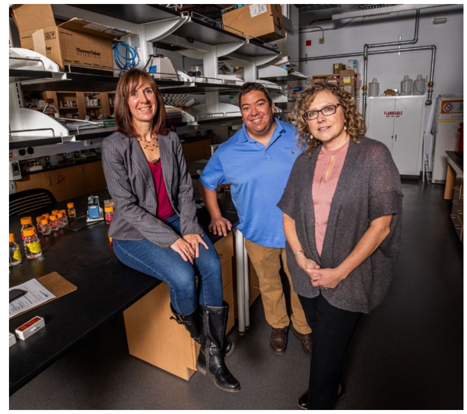




12.7. Nanotechnology Collaborative Infrastructure Southwest (NCI-SW)

Facility, Tools, and Staff Updates

For the Year 6-10 renewal period we have added two major expansions to the NCI-SW infrastructure capabilities. First amongst these is our collaboration with the Center for Materials Interfaces in Research and Applications, or ¡MIRA! at Northern Arizona University. This new inter-disciplinary materials science initiative is focused on the development of functional materials through the exploration of materials interfaces. Users of the ¡MIRA! Center have access to capabilities and expertise in characterization and modeling of hard and soft materials. Existing foci are in-situ scanning probe microscopies, modeling and simulation of light-matter interactions as well as quantum training in areas such as quantum information. Scanning probe capabilities include an Asylum MFP-3DSA and an MFP-3D BioScope with temperature and environmental control including liquid AFM, electrochemical, piezoresponse force and conductive AFM. In addition, ¡MIRA! has cantilever design capabilities with in-house developed cantilever fabrication (colloid or biomaterial cantilever probes) for scanning force microscopy.



The ¡MIRA! leadership team includes Cindy Browder (Deputy Director), Gabriel Montaño (Chief Scientist) and Jennifer S Martinez (Director) (left to right).

The other new initiative for the renewal period is adding the Advanced Electronics and Photonics (AEP) core facility under the NCI-SW umbrella. The AEP is housed in a 250,000 ft^2 manufacturing facility originally built by Motorola. It offers state-of-the-art capabilities in semiconductor processing, solar cell manufacturing and flexible electronics in a 43,000 ft^2 cleanroom. The building is currently home to ASU faculty labs and start-ups with their own "proprietary" space arrayed around the core user facilities. Other occupants include equipment manufacturers who enhance the AEP toolset though a lease plus user-fee tenancy model. The AEP core supports prototype and low volume manufacturing, including an industry standard photovoltaics pilot line.

The AEP core facility is located on ASU's Science Park, a few miles from the main campus.

The Eyring Materials Center Environmental TEM has been upgraded with a state-of-the-art Gatan imaging filter continuum system and K3-IS direct electron camera for high-speed video recording of material structure dynamics at the atomic level. Using the highly sensitive K3 camera, the instrument can measure very weak electron energy loss (EELS) data, offering fast low noise sample elemental mapping. The high sensitivity EELS mapping allows for the analysis of heavy elements including Pt and Au.

The Titan environmental TEM can record high speed video at liquid nitrogen temperatures.

User Base

Before the Covid pandemic the NCI-SW would regularly host an annual High Resolution Electron Microscopy winter school. The winter school combines theoretical classes with hands on sessions for scientists and engineers familiar with transmission electron microscopy but who need more advanced training. The workshops serve as a useful recruitment and outreach tool to attract users of the NCI-SW Eyring Materials Center. Unfortunately, the Winter School scheduled for January 2021 had to be cancelled but is being offered again in January 2022.

In Year 4 we started a seed funding program to recruit new users for the NanoFab and EMC core facilities. Academic users not affiliated with ASU can apply for up to $5,000 in laboratory fees to offset the costs of using the ASU Nanofab and/or Eyring Materials Center. Interested users submit a short proposal that is reviewed by the Governance Boards of the NanoFab or EMC. During Year 6 we are supporting Sreeprasad Sreenivasan from the Department of Chemistry and Biochemistry, at the University of Texas at El Paso. Dr. Sreenivasan's seed funded project is exploring the impact of defects on carrier dynamics of 2D quantum structures and hetero-structures. Before joining the NCI-SW as a Co-PI Dr. Miguel José Yacamán at NAU received seed funding to use the advanced TEM facilities in the EMC core facility at ASU. He is now preparing the results of this work for publication. An example of Dr. Yacaman's work to develop a physics-based test for the COVID-19 virus is described in the research highlights below.

Research Highlights and Impact

The research focus of the NCI-SW is to provide general R&D micro- and nano-fabrication support across a broad range of disciplines including the life and health sciences; environmental nanotechnology; geological nanoscience; and renewable energy. The NCI-SW also established a user facility for the Societal and Ethical Implications (SEI) of nanotechnology that develops tools for the broader social science community to explore the social aspects and implications of nanotechnology. The addition of the ¡MIRA! Center at Northern Arizona University in Year 6 brings new expertise and infrastructure related to materials science and quantum information.

We impact regional economic development by supporting the needs of the small business community and by workforce development through our partnership with Rio Salado College (RSC) to graduate nanotechnology technicians with AAS degrees. The partnership with RSC has been on-going for more than 5 years. In October 2020 Dr. Rick Vaughn, the STEM Program Chair at RSC and Thornton submitted a "New to ATE" proposal to the NSF Advanced Technological Education (ATE) program. ***The proposal entitled "Supporting Micro and Nano Technicians through Hybrid Teaching Methods" has been funded for three years with a start date of July 1, 2021.*** The new award will enable Rio Salado College to (1) offer a six-course certificate, and an associate degree in Nanotechnology, (2) provide an accessible and affordable academic program for students to gain employable skills, (3) actively recruit students from underrepresented and underserved groups, and (4) establish partnerships with industry and other partners to prepare students to fabricate and characterize materials for biological, textile, chemical, light, and electrical applications, all at the micro and nanometer scale.

During Year 6 considerable resources at ASU and NAU have been dedicated to addressing the COVID-19 pandemic. Miguel José Yacamán, a principal investigator for the NCI-SW renewal and a faculty member in the ¡MIRA! Center at NAU, was awarded a grant from the NSF's Rapid Response Research (RAPID) funding program to develop a physics-based technology for COVID-19 testing. The new project, called "Development of a New Test for SARS-CoV-2 using Single

Molecule Surface Enhanced Raman Spectroscopy," will use surface enhanced Raman spectroscopy to identify unique proteins on the surface of the COVID virus. The technique exploits a resonance effect due to the electromagnetic field around gold-copper nanoparticles that amplifies the otherwise very weak Raman signal. The goal of the work is to come up with a rapid, point-of-care sensor that can detect the COVID virus with the same precision as PCR tests.

Mark Hayes (School of Molecular Sciences) and Jennifer Blain-Christen (School of ECEE) received a $6M grant from the State of Arizona to develop a lab-on-a-chip device to detect the presence of the COVID-19 virus. The new rapid saliva test detects the viral RNA and combines the ease of use and speed of the newly FDA-approved antigen tests with greater accuracy similar to PCR-based RNA tests. If the virus is detected, a strong, green fluorescent signal is generated on the device. Unlike the PCR method, which needs a few hours of time because of several steps performed at different temperature cycles, the new device is designed to have all of the reactions performed at the same temperature. The team is working to align their microfluidic chip technology with several companies for scalable production.

Education and Outreach Activities

For Year 6 of the NNCI, much of our education and outreach (E&O) program (led by Dr. Ray Tsui) was impacted by the COVID pandemic. The number of advanced lab classes for students enrolled in the nanotechnology programs at Rio Salado College (RSC) was significantly reduced compared to prior years. Other in-person events such as lab tours and nanotechnology workshops for teachers were cancelled. However, the situation began to improve by spring 2021, and an in-person REU program for the summer was completed. Caroline VanIngen-Dunn and her team at Science Foundation Arizona have restarted their outreach program to rural Arizona community colleges and they have recently hired Mara Lopez to lead this effort. Additional details about the NCI-SW E&O activities are described below.

i) Labs for Rio Salado College Students: In the collaboration with RSC (part of the Maricopa County Community College District), the NCI-SW hosts advanced laboratory curriculum at ASU for students enrolled in RSC's two-year, 62 credit AAS degree in Nanotechnology which contains an 18 credit Certificate of Completion. In Year 6 three in-person labs were conducted for RSC students through February 2021, with the pandemic imposing constraints at ASU and causing significant enrollment drops (~15%) at the Maricopa County Community Colleges. However, there is optimism that the situation will improve as Intel and Taiwan Semiconductor Manufacturing Company both plan to build new semiconductor facilities in the metro Phoenix area and will need to hire technicians such as those trained at RSC.

ii) Research Experiences for Undergraduates and Teachers: The NCI-SW was able to support five REU students during the summer of 2021. As in previous years we were able to recruit students from community colleges and other institutions that might not usually enable REU experiences. The student project titles and institutions are provided in the table below. The REU projects were hosted on both the ASU and NAU campuses with weekly Zoom meetings during which all students took part to present their progress reports, interact with faculty research seminars, and practice their convocation presentations. All of the students took part in the online NNCI convocation held August 3-5.

Student	Project Title	Faculty Mentor
Jeremy Barrios, Hunter College CUNY	Quantum Simulation Tools Applied to the Modeling of Bio-Photonic Quantum Materials	Ines Montaño NAU
Teresa Nehls, Chandler Gilbert Comm. Coll.	Development of Photoactive Silk Films for Laser Activated Tissue Sealing	Kaushal Rege ASU
Stephanie Polk, Chandler Gilbert Comm. Coll.	Structural Morphology of Polymer-Alginate Composites	Gabriel Montaño NAU
Irena Lizier-Zmudzinski, Colorado School of Mines	Silver Nanowires as SERS Substrates to Differentiate E. Coli and Klebsiella Bacteria	Miguel Yacaman NAU
Nathan Zhang, Vanderbilt University	Characterizing Airborne Nanoparticles to Study Neurotoxic Risk	Paul Westerhoff ASU

iii) Public Events: The major public outreach activities supported by the NCI-SW are the ASU "Open Door" and "Geeks Night Out" hosted by the City of Tempe. Both are signature events of the Arizona SciTech Festival. In 2021, Geeks Night Out was cancelled while Open Door changed to an online format offering pre-recorded videos. The NCI-SW hosted two short videos: "Nano in Your Pocket – Ferrofluid" in which Dr. Wetmore demonstrated the use of nanoscale ferromagnetic particles in the printing of paper money; and "What is a NanoFab?" which provides a tour of the NCI-SW's cleanroom with a narration about the equipment and processes provided by Dr. Tsui.

Wetmore using a magnet to demonstrate the properties of a ferrofluid and discuss an application for the nanoscale material during a video made for Open Door.

SEI Activities

Dr. Jameson Wetmore and his colleague Dr. Ira Bennett, run the NCI-SW SEI User facility, which works one-on-one with visiting scholars and aso facilitates workshops to do in depth training with groups of people. The flagship activity of the SEI user facility is Science Outside the Lab, a weeklong program traditionally held in DC every June. The program brings together graduate student scientists and engineers from across the NNCI to get a crash course in how science influences policy and how policy influences science. For 2021 it was decided to run a remote version of the program from May 1st – June 11th for two hours a day via Zoom. With this schedule it was possible to hold approximately twenty meetings – about what we schedule when we are on the ground in DC. In total we had one student from Cambridge University and an additional 19 students from 12 NNCI universities, including students from 4 NNCI universities that have never sent a student before.

New for 2021 was the creation of "SEI Ambassadors" who have developed projects to continue the conversations they had in the SOtL program with others at their universities. Projects include outreach efforts to K-12 students, podcasts on the struggle to fund research at traditionally black institutions, and gatherings of graduate students to discuss science policy issues.

We also hear good news about program alums. Moriah Locklear (University of Nebraska, 2018 participant/2019 TA) successfully completed her PhD in 2020 and has already begun a position at the Potomac institute, a non-partisan think tank that works on Science and Technology Policy. Moriah says that SOtL was a "transformative experience" for her and shaped the career path she is now headed on.

Our efforts to support SEI work and discussion has continued in other venues as well. Over the past year Wetmore has engaged a number of organizations to promote SEI in their work. For instance, in June he hosted an online seminar for the TEDI London Summer School on "Users of Technology in the Developing World." And in August he discussed the societal and ethical implications of nanotechnology with Lisa Friedersdorf, Director of the National Nanotechnology Coordination Office, on two podcasts: "Stories from the NNI," which is designed for nanotechnology professionals, and "Nano Matters," which is aimed at a more public audience (see: https://www.nano.gov/podcast). Wetmore also looks forward to reaching audiences well beyond the NNCI through the August release of the second edition of his co-edited book Technology and Society: Building our Sociotechnical Future (MIT Press), which packages many SEI lessons for undergraduates and the general public.

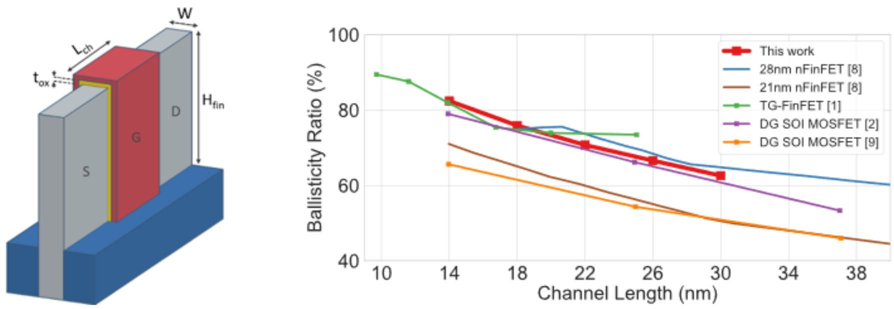
Computation Activities

Dr. Dragica Vasileska at ASU, leads the computational activity for the NCI-SW, including educational activities that involve the nanoHUB. Dr. Vasileska has been a long-time contributor and user of the NCN's nanoHUB (3rd largest contributor out of 2439 contributors), although she is not funded by the nanoHUB contract. Within ASU, Prof. Vasileska has been involved in the development of several computational modules, including:

- 2D Schrödinger-Poisson solver for modeling the electrostatics in arbitrary heterostructure nanowires. The tool is currently being ported on nanoHUB.org. The tool has been used at ASU for modeling electrostatics in GaN/AlGaN heterostructure nanowire FinFETs.
- 1D Monte Carlo transport simulator for GaN/AlGaN nanowires. Excellent agreement was obtained with this tool between the calculated and the available experimental mobility data.
- Machine Learning models for prediction of the doping profiles in CdTe solar cells due to diffusion of Cu. This work has been accepted for presentation at the PVSC and the IWCN conferences to be held online this year.

Outside of ASU, Prof. Vasileska is collaborating with:

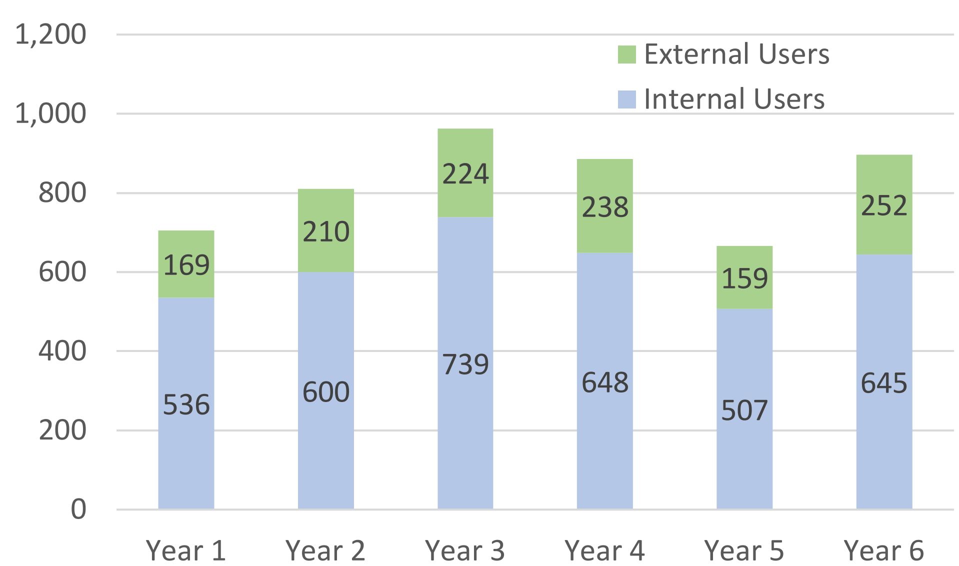
- Dr. Michael Povolotskyi from NRL on using PETSc and SLEPc numerical libraries for solving 2D Schrödinger-Poisson problems. The tool is currently ported on nanoHUB.org.
- Ass. Prof. Amir Goldan Hossain from Stony Brook to understand the impact ionization process in amorphous Se photodetectors.
- Prof. Z. M. Zhang from Georgia Tech. on the subject of thermophotovoltaics.
- Prof. Gilson Wirth from UFRGS in Porto Alegre, Brazil to study ballisticity effects in Si nano FinFETs (see figure below).



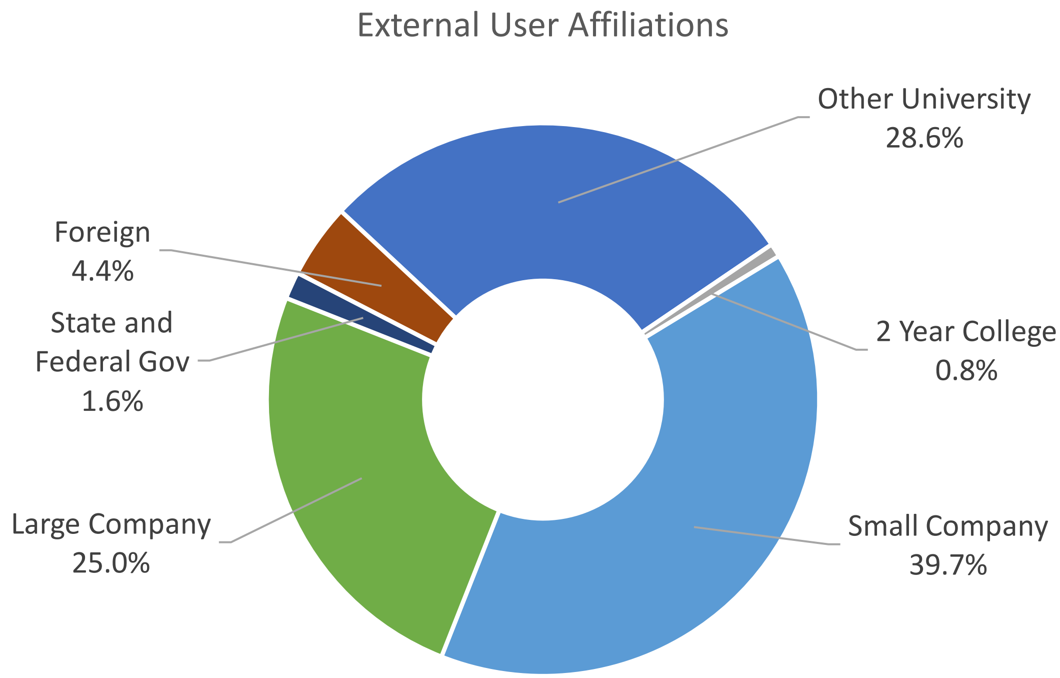
Left panel: Basic structure of the FinFET used in this work. Right panel: The ballisticity ratio in a Si nano FinFET as a function of the channel length.

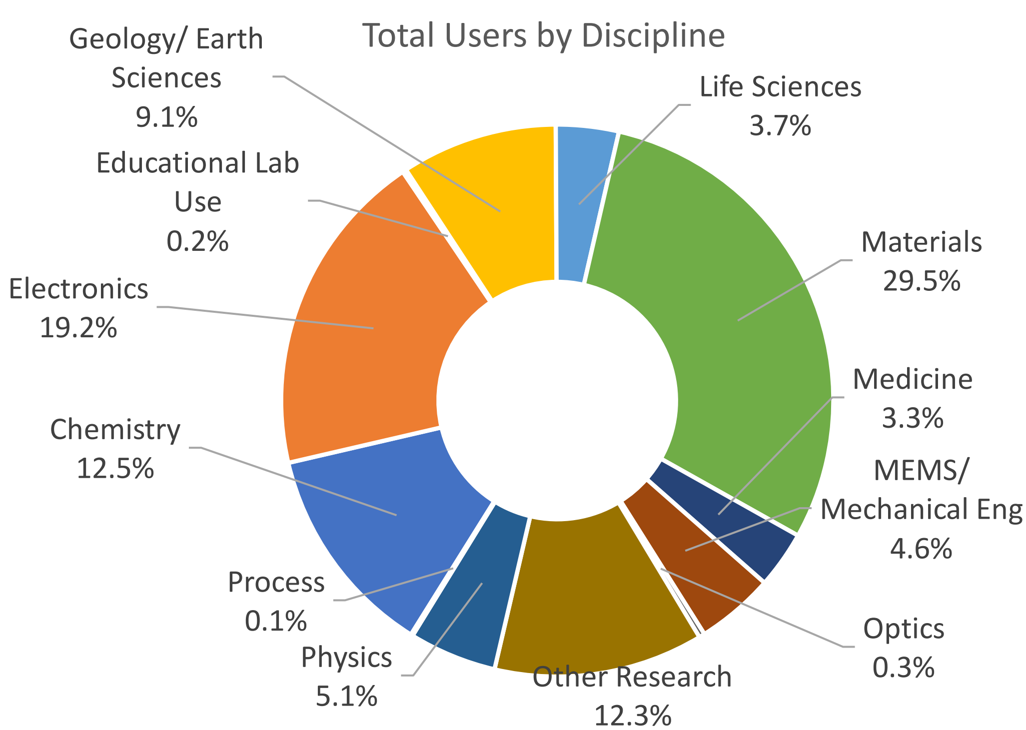
NCI-SW Site Statistics

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



NCI-SW Year 6 User Distribution





12.8. Nebraska Nanoscale Facility (NNF)

The *aim* of the Nebraska Nanoscale Facility (NNF) is to be an internationally recognized center of excellence for nanoscience, and a NNCI research hub for integrated fabrication, characterization and education in nanotechnology for the western region of the US Midwest.

Facility, Tools and Staff Updates

The enhancement of NNF facilities has proceeded in the last 5 years through funds received from the University of Nebraska, U.S. Army Research Office, NSF:NNCI, and NSF MRI. The Surface and Materials Characterization facility (SMCF) completed the installation of the advanced attocube system earlier this year for enabling low temperature and high magnetic field SPM. The Nanoengineering Facility recently added a new ZEISS Laser Confocal Scanning Microscope, and an EnvisionTEC 3D-Bioplotter 3D printer for tissue engineering research. Staff members supported wholly or in part by NNCI:NNF include: NNF Coordinator and User Contact: Dr. Jacob John; NNF Research Technologists: Dr. Anand Sarella, Dr. Andrei Sokolov; and Dr. Bala Balasubramanian. NNF Education-Outreach Coordinators: Steve Wignall and Dr Hanh Phan.

User-Base

The 6th year NNF usage statistics showed a recovering trend in terms of the number of users compared to the big drop in total number of users due to Covid-19 in previous year. Almost all of the internal users returned, and the number of current internal users is close to the pre-Covid level. The external user numbers remained virtually constant. Bringing external usage back to the pre-Covid level and continuation of the previous growth track remains the major focus of the NNF site in the coming years. Several programs focused on expanding the external usage had to be suspended due to Covid-19. We plan to restart all of those programs in the 7th year. We had to limit the number of external users for the NNF Minicourse during the 6th year since students were not able to travel from neighboring states due to Covid-19 related travel restrictions by the external institutions. Over 95% of our external users are remote users. Supporting this volume of external services would not have been possible without the NNCI grant. **Nanotech Lab Course for Users**: This one-credit hour per semester course provided graduate students with an introductory, but yet comprehensive view into the large variety of the instruments available at the NNF. The course spanned two semesters and covered theoretical introduction and demonstration of technical capabilities in materials and nanoscience areas.

Research Highlights and Impacts:

Research Focus Areas in NNF: The UNL hired four faculty in QMT in the Departments of Physics, Chemistry, Electrical and Computer Engineering, and Mechanical and Materials Engineering. These new faculty, along with several present faculty, will form a strong research group in the NSF Big Idea: Quantum Leap. Because of UNL's commitment to a quantum materials cluster hire, expertise in this forward-looking field is on an upward trajectory in NE. The NSF recently awarded $20M funding for the EPSCoR proposal on "Emergent quantum materials and quantum technologies" lead by the NNF Director Prof. Christian Binek. The interdisciplinary research by a team of 21 PIs and 4 universities in the state of Nebraska will add to the pool of NNF users and transform NE into an internationally recognized hub in the field of quantum materials. The NNF facilities will play a critical role in facilitating, supporting and enabling advanced quantum materials and technology research of the new EPSCoR EQUATE Center. The NNF also supports major sponsored research programs at the NCMN, an institutional Nanoscale Science and

Technology Program of Excellence, the Nebraska Innovation Campus, UNL's new Voelte-Keegan Nanoscience Research Center, the NSF-MRSEC, the DOE-EERE Collaboration on Magnetic Materials, and several other research centers and programs in other universities and colleges in the western region of the US Midwest.

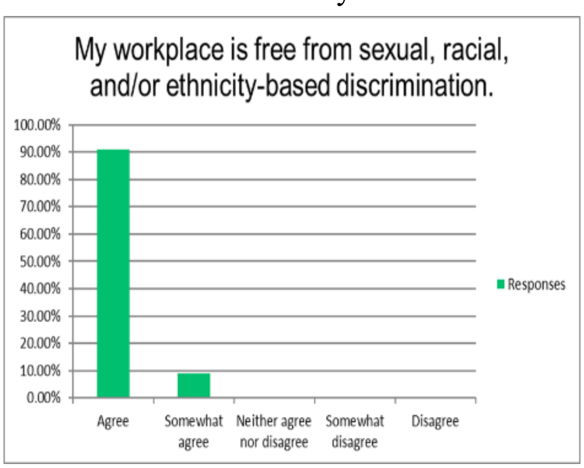
Projects of External Users

- *Monolith Materials, CA and NE*: Monolith, a California-based company, has invented and developed carbon nanoparticle production by burning natural gas. A new plant, under construction in Nebraska, will replace a coal-fired power plant with a hydrogen-burning one and employ 300 people when fully developed. The company is using NNF for characterizing the NPs using high-resolution S/TEM. NNF technologists provide their expertise to obtain HRTEM images for particle quantification and process control.
- *Vishay Dale Electronics, NE*: Vishay Dale Electronics's Nebraska plant located in Columbus is extensively using the X-Ray Photoelectron Spectrometer and X-Ray Fluorescence Spectrometer in the NNF for the elemental detection and composition analyses of thin films, plated sheets and other electronic parts. The company uses NNF equipment for the advanced investigations of the thin-film devices and fabrication-process failure mechanisms.

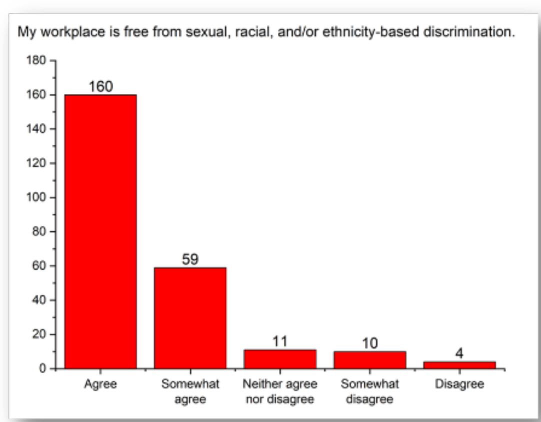
Economic Impacts: The NNF critically supports all research in materials and nanoscience at the Univ. of Nebraska. NNF also supports the Manufacturing economic sector of Nebraska's economy which, at $12.9 B, is third in the state's gross domestic product after Government ($14.8 B) and Finance/Insurance ($13.3 B). The NNCI grant enables NNF to provide critical resources necessary for many companies, smaller universities and colleges in the Midwest region. The NNF supported more than 30 regional institutions in 5 states in the Midwest region during the 6th NNCI year in terms of R&D, innovation, product development and testing, quality control, solving and identifying problems in product lines and identifying reasons of product failures in the field, etc.

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

NNF Survey Results



NNCI Network Survey Results



Education and Outreach Activities

NNF-Sponsored Events: ***National Nanotechnology Day Celebrations*** on Oct. 9, included a variety of different events by the Nebraska Nanoscale Facility (NNF) 1) images contributed to the national NNCI 2020 **Plenty of Beauty at the Bottom** image contest (placed first in the Most Stunning Category). And 2) hosting of an outreach booth to communicate about Nanotechnology at the Nebraska Associations of Teachers of Science Conference at Doane University, and at the Astronomy Day/AAPT workshop at the UNL Physics building.)

Student Conferences sponsored annually were the *Conference for Undergraduate Women in Physical Sciences, WoPhyS* where NNF partnered with MRSEC, along with other sponsors, to bring together outstanding undergraduate researchers in science. Students from across the US attended the national conference to build on their current research experiences.

We continued hosting ***Junior/Senior High Tours*** to interested junior and senior high students, parents and teachers visiting the UNL campus we began doing live tours again. Before the University allowed in person activity, we continued doing virtual tours for those interested in learning more about what UNL has to offer in nanoscience research. NNF helped coordinate tours and hands-on experiences with a variety of departments.

Partnerships: *Nebraska Math Day*: We had the opportunity to talk with some of the best and brightest high school students from across Nebraska virtually via ZOOM at the annual Nebraska Math Day. Our virtual booth allowed questions about STEM/Nano so high school students could get an idea of what UNL has to offer in the area of Nanotechnology.

***Nano and Discover Engineering Days*:** NNF partnered with the College of Engineering to virtually 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 apply math, science and creative thinking skills. Throughout 2020; 100's junior high students from rural schools throughout Nebraska receive synchronous Zoom nano lessons using hands-on materials mailed in advance.

In September of this year we returned to in-person activities again.

Workforce Development: *Lincoln STEM Ecosystem -* NNF is still part of this beginning Ecosystem which includes: Lincoln STEM-rich organizations and nonprofits. The goal of this group is to better connect the STEM organizations serving youth K-12 and post-secondary to the businesses that are hiring in our community to ensure equity in awareness of and connection to STEM skills and careers. Meetings were halted with the onset of Covid, and should resume in the near future.

Research Experience for Undergraduates (REU): With funding through the NNCI, 4 students worked in research labs 8-10 weeks during the summer focused on nanoscience areas. 2 of our students in this group were nontraditional, both being form Columbus Community College. We plan to continue this partnership again this summer, as it seemed very beneficial for both institutions.

High School Intern Program: Due to Covid-19 the Internship program pivoted to virtual format and continued remotely with limited on-site participation. Students were still able to present their research results at UNL's Summer Research Program Symposium at the end of the program remotely, to which faculty, parents and others were invited.

Rural Workforce Development: 1) We hosted tours for 12 undergraduate student cohorts from Central Community College (CCC), Columbus, NE. Students were able to experience firsthand our NNF Facilities. They are now performing research in NNF labs along with CCC faculty on a regular basis.

Teachers: ***Teacher Education Classes:*** NNF complimented efforts by UNL's College of Education and Human Sciences by providing nanoscience-related lessons and resources to 14 undergraduate students in one of their core education classes. Students received training on nanoscience lesson preparation with activities as part of their science education program using COVID safety procedures ***Research Experience for Teachers:*** With funding through the NNCI we were able to get 2 Community College Teachers and 3 High School classroom teachers for our summer experience. This 6-week activity was done simultaneously with Georgia Tech, Minnesota, and Northwestern, so weekly remote interactions with the groups could be scheduled via ZOOM. Teachers were required present their research to the group, and prepare a lesson to use in their classroom during the next school year. ***NanoSIMST***: 5 middle teacher were remotely taught over a 4 day period about lessons and activities that could be used in their classrooms to teach Nanotechnology at the Middle School level. They were responsible during the workshop to develop a lesson to be used in their classroom. This Curriculum was developed through Stanford University.

Diversity: ***K-12 Diversity Programs***: NNF partnered with Title 1 After-School programs in person and virtually, the local Girls, Inc. and summer Nano camps remotely to underrepresented and first generation 10-12th grade students from regional high schools. The camps included virtual tours of nano-related research in NNF facilities and hands-on activities. 2) New nano lessons were provided for 4H/Nebraska Extension for rural 6-8th graders during the 2020-21 school year. 3) A new partnership beginning in September 2020 with Educational Talent Search (ETS) created virtual lessons for 50 junior high/25 high school underrepresented M/H school students and ETS staff training for After-School programs to continue.

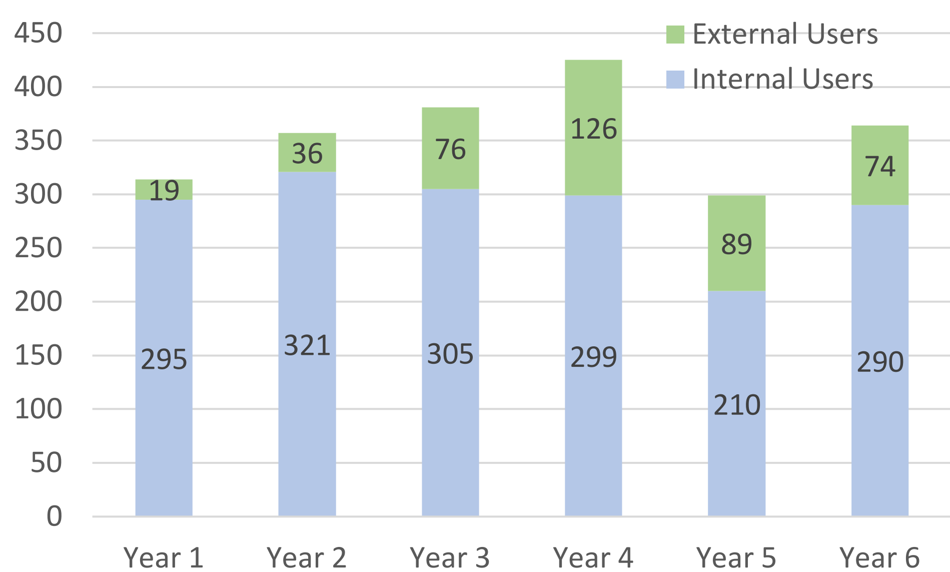
Traveling Nanoscience Exhibit and Sun Moon Earth Exhibit: Our 400-sq.-ft.hands-on Nano exhibit was hosted by the W.H. Over Museum in Vermillion, South Dakota. Our new Sun Moon Earth exhibit was hosted at the University of Nebraska State Museum at UNL, and then Transferred to the Kearney Children's Museum, We added a display on nano technology to this exhibit that relates to Carbon Nanotubes and a possible Space Elevator in the Future.

Resources: ***Nano/STEM Kits*****:** We provided Nano/STEM activity kits (developed by NISE Net, a NSF-funded organization) to many teachers in the area. Multiple locations throughout the state and into South Dakota used Nano/STEM kits for the first time in classrooms, museums, and other venues to provide hands-on activities about nanoscience topics.

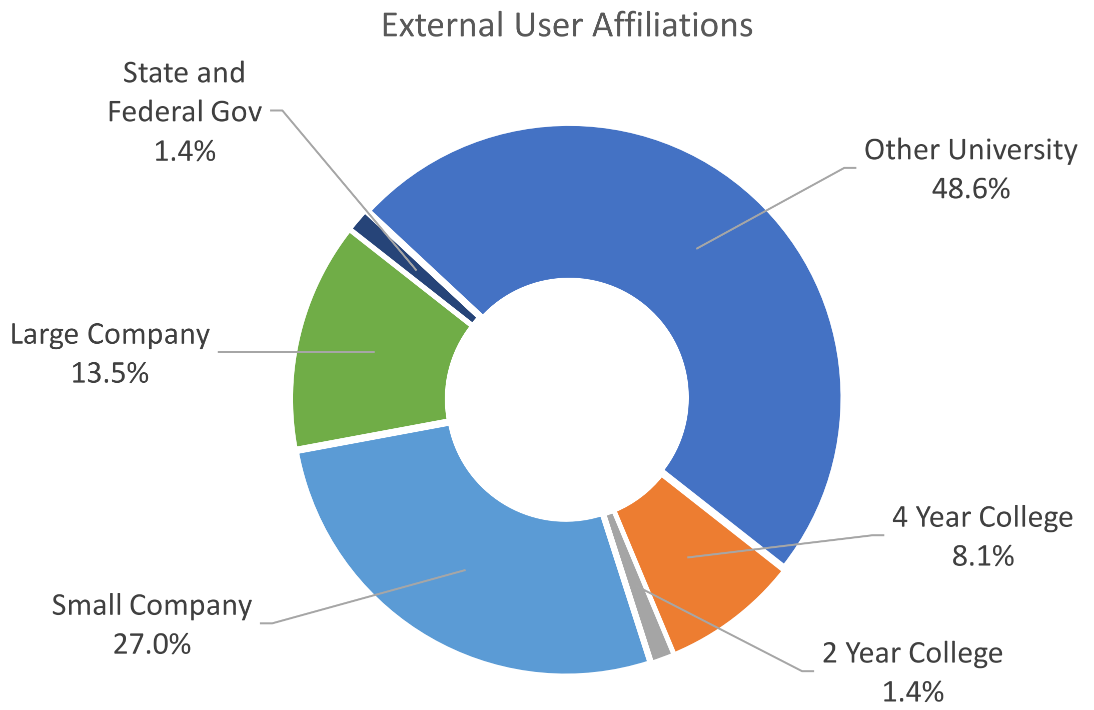
Assessment Activities: The Nebraska Nanoscale Facility (NNF) evaluated efforts to promote nanoscience among diverse, underrepresented groups, by surveying participants at the completion of After-School programs, the Summer Nano Camp and workforce and development efforts to middle school girls in northeast Nebraska. Participants in the remote high school program completed pre/post surveys about their remote work in nanoscience labs during the summer. The Rural Teacher Workshop surveys provided information to us about teacher's nanoscience knowledge and what tools and activities were needed to influence their students in the nanoscience area. Students in the fall 2020 Discover Engineering virtual outreach were surveyed and 42 percent responding indicated that the lesson and activities had increased their interest in studying science and engineering, and 61 percent said I understand more about nanotechnology after participating in this event.

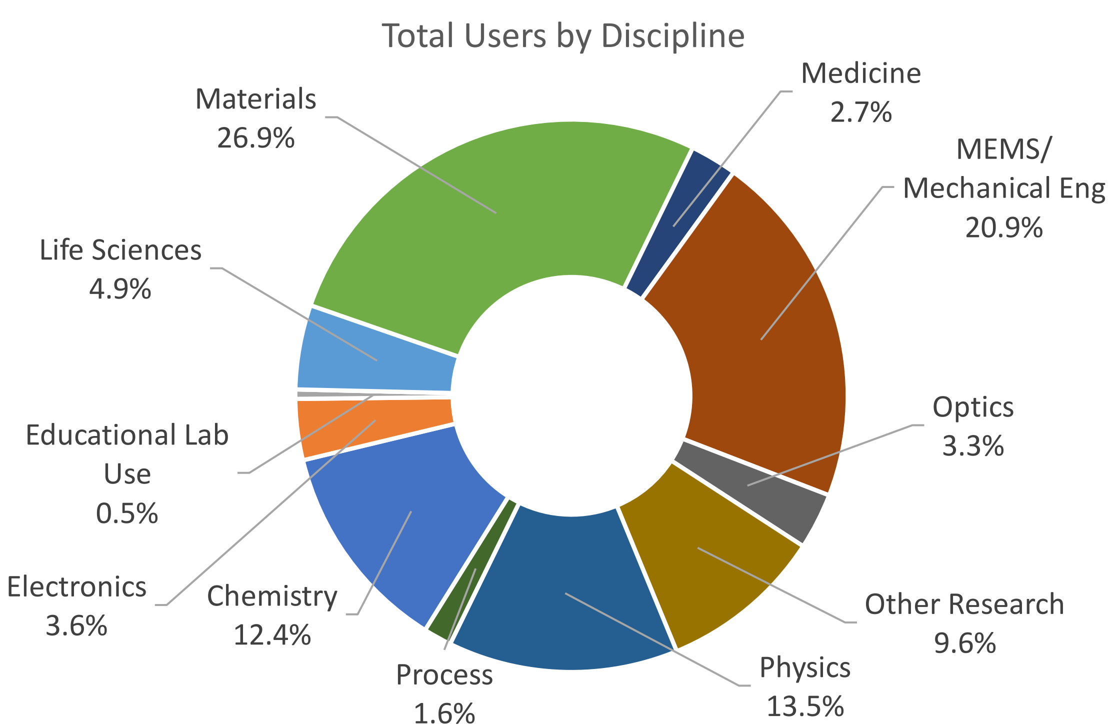
NNF Site Statistics

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



NNF Year 6 User Distribution





12.9. NNCI Site @ Stanford (nano@stanford)

Facility, Tools, and Staff Updates

nano@stanford

The NNCI Site @ Stanford University provides access to world-leading facilities and expertise in nanoscale science and engineering for internal users and for external users from academic, industrial, and government labs. Furthermore, we seek to develop and propagate a national model for educational practices that will help students and visitors become knowledgeable and proficient users of the facilities, as well as contribute to workforce development among underrepresented communities through our Community College Internship programs.

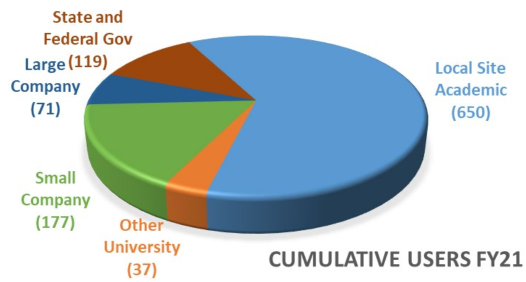
Stanford's facilities offer a comprehensive array of advanced nanofabrication and nanocharacterization tools, including resources that are not routinely available at shared nanofacilities, such as an MOCVD (Metalorganic Chemical Vapor Deposition) laboratory that can deposit films of GaAs or GaN; a JEOL electron-beam (e-beam) lithography tool that can inscribe sub-10-nm features over 8-inch wafers; a Cameca NanoSIMS (Secondary Ion Mass Spectrometer) that combines the high mass resolution, isotopic identification, and sub-ppm sensitivity of conventional SIMS with 50-nm spatial resolution; and a unique scanning SQUID (Superconducting Quantum Interference Device) microscope with world-leading spin sensitivity. The facilities occupy ~30,000 sq. ft. of space including 16,000 sq. ft. of cleanrooms, 6,000 sq. ft. of which meet stringent specifications on the control of vibration, acoustics, light, cleanliness, and electromagnetic interference. They offer state-of-the-art equipment as well as processes developed by scientists who work at the cutting edge of nanoscience. Close to forty expert staff members (including eighteen PhDs) maintain the instruments, teach users to operate them, and consult with users to optimize processes for their applications. The NNCI Site @ Stanford provides access to the ***Stanford Nano Shared Facilities*** **(SNSF)**, the ***Stanford Nanofabrication Facility*** **(SNF)**, the ***Stanford Microchemical Analysis Facility*** **(MAF)** and the ***Stanford Isotope and Geochemical Measurement & Analysis Facility (SIGMA).*** **New Capabilities:** During Year 6 of the NNCI award we have added a number of new instruments accessible to the internal and external users, including a Gatan K3 TEM Camera System for real-time, single electron counting TEM detection, a Fischione Model 1061 SEM Ion Mill for broad beam argon milling and polishing of SEM samples, a JEOL JSM-IT500HR Scanning Electron Microscope (SEM) with Energy Dispersive X-ray (EDS) detector and a panchromatic Cathodoluminescence (CL) spectrometer, a Samco 300 Capacitively Coupled Plasma (CCP) Etcher for low damage surface treatment, an AJA Evaporator for deposition of a variety of materials, and an Osiris Affix 20m bonder for adhering small, flexible, or very thin samples (<40 µm) to larger substrates. **Personnel**: Daniella Duran joined nano@stanford as Education & Outreach Program Manager, Cliff Knollenberg returned to nano@stanford and joined SNF as Lithography Process Engineer, and Jim Peterson joined SNF as a MOCVD Lab Manager. Dr. Pinaki Mukherjee joined SNSF as a TEM Scientist, and Marlinda Novitasari joined SNSF as an administrative associate for external user intake. Finally, Prof. Philip Wong has taken on a new leadership role as

Fischione Ion Mill for SEM sample preparation.

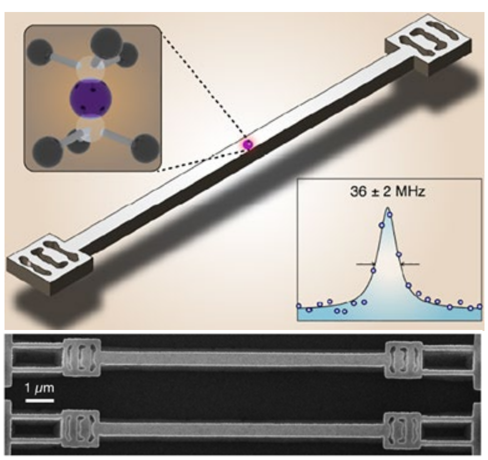
the SNF Faculty Director (replacing Prof. Nick Melosh) while Prof. Yuri Suzuki became the SNSF Faculty Director (replacing Prof. Bruce Clemens).

User Base

During the Fiscal Year 2021 the nano@stanford NNCI site served a total of 1054 users, despite partial access restrictions due to the COVID-19 pandemic. This included 650 internal users, 248 industrial users, 119 state and federal government users, and 37 users from other academic institutions. Billed user fees during that period accumulated to a total of $6.3M, of which $3.4M was collected from external users. During the 2020 calendar year we have captured 304 published journal articles from internal users, 9 articles from external users, 22 conference presentations, 6 patent applications filed, 11 patents granted, and 1 book chapter. This data was captured through self-reporting and we estimate the true number to be approximately three times larger. We continue to struggle to develop an effective way of accurately capturing publications from all site users, and have partnered with Stanford Libraries to try to automate and improve the process.

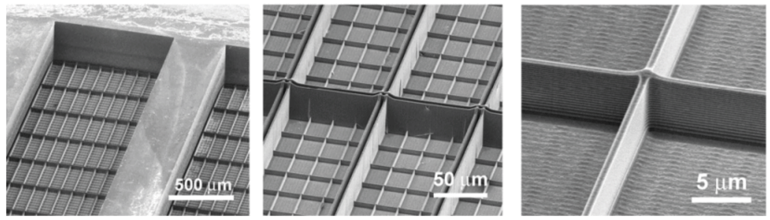


Research Highlights and Impact:



(Top) Schematic of the diamond waveguide with implanted SnV- center at the center of the device. (Bottom) SEM image of the fabricated device.

Integrating solid-state quantum emitters with photonic circuits is essential for realizing large-scale quantum photonic processors. Negatively charged tin-vacancy (SnV−) centers in diamond are promising candidates for quantum emitters due to their excellent optical and spin properties, including narrow-linewidth emission and long spin coherence times. SnV− centers need to be incorporated in optical waveguides for efficient onchip routing of the photons, but such integration is yet to be realized. **Profs. Shen, Melosh and Vuckovic** research groups demonstrate the coupling of SnV− centers to a nanophotonic waveguide. They realized this device by leveraging their recently developed shallow ion implantation and growth method for the generation of high-quality SnV− centers and the advanced quasi-isotropic diamond fabrication technique. Furthermore, they demonstrate successful coupling of narrow-linewidth SnV− centers (as narrow as 36 ± 2 MHz) to the diamond waveguide, and investigate the stability of waveguide-coupled SnV− centers under resonant excitation. Their results are an important step toward SnV−-based on-chip spin-photon interfaces, single-photon nonlinearity, and photon-mediated spin interactions. Their work was published the journal *ACS Photonics* and supports the NSF Quantum Leap Big Idea.



Progressive close-up images showing mega-ribs, mini-ribs, and nanopores on the silicon membrane.

With nearly 100,000 people on the waiting list, the availability of kidneys for transplant is of critical importance. Silicon nanoporous membranes provide the fundamental underlying technology for the development of an implantable bio-artificial kidney. These membranes, which are comprised of micromachined slit-pores that are nominally 10 nm wide, allow for high-efficiency blood filtration as well as immunoprotection for encapsulated cells. The work of **Prof. Roy (UCSF) and researchers from Silicon Kidney LLC** takes advantage of well-established semiconductor fabrication technology to achieve precise control over pore widths, allowing for highly selective filtration and a clear path towards further miniaturization. This work builds on their prior results on "ribbed nanoporous membranes" by adding a second-level hierarchy of significantly taller "mega-ribs" to further strengthen the membranes. Relying on a two-step Deep Reactive Ion Etch (DRIE) process, and the availability of the ASML stepper system with a unique 3-D align capability (available at nano@stanford facilities), the group has fabricated and tested freestanding membrane spans that are up to 14 times wider than before, with approximately double the measured permeability per unit area. The new architecture can also improve cross-membrane mass-transfer rates and reduce chip-fabrication costs. The results have been published in the *Journal of Microelectromechanical Systems* and supports the NSF Growing Convergence Research Big Idea.

<u>Education and Outreach Activities</u>

The nano@stanford NNCI site is dedicated to developing and implementing activities targeted at youth, community college students, schoolteachers, and the public that will increase their interest, understanding, and involvement in STEM. These initiatives range from volunteer participation in outreach events to more in-depth workshops that span multiple days. During this reporting period, about 2,300 people were involved in these types of activities. Due to COVID-19 restrictions, many events and programs, such as the Nanoscience Summer Institute for Middle School Teachers (NanoSIMST) program, were held remotely. This year's NanoSIMST program was opened to teachers from across the country and we recruited local NanoSIMST alumni to support pedagogical efforts. We provided hands-on activity kits, held Zoom meetings, and led virtual cleanroom tours to support teachers. Due to a staff change, we leveraged the power of the network to combine our efforts with SENIC to maintain the NanoSIMST program in the summer of 2021. External evaluation of the program found a statistically significant increase in concept knowledge and 100% of teachers surveyed would recommend the program to a colleague.

We restarted the partnership with local community colleges focusing on internships for workforce development. **We hired 4 interns (half of whom are from minority serving institutions)**. To support social distancing and increase accessibility, we published several modules on EdX for remote training, and have added 80 videos to support various fabrication and characterization tools on our YouTube channel. We hope to continue leveraging our online resources to adapt to the dynamic changes of these unprecedented times and are **leading a network wide initiative for a permanent virtual NanoSIMST, in addition to our traditional in-person program, to continue to serve teachers from around the country, especially in under-resourced communities**.

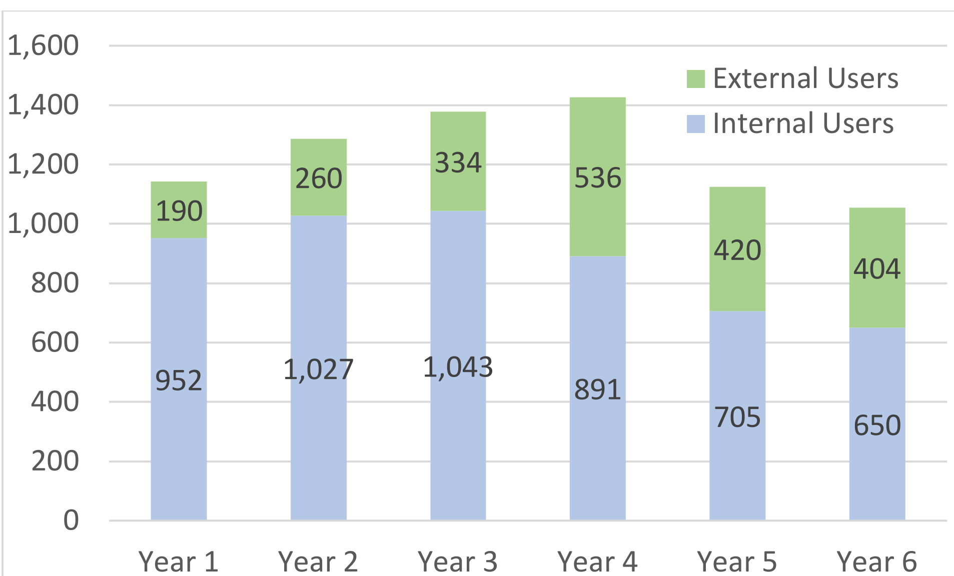
Societal and Ethical Implications Activities

The SEI effort was rebooted in 2021 with the intention to bring ethical considerations and discussions more directly into our nano@stanford culture. In April, we co-hosted a well-attended **talk (approximately 58 participants) given by Professors Robert McGinn and Robert Howe entitled "Ethical Responsibilities of Nanotech Researchers."** Additionally, the Stanford delegation at the **NNCI "Science Outside the Lab"** summer program included four students and one TA, all of whom greatly enjoyed the experience and are now working to create an ethics curriculum for the lab members. The plan is to integrate the online materials they are creating into the onboarding process for the nano@stanford lab members.

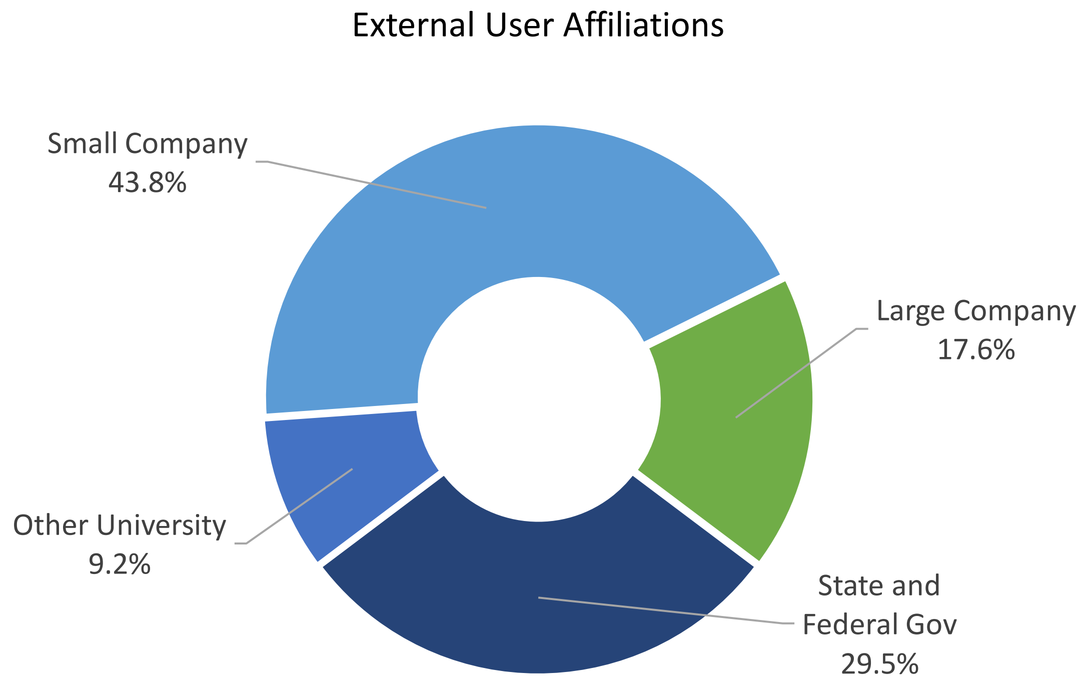
nano@stanford Site Statistics

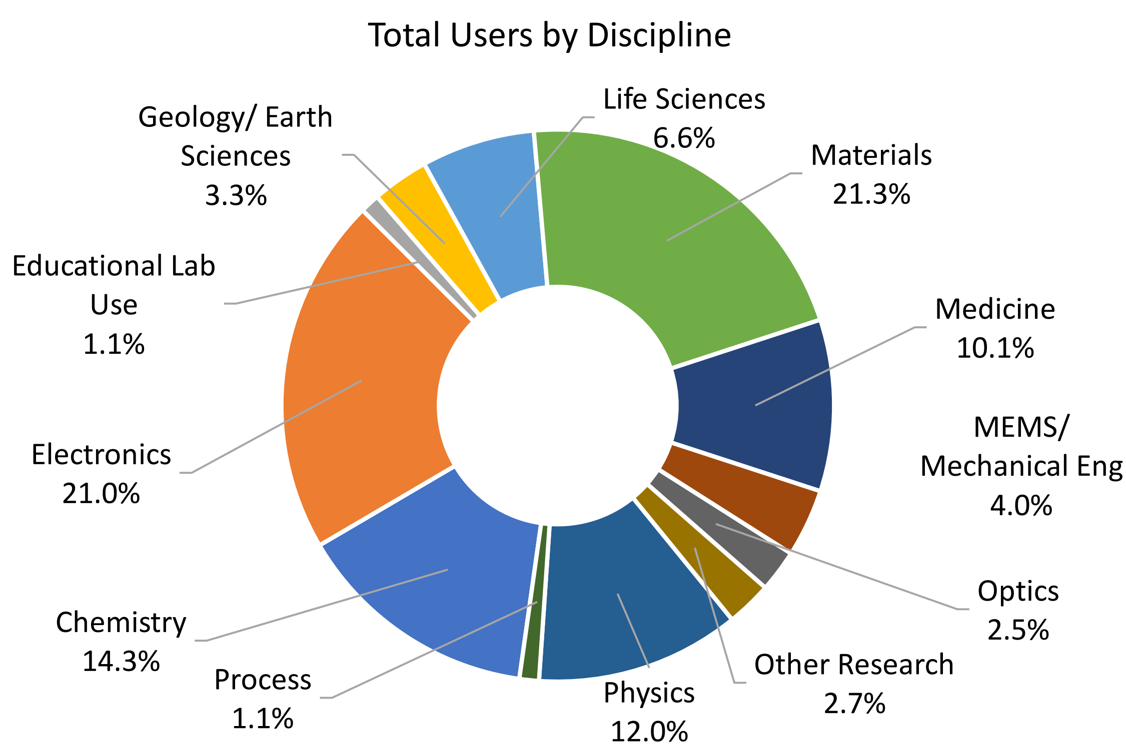
Yearly User Data Comparison						
	Year 1	**Year 2**	**Year 3**	**Year 4***	**Year 5**	**Year 6**
Total Cumulative Users	1,142	1,287	1,377	1,427	1,125	1,054
Internal Cumulative Users	952	1,027	1,043	891	705	650
External Cumulative Users	190 (17%)	260 (20%)	334 (24%)	536 (38%)	420 (37%)	404 (38%)
Total Hours	113,089	113,193	135,054	119,877	78,663	104,536
Internal Hours	94,996	91,248	105,083	72,408	47,856	63,013
External Hours	18,093 (16%)	21,944 (19%)	29,971 (22%)	47,469 (40%)	30,807 (39%)	41,523 (40%)
Average Monthly Users	520	572	601	615	405	470
Average External Monthly Users	74 (14%)	92 (16%)	115 (19%)	213 (35%)	136 (34%)	162 (34%)
New Users Trained	550	579	584	596	359	491
New External Users Trained	97 (18%)	143 (25%)	194 (33%)	262 (44%)	159 (44%)	186 (38%)
Hours/User (Internal)	100	89	101	81	68	97
Hours/User (External)	95	84	90	89	73	103

*Starting in Year 4 the Stanford site began to categorize users from the SLAC National Lab as federal government (external) users instead of internal users.



nano@stanford Year 6 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. Moreover, NNI leverages collaborations with academic, industry, and government partners, such as the Department of Energy's Pacific Northwest National Laboratory (PNNL) in Eastern Washington State, to expand NNI capabilities. By linking together characterization and fabrication capabilities across the Pacific Northwest, NNI streamlines and expands the breadth of equipment and expertise available to scientists with diverse research interests and needs. The increasingly large and distributed user base of NNI facilities includes academic and industrial users as well as nontraditional users in clean energy and biotechnology. NNI also plays an important role in educating and training the highly skilled workforce of engineers, researchers, and technicians needed by industry. NNI continues to be key to affirming the Pacific Northwest's leadership in research and innovation for nanotechnology and quantum information science and technology.

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

<u>Infrastructure Investments</u>

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

<u>Major New Tools and Capabilities</u>

University of Washington:

- Zygo ZeGage Pro HR, high resolution 3D optical profilometer at the WNF
- VibroMet® 2 Vibratory Polisher installed in the MAF
- New EDAX Elite T energy dispersive x-ray spectroscopy (EDS) detector installed on MAF TEM

Oregon State University:

- Ultra-fast laser system for characterization of thin films under development, funded by an NSF MRI award
- Meltio M450 laser direct energy deposition metal 3D printer.

<u>Staff Updates</u>

In April 2021, the WNF hired an engineer, Brant Hempel, to support Electron Beam Lithography. Jason Tauscher, WNF business development manager, left to pursue a career in the private sector. The WNF has recently filled two open staff positions for process engineers, who will join the team in early 2022. Dr. Timothy Pollock (previous MAF student/temporary staff) has been hired as permanent, full-time staff by the MAF. Dr. Pollock is an expert in advanced laser techniques. Long time MAF staff member Dr. Micah Glaz has left for a materials scientist job at local startup

GlowForge. The MAF hired Dr. Heather Niles to take over Micah's job. Dr. Niles has expertise in sustainable bio-based materials and materials characterization with AFM and nanoindentation. Dr. Rafik Addou left the Ambient Surface Characterization Laboratory (APSCL) at OSU to pursue a career in industry. Heath Kersell was hired in August 2021 to support the suite of surface characterization equipment in APSCL. Dr. Sam Angelos retired from his position as director of the Advanced Technology and Manufacturing Institute (ATAMI) at OSU. Todd Miller was promoted to director of ATAMI. Additional hires at ATAMI include administrative assistant Hyojung Kwon and engineer Michael Callaway.

User Base

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

Following a tumultuous 2020, the WNF saw steady increases in user activity in 2021. The facility has maintained staff rotations, while offering 24/7 operation apart from holidays and necessary shutdowns for facility needs. Dr. Darick Baker, a lead engineer at the WNF, has taken over business development responsibilities following the departure of the WNF Manager of Business Outreach and Customer Development. WNF monthly revenues have recovered to levels even higher than pre-COVID. At least three companies in the WNF (Hummingbird Scientific, EOspace, Tunoptix) are supported in part by SBIR/STTR grants.

MAF staff have continued to put a major effort into making training videos and developing remote methods to get people trained on MAF tools. A video version of the MAF lab tour for safety introduction is now included in the new user registration process through Coral. In addition, MAF staff are, as usual, available to acquire data for users. The MAF is now back up to full capacity after the partial shutdown during COVID and revenue levels are at pre-COVID levels. The MAF has been seeing an increase in interest from industrial users. Additionally, MAF staff are currently working on funding to update 'workhorse' tools such as the x-ray photoelectron spectrometer, as well as upgrading it with capabilities that will better serve MAF users.

During the past year, ATAMI, APSCL, and the Materials Synthesis and Characterization Facility (MASC) at OSU experienced growing user access and revenue. The three-month moving average of revenue increased by over 40% during the past year. We have added two new ATAMI tenants: Phosio (NSF SBIR Phase I recipient) and nexTC (DOE EERE SBIR Phase II recipient).

Research Highlights and Impact

Here we highlight *quantum information science and technology (QIST)* activities, which have continued to expand, driven by QuantumX, a UW campus-wide interdisciplinary initiative of faculty performing cutting-edge research in QIST, and the Northwest Quantum Nexus (NQN), a UW-led coalition of research institutes and industrial organizations in the Pacific Northwest and neighboring regions (including Microsoft and Pacific Northwest National Labs) with the goal of advancing QIST research and developing a QIST-trained workforce. QuantumX faculty such as Mo Li (NNI co-PI), Kai-Mei Fu (NNI senior personnel, QuantumX co-chair), and Arka Majumdar (QuantumX co-chair) now constitute the heaviest academic users in our site.

Co-PI Mo Li leads an NSF Convergence Accelerator in Quantum Technology program whose Phase-1 team included PI Böhringer as well as other colleagues from UW, UIUC, and Atom

Computing, a start-up company in the Bay Area. The recently awarded Phase-2 grant added members from Berkeley, JILA, and Sandia National Labs. The goal of this program is to develop a chip-scale acousto-optic beam steering system for cold-atom quantum computing. If successful, this system will enable a dramatic scale-up of the current state of the art to an intermediate system consisting of more than 1,000 qubits, capable of performing simulation tasks for quantum chemistry and optimization algorithms.

Co-PI David Ginger leads a new NSF Science and Technology Center for Integration of Modern Optoelectronic Materials on Demand (IMOD). Research in IMOD will focus on new semiconductor materials and scalable manufacturing processes for new optoelectronic devices for applications ranging from displays and sensors to a technological revolution, under development today, that is based on harnessing the principles of quantum mechanics.

A cluster hire of at least 5 new QIST faculty in the UW College of Engineering commenced in autumn 2020. Successful hires include ECE Assistant Professor Sara Mouradian, an MIT graduate and Berkeley postdoc focusing on trapped-ion quantum sensing, and ECE Assistant Professor Rahul Trivedi, a Stanford graduate and Max Planck-Harvard Research Center for Quantum Optics postdoc working on simulation and design of next-generation quantum devices. Rahul's position is supported in part by an NSF Quantum Computing & Information Science Faculty Fellow grant to the UW. Additional quantum cluster hires in Mechanical Engineering and Materials Science & Engineering are currently ongoing.

Senior personnel Kai-Mei Fu leads a $3M NSF Research Traineeship for graduate students in quantum information science and technology. This traineeship — known as Accelerating Quantum-Enabled Technologies (AQET) —makes the UW one of just a handful of universities with a formal, interdisciplinary curriculum in this field. AQET students can come from doctoral programs across Arts & Sciences, Engineering, and Computer Science & Engineering.

NNI is a partner site in the recently approved NSF AccelNet program "Global Quantum Leap." This program creates network-to-network partnerships between NNCI and partner networks around the world that have long-standing collaborations with several NNCI sites. The goals of this network are to create key linkages between nanofabrication and quantum information communities on a global scale, develop a process and fabrication technology roadmap for emerging quantum computing systems, and to equip students and early-career researchers with skills to collaborate with international teams that will tackle challenges related to quantum computing systems.

Other major developments:

Senior personnel Líney Árnadóttir, an Associate Professor of Chemical Engineering at Oregon State University and a UW graduate, received the inaugural Early Career Impact Award from UW Chemical Engineering, as well as the Graduate Mentoring Award and the Thomas Meehan Honors College Eminent Mentor Award in OSU's College of Engineering. She is recognized for her contributions to the mechanics of surface reactions at the molecular level, and for her passion about mentoring graduate and undergraduate students.

Inpria, which is developing resists for extreme ultraviolet photolithography, uses ATAMI, OPIC, and APSCL facilities and has been recently acquired by JSR Corp. for $514M.

Anavasi Diagnostics, a UW spin-out with labs located in NanoES, has been awarded $14.9 million from the National Institutes of Health (NIH) Rapid Acceleration of Diagnostics (RADxSM) initiative. The funding will accelerate the launch and broad market availability of the

AscencioDx™ molecular diagnostic platform for the detection of RNA indicative of the SARS-CoV-2 / COVID-19 virus.

UW spin-out *Tunoptix, LLC,* which develops tunable metasurface optics for machine vision and AR/VR applications, received additional seed funding from a leading intellectual property commercialization company and SBIR grants from DARPA, NASA, and NSF.

Education and Outreach Activities

NNI's E&O portfolio continues to emphasize workforce development, K-12 outreach, underrepresented populations in nanotechnology (including women and communities farthest from educational justice), and engagement of Regional First Nation Tribes. While NNI's traditional K-12 in-person E&O activities continue to be significantly hampered by the global COVID-19 pandemic, we are focusing on supporting on-campus college transition programming for underserved populations. Meanwhile, we continue our workforce development and training efforts under the safety protocols developed by the UW and OSU.

Workforce Development

NNI facilities support the development of highly skilled researchers, engineers and technicians to supply increasing demand from industry. In addition to helping students and young professionals gain training and experience, NNI facilities also provide students with unique opportunities to interact with users in industry.

Providing traditional 4-year undergraduates and community college students engaging research opportunities is one of several ways NNI facilities have supported workforce development in the region. Even during the COVID-19 pandemic, WNF has several undergraduate students

through the Student Laboratory Assistant Program. Students from the UW and partner community colleges worked with WNF staff on research and contract projects, gaining hands-on nanofabrication experience that helped advance their academic and professional careers. Many students continued their nanotechnology training in graduate school while others were hired directly into jobs in industry (often recruited by WNF industry clients). This past year, there were 18 student lab assistants, a third of whom are women.

In addition to WNF's Student Lab Assistant Program, this past year, the MAF also employed two paid UW undergrad research assistants. MAF student assistants learn about lab safety, and data processing, and how to use various MAF instruments.

NNI facilities at OSU have increased the number of undergraduate researchers this year to 7, where all were working on different nanotechnology related projects under the guidance of NNCI faculty and staff. Students ranged in experience from freshman to seniors and included participants in STEM Leaders, a mentoring and research program aimed at increasing diversity in STEM fields. Close to a third of students participating in OSU NNI related activities identify as female or other underrepresented groups in engineering.

First Nations Engagement

NNI is committed to engaging first nations to expand access to nanotechnology and to connect opportunities for nanotechnology to address needs identified by communities from diverse backgrounds. NNI has sought candidates from local tribal nations to participate in the cleanroom internship program. Our longest partnership includes a student who is now in his senior year at UW, having joined WNF as a high school intern from Chief Leschi School.

NNI typically hosts visits for middle and high school students from local Native American schools, including multi-day visits by the Paschal Sherman Indian School in Omak, Washington. These have been overwhelmingly positive experiences but could not happen this year due to the COVID-19 pandemic. While in-person visits were not possible, PI Ratner has engaged with the Western Washington Native Education Consortium to train district staff in over 20 regional school districts on 4-year pathways and access programs at the University of Washington. This engagement is being expanded into relationships to support remote student engagement in the coming academic quarters subject to COVID-19 restrictions.

Educators-in-residence

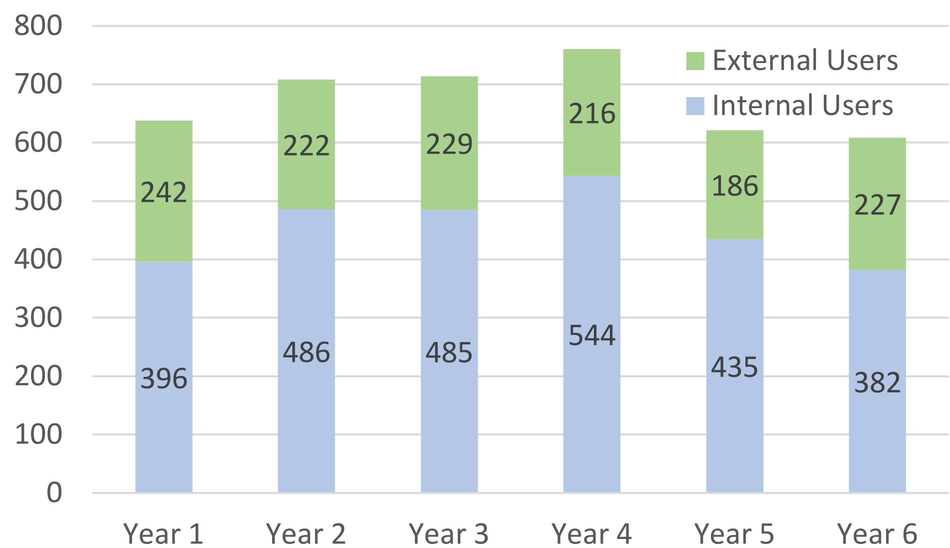
Co-PI Baio has designed a program to bring science teachers from schools within local tribal communities to OSU to participate in a NNCI supported research project. Each participant will work for 5 weeks and partake in data collection and analysis, literature discussions and weekly lab meetings with the project team, thereby exposing the instructor to state-of-the-art experimental protocols, numerical methods and advanced spectroscopic techniques. During this program each teacher will be paid $1,000/week plus material expenses for the course development work. Unfortunately, these teacher training activities planned for this final award year were significantly hampered by the global COVID-19 pandemic, but we are in the process of pivoting E&O activities for a remote environment.

Undergraduate and Graduate Courses

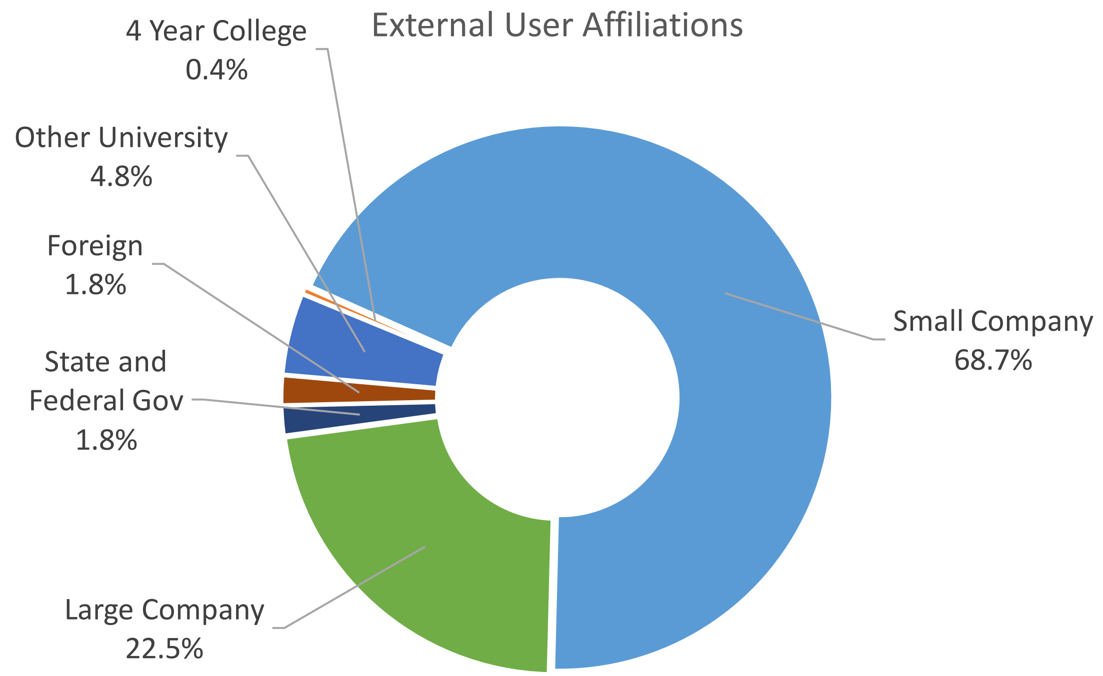
The University of Washington and Oregon State University offer comprehensive curricula with both conventional graduate courses and evening classes for professional master's program (PMP) students. Currently, several courses utilize the NNI facilities: EE 527 Nanofabrication Techniques, EE/ME/MSE 504 Introduction to Microelectromechanical Systems (MEMS), EE/MSE 486/528 Integrated Circuit Fabrication, ME 461/561 Mechanics of Thin Films, BIOEN 492/592 CHEME 458/558 Surface Analysis, and OSU's CHE 444/544 Thin Film Processing.

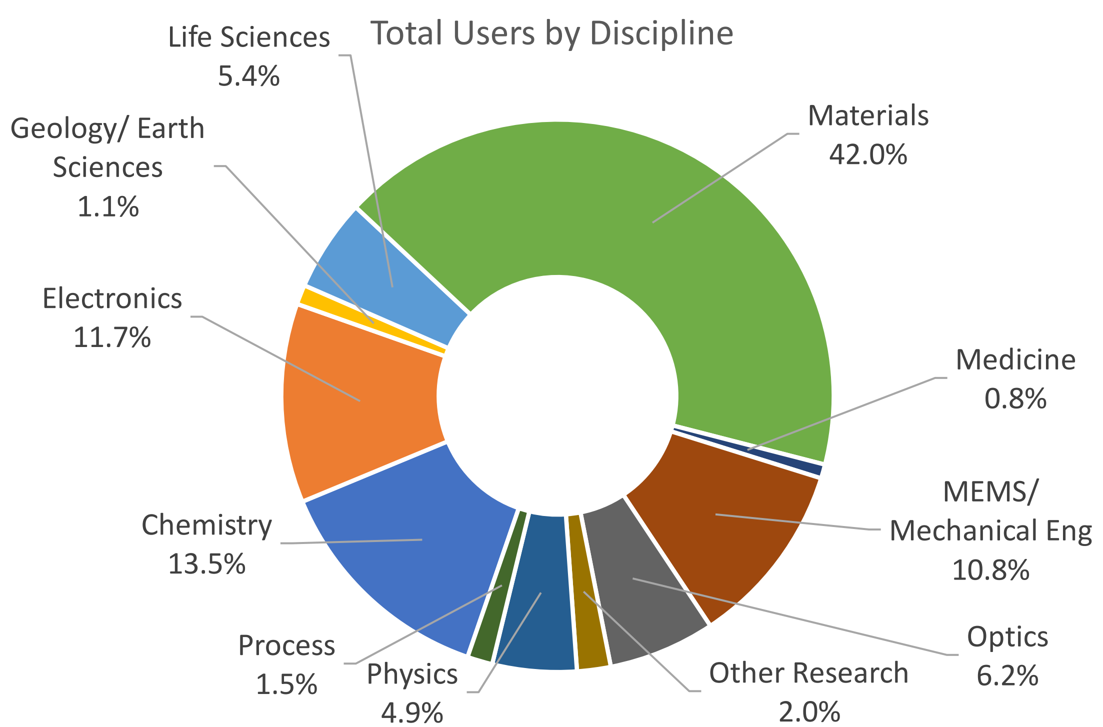
NNI Site Statistics

Yearly User Data Comparison	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Total Cumulative Users	638	708	714	760	621	609
Internal Cumulative Users	396	486	485	544	435	382
External Cumulative Users	242 (38%)	222 (31%)	229 (32%)	216 (28%)	186 (30%)	227 (37%)
Total Hours	38,350	46,562	55,925	65,032	55,939	72,122
Internal Hours	21,822	30,600	27,695	35,564	22,262	26,740
External Hours	16,528 (43%)	15,962 (34%)	28,230 (50%)	29,468 (45%)	33,677 (60%)	45,382 (63%)
Average Monthly Users	267	277	266	304	226	252
Average External Monthly Users	103 (39%)	98 (35%)	93 (35%)	93 (31%)	77 (34%)	88 (35%)
New Users Trained	126	159	206	134	64	115
New External Users Trained	41 (33%)	37 (23%)	57 (28%)	31 (23%)	18 (28%)	31 (27%)
Hours/User (Internal)	55	63	57	65	51	70
Hours/User (External)	68	72	123	136	181	200



NNI Year 6 User Distribution

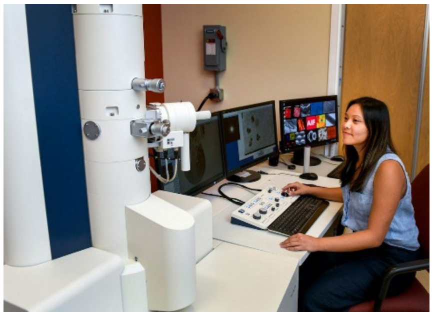




12.11. Research Triangle Nanotechnology Network (RTNN)

Facility, Tools, and Staff Updates

Staff: Dr. Jenny Forrester joined NC State's Analytical Instrumentation Facility (AIF) as the new XRD Lab Manager in June 2021. Jenny has a Ph.D. in Materials Engineering from the University of Newcastle in Australia and 20+ years of experience in XRD measurement and analysis. Dr. Jin Nakashima also joined AIF as a Senior Research Scholar in October 2021. Jin earned his MS and PhD in Wood Science and Technology from Kyoto University in Japan and has 20+ years of experience sample preparation and microscopy experience focused mostly on biological specimens. In AIF, Dr. Nakashima helps clients and manages the biological sample preparation and bio-EM laboratories alongside Dr. Aaron Bell. Dr. Nina Balke, an Associate Professor in the MSE department at NC State, was appointed as the new Director of the AIF in place of Dr. Jacob Jones, who remains involved with AIF in an official advisory role. The Public Communication of Science and Technology (PCOST) program welcomes Anne Njathi as the new acting assistant director of assessment while the role is vacated by Ekaterina Bogolometc as she graduates and moves to a new position. Anne is a doctoral student in Communication, Rhetoric and Digital Media with over 8 years of multidisciplinary work experience. **Tools:** In Year 6, 8 new instruments valued at >$3.1 million were acquired including a plasma assisted Focused Ion Beam (pFIB-SEM), a Hitachi HT7800 RuliTEM Transmission Electron Microscope (TEM), a Leica UC7/FC7 Cryo-Ultramicrotome, a Shimadzu UV-3600i UV-Vis-NIR Spectrophotometer with ISR-603 Integrating Sphere, a Kratos Analytical AXIS Supra X-ray photoelectron spectroscopy (XPS), an optical thin film measurement tool (Filmetrics F20-UV), a Hitachi SU3900 Variable Pressure SEM, as well as a previously-owned PANalytical X'Pert Pro X-Ray Diffractometer (XRD). **Techniques:** A motorized stage was installed on SMIF's Horiba LabRam Aramis Raman system, and the mapping function of the software was enabled, allowing a method for generating detailed chemical images based on a sample's Raman or PL spectrum. EBL/CAD hardware and software were upgraded for ease of use, more streamlined pattern layouts, reduced write times and alignment upgrades for better overlay accuracy. NNF added many capabilities, including an Automated TLM measurement process, added a III-nitride low-resistivity contact process for their metal evaporator, Low-stress PECVD Si_3N_4 deposition, a new capability of metal liftoff with 150nm and 50nm resolution for Electron beam lithography (EBL), a new high resolution (500nm) lift-off process and 400nm deep etching resolution to their i-line stepper, a new High-temperature oxidation process of n-type SiC, a high-carrier concentration ($>10^{19}cm^{-3}$) n-type doping of Si and poly-Si process using a spin-on dopant/rapid anneal process, new fabrication process of interlayer dielectrics (ILD) with rounded features, and finally an expanded capability for deposition, anneal, and etch of low resistivity contacts to n- and p-type SiC using ILD. Upcoming acquisitions include a 2D wide angle x-ray scattering (WAXS) stage for CHANL's XRD while NNF is also acquiring an Apogee spray developer to improve repeatability and efficiency in their lithography techniques.

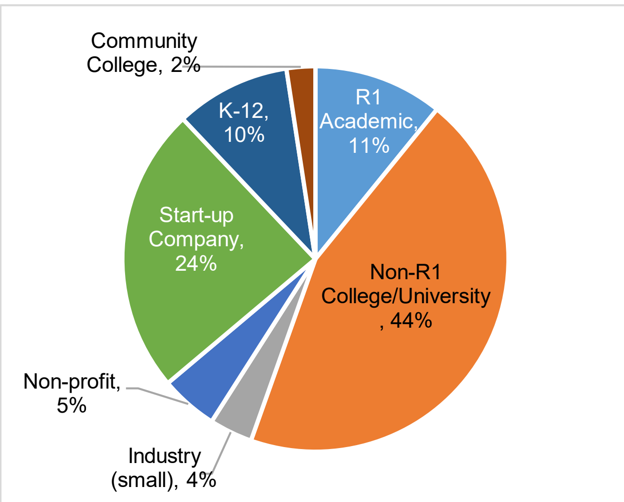


Chloe Eater, a graduate assistant at NC State, images biological samples on AIF's Hitachi HT7800 TEM

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: Unique surveys conducted during Year 6 were used for collecting demographic and user satisfaction data from various RTNN programs. Surveys were hosted on Qualtrics, the analysis was done on SPSS with some original SAS coding, and all surveys were IRB-approved. Overall, facility users who responded to the survey were very satisfied with their experiences in the facility they used in Year 6 (6.28 ± 1.22 on a 7-point Likert scale where 7=very satisfied, n=213). This level of satisfaction was consistent with responses from previous RTNN years (Year 5: 6.34 ± 1.05, n=326). Greater than 99.5% of users (n=216) indicated that they would return to the lab they utilized if further work was necessary.



Affiliations of participants in the Kickstarter program (n=83)

RTNN Kickstarter Program: This program supports use of the facilities by new, non-traditional users by providing free initial access. To date, 83 projects have been selected for over 1,350 hours of use (Year 6: 8 projects, >85 hours use). The figure at left shows the affiliations of the program participants. Most participants are from non-R1 colleges/universities (44%), start-ups (24%), while K-12 students/classrooms make up about 10%. The RTNN strives to retain the participants as long-term RTNN users and to highlight their successes via social media campaigns to recruit new users and solicit proposals. Of the projects who completely used their time in the program, >40% subsequently continued to use facilities spending >$207,000 of their own funding in facility use. The program brings in new users and provides a pathway to facility sustainability. Several recipients utilized data generated with the Kickstarter program to publish as well as propose and secure additional funding such as SBIR Awards. Applications to the Kickstarter program are consistently lower than pre-pandemic levels this year. Eligibility requirements for Kickstarter applicants were expanded to include consideration based on funding issues related to COVID-19, allowing consideration of a broader base of candidates. Ongoing assessment and interviews of Kickstarter recipients reveals that respondents continue to be happy with the overall program, indicate that they will return to the facilities, and have positive interactions with RTNN staff.

Online Coursera Course: "Nanotechnology, A Maker's Course," introduces nanotechnology tools and techniques while providing demonstrations within RTNN facilities. The course targets students who have a high school or higher science background and limited exposure to these facilities. **Since the course launch, over 222,500 people have visited the course website, over 28,300 have engaged with course components, and over 8,100 have completed the course.** Several participants have engaged with RTNN outside the course (e.g., Kickstarter program, workshops, newsletter subscription). *Assessment:* Students were highly satisfied (7=very satisfied) with the course materials on all five measures (6.33). Students were also highly satisfied with the course instruction on all five measures (6.28). Similarly, students were also highly satisfied with the multimedia content of the course (6.44). Over 93% of respondents noted they were "likely" or "very likely" to recommend the course to others. 72% of respondents noted they had a better knowledge of the capabilities of RTNN's facilities.

Kolemann Lutz, co-Founder of Mars University, with his Coursera Certificate of Completion for RTNN's Course.

Workshops, short courses, symposia: In Year 6, RTNN held 15 virtual short courses with over 140 participants. Standard-instrument-focused short courses introduce tools and techniques to provide a foundation for subsequent training on a specific tool. To provide a library of reference materials, the virtual courses are recorded and edited. The RTNN also helps to plan and execute the Carolina Science Symposium on an annual basis with collaboration from the Joint School of Nanoscience and Nanoengineering (JSNN) which is part of SENIC. This event is student-focused, giving many early career students their first opportunity to present research in a professional setting. In 2020, this event transitioned to a two-day virtual event and attracted 106 participants. The event was intended to be in-person for 2021 but reverted back to the 2-day virtual format due to emerging COVID-19 variants.

Communication: One of our main methods to disseminate information to stakeholders is via the RTNN website (www.rtnn.org). The website describes RTNN events, programs, and opportunities (e.g. nanotechnology jobs board). It also highlights recent nano-related news and provides an overview of research being pursued by principal faculty. The website had >1,150 unique visits monthly with >90% of these new visitors to the site in Year 6. We also maintain two subscription lists to share information and opportunities: one to principal faculty (>260 PIs) and one to other stakeholders (>3,750 subscribers).

We are active on multiple social media platforms including Twitter, Facebook, and LinkedIn as a means to promote our activities, events, and opportunities. Facebook was chosen as the main social media platform for RTNN, as it reaches a broad range of the public including the professional community, students, and educators. We have seen a 21% increase in Facebook followers, 300% increase in Twitter followers, and a 234% increase in LinkedIn followers since the end of Year 5.

Research Highlights and Impact

Core technical capabilities and specialized expertise and facilities in the RTNN span the following areas: organic and carbon-based 1-D and 2-D nanomaterials; materials for energy efficiency and sustainability; heterogeneous integration and interfacial studies of nanomaterials and nanostructures; and nanostructures for biology, medicine, and environmental assessment.

Scholarly and Economic Impact: Work performed in the RTNN led to >230 publications in 2020 by our users (171 of which cited the NNCI award number). 46 of these publications were authored by external users (32 cited the NNCI award). In the last complete fiscal year, the RTNN supported >$58 million in research activity, as defined by annual research expenditures, for NC State, Duke, and UNC projects that utilized the facilities. Work performed in the facilities led to >157 patents filed and >53 patents awarded in 2020 alone.

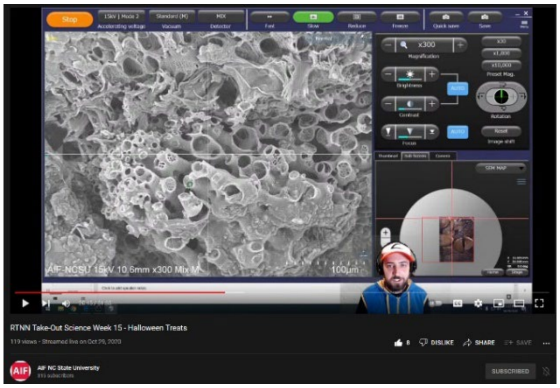
Education and Outreach Activities

The RTNN's educational and outreach activities are a focal point of RTNN's goal to build the user base; the table gives an overview of RTNN's educational and outreach activities. In Year 6, facilities accommodated in-person outreach activities where possible. However, emerging COVID-19 variants did result in a continued focus on remote and virtual outreach activities that will likely continue into Year 7.

Take-out Science: During the COVID-19 pandemic, RTNN designed a program to connect our facilities to people at home and bring them "Take-out Science." This started out with staff member Holly Leddy setting up one of our portable SEMs in her guest bedroom. Take-Out Science continued into Year 6 with a relaunch that coincided with National Nanotechnology Day in a collaborative episode hosted by RTNN with special guests from other NNCI sites (SDNI, NNI, and CNF).

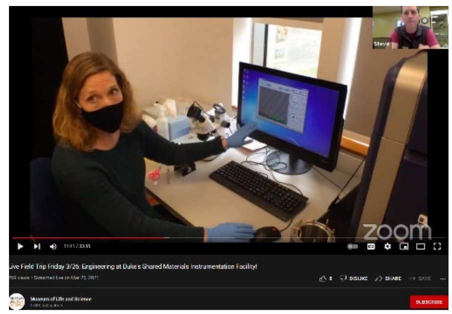
RTNN E&O Events. Evaluated programs are highlighted.

Year 6 Education & Outreach Events	
	Remote Participants
Kickstarter Program	8
Engaged learners in Coursera course on nanotechnology	>6,700
Remote outreach events (e.g., SEM demonstrations in classrooms)	808
Virtual technical events (e.g., short courses, workshops)	143
Virtual symposia/conferences	106
Outreach content YouTube views (e.g., Take-out Science, Sciencing with Abby)	>2,400
Technical content YouTube views (e.g., short courses, training)	>131,000
Synchronous Events (Total)	>1,060
Asynchronous Events (Total)	>140,000
Total	>141,060



Left: RTNN staff member, Phillip Strader shows parts of a pumpkin seed in a Halloween themed episode (in costume) in a Take-Out Science broadcast. Right: Cian-Fox and a colleague (WNF) teach about cleanrooms and microelectronics during RTNN's National Nanotechnology Day collaborative episode

Community Engagement: "Building the user base" activities optimally have an important long-term component, which we emphasize with community and K-12 engagement, particularly for under-represented groups in STEM. Many of our in-person activities are still suspended as a result of COVID-19 variants, but when feasible we hosted in-person events. Many community programs with which RTNN interacts opt for virtual interactions with the RTNN (i.e. SciREN collaborative events with local museums, and others).



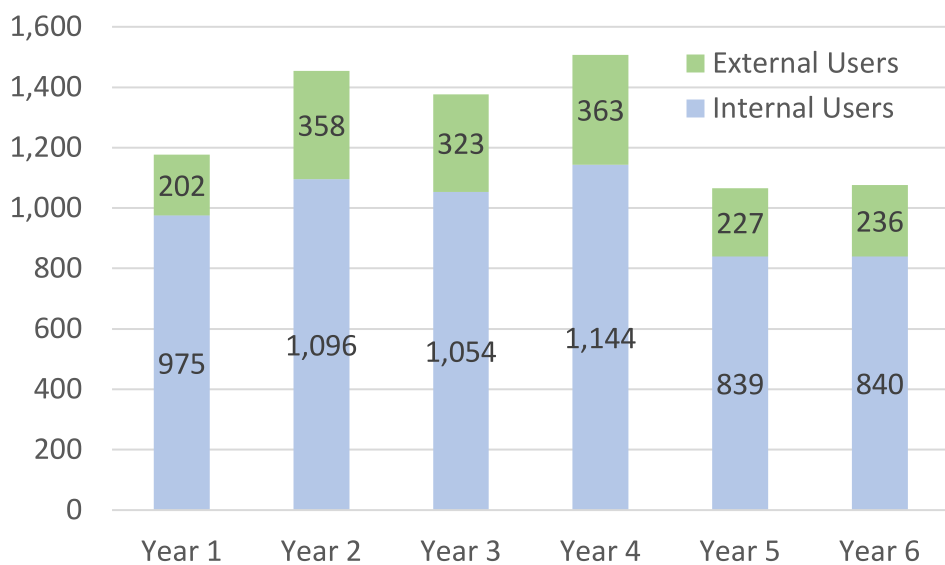
RTNN staff member Holly Leddy demonstrates microscopy in an event with the Museum of Life and Sciences

Societal and Ethical Implications Activities

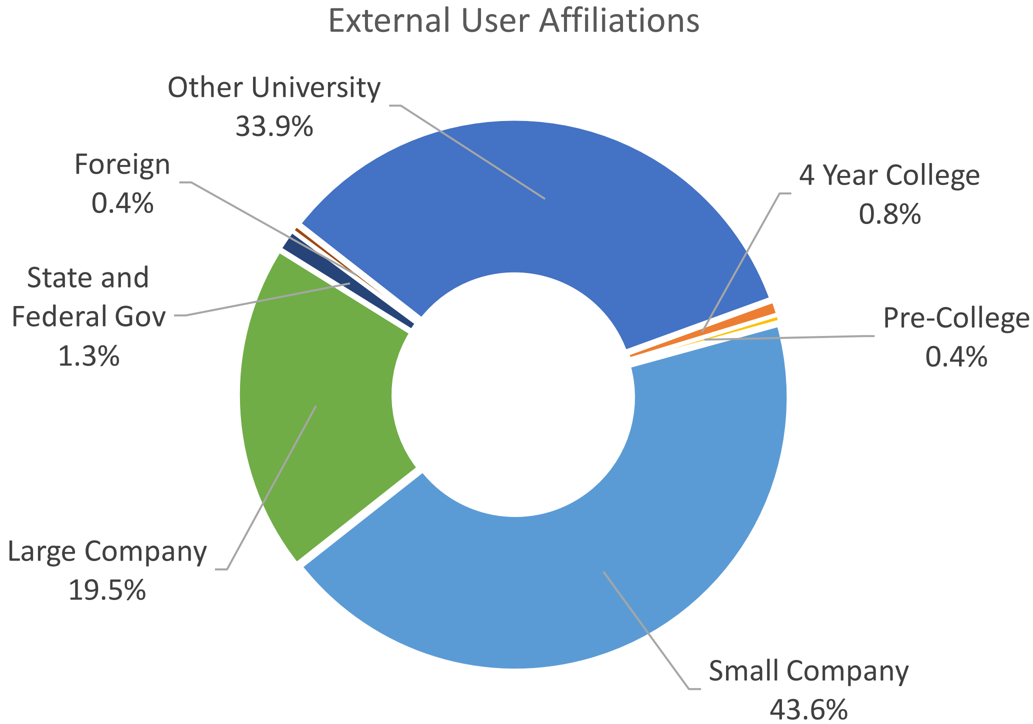
The RTNN's research in the area of Social and Ethical Implications (SEI) of nanotechnology leverages the RTNN team and user base to enhance the instruction and understanding of how humans engage with nanotechnology. The SEIN team is actively working with the NNCI Diversity Subcommittee on their data collection tools to maintain internal and external validity. SEIN is also reviewing and analyzing the data collected at the Nanotechnology Convergence for Food and Nutrition Security meeting on March 9, 2021, to produce a report and articles on future needs in agriculture, food, nanoscience, and core facilities. They are also pursuing a Phase 2 study on Zoom fatigue (Delphi) and planning a Phase 3 national survey on Zoom fatigue and plan presentation of findings at SRA 12/21.co-PI Berube participated in a live webinar organized by Jamey Wetmore (NNCI Associate Director for SEI) titled "Societal and Ethical Implications across the NNCI".

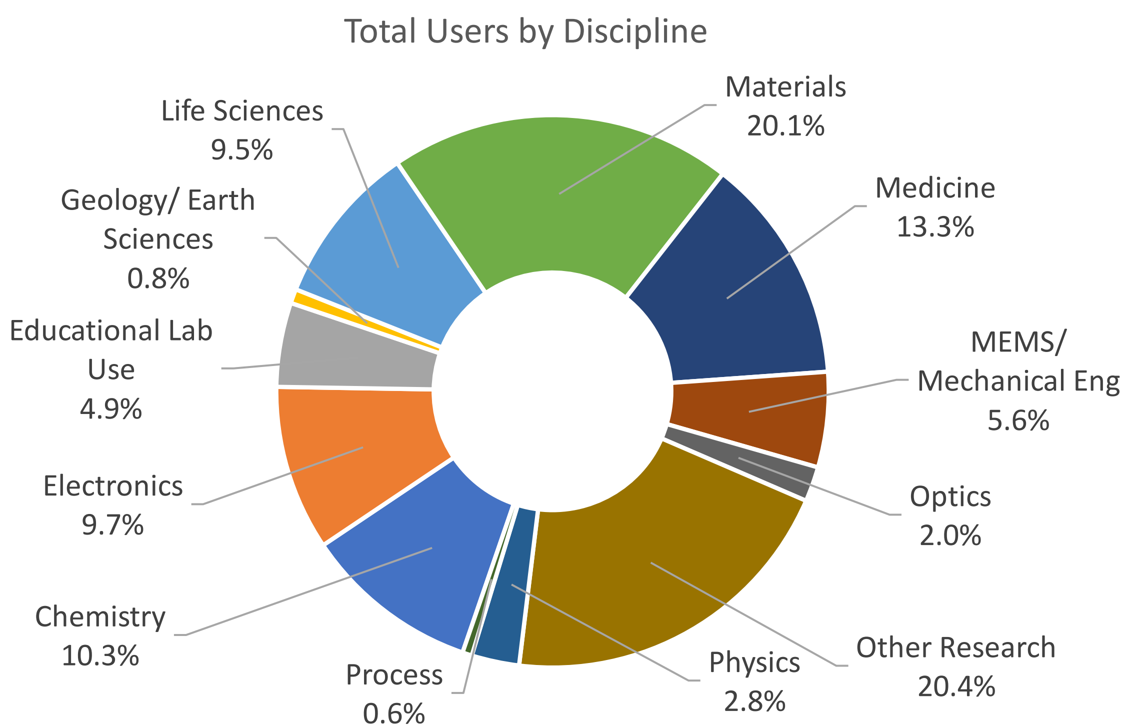
RTNN Site Statistics

Yearly User Data Comparison						
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**
Total Cumulative Users	1,177	1,454	1,377	1,507	1,066	1,076
Internal Cumulative Users	975	1,096	1,054	1,144	839	840
External Cumulative Users	202 (17%)	358 (25%)	323 (23%)	363 (24%)	227 (21%)	236 (22%)
Total Hours	53,044	51,747	55,684	61,404	43,099	53,491
Internal Hours	46,908	43,053	46,422	49,685	33,636	43,209
External Hours	6,136 (12%)	9,694 (17%)	9,263 (17%)	11,719 (19%)	9,463 (22%)	10,282 (19%)
Average Monthly Users	395	422	420	445	308	352
Average External Monthly Users	50 (13%)	63 (15%)	71 (17%)	74 (17%)	53 (17%)	67 (19%)
New Users Trained	433	527	695	627	288	435
New External Users Trained	71 (16%)	69 (13%)	82 (12%)	102 (12%)	54 (19%)	74 (17%)
Hours/User (Internal)	48	39	44	43	40	51
Hours/User (External)	30	24	29	32	42	44



RTNN Year 6 User Distribution





12.12. San Diego Nanotechnology Infrastructure (SDNI)

Facility, Tools, and Staff Updates

Facilities and tools: In Year 6 of NNCI, the capabilities of SDNI continued to be centered on UCSD's well-established Nano3 cleanroom fabrication and characterization facility. The integration of Nano3 into the NNCI network has resulted in rapid expansion and integration of several new facilities under the SDNI umbrella, including facilities for magnetics, energy, and quantum devices materials characterization, microfluidics medical device fabrication, high-resolution imaging, and photonics testing, and these additional facilities continued to expand their equipment base during Year 6.

The Covid pandemic continued to impose limitations on the accessibility of SDNI's facilities during Year 6. Considering the resulting financial impact, we have limited acquisition of new tools for SDNI's facilities during Year 6, advised by the executive committee. A notable exception is SDNI's Chip-Scale Photonics Testing Facility (CSPTF), which made several tool acquisitions, including an Anritsu MS9740B Optical Spectrum Analyzer, a Santec TSL-550 tunable laser, and a Pembroke Instruments WIDY SenS 640V-ST camera.

The Nano3 facility focused on improvement of operation software, remote operation, and increase in the equipment utilization efficiency so that our users and staff were able to maximize their productivity within the limits of permissible physical presence in the facility. Activities include:

- Procurement of a transportable electrostatic chuck on loan for dry etch testing purposes and sharing of resulting information with our NNCI partner site (MANTH) at University of Pennsylvania.

- Design, procurement and installation of an acetone spray gun to improve lift-off processes for our users.

- Redesign and upgrade of the vacuum system for one of our heavily utilized "work-horse" sputter deposition tools.

- Completion of the installation of a Plasma-Therm PECVD system for thin film deposition.

- Completion of the installation of a Plasma-Therm plasma etching system dedicated to Si-based nanophotonics and photonic integrated circuits.

- Development of multiple training videos for initial facility access/safety orientations and for tool training, primarily driven by our need to respond to the Covid-19 pandemic. The development material proved very successful and will continue to provide benefits for the future.

- In support of and in collaboration with UCSD's new MRSEC, a full training course on electron microscopy for beginning and intermediate level users, was developed. The training course consists of hands-on activities and remote lectures.

- Upgrade/customization of our FOM lab management system to streamline the registration process and record-keeping, reconfigure billing account entries for the fully revamped UCSD accounting system implemented during Year 6, integrate Covid related safety checks, develop user access records for automatic inputs into the FOM system.

- Partnership with Hitachi to receive a loaner SEM system dedicated to our education and outreach programs.

Staff: The pandemic had a strong impact on staffing during Year 6. Early in the pandemic, we lost a newly hired process engineer and were not able to rehire because of a university hiring freeze. Two additional process engineers (one PhD level engineer, the other an experienced BS level engineer) accepted offers from technology companies which have received extensive services from SDNI, and one of our senior equipment engineers retired at the end of June 2021. We were able to hire a junior staff member to carry out logistics and safety related responsibilities, and we spent significant effort on finding replacements staff. Given the strong market demand for equipment and process engineers in the commercial sectors, we faced major challenges in finding the right talents in a highly competitive market. The large investments in the semiconductor industry further compounded these challenges. By the end of Year 6, we were able to rehire two equipment engineers, one PhD level process engineer, but facility staffing remains a primary challenge for our site.

Our previously highly successful training program that offers internship and employment opportunities to undergraduate students was essentially frozen and we had to lower the previous number of approximately 20 undergraduate students by 75% because of the pandemic. However, by the end of Year 6, we were able to fully rebuild our undergraduate student staffing, and even create an expanded internship program beyond the pre-pandemic level.

Despite the effects of shortage of staff and other pandemic related impacts, thanks to the extraordinary dedication and efforts of our current staff, SDNI was able to maintain significant activities during Year 6. User hours for Year 6 are nearly 90% back to pre-pandemic (i.e. Year 4) levels and are about 15% higher than those reported for Year 5 (impacted by the pandemic). Resulting from the shift to increased direct services from staff and increased portion of external utilization, Year 6 site user fees collected were 3% above pre-pandemic (i.e. Year 4), and 25% above Year 5.

<u>User Base</u>

SDNI continues to be the central place that enables groundbreaking fundamental and applied research in nano/meso/metamaterials, nanophotonics, nanobiomedicine, and nanomagnetism. By expanding our tool sets and processing capabilities because of our participation in the NNCI, we have equipped ourselves to support broader science and technology areas such as next generation semiconductor materials and devices, quantum devices and systems, condensed matter physics and materials research. Our facility has also contributed, in a significant way, to the development and commercialization of innovative technologies.

Although overall site usage during Year 6 in total user hours was still impacted by the pandemic, SDNI successfully pivoted to more direct staff services for remote usage, which resulted in regaining total hourly usage to nearly 90% of pre-pandemic level. This also had a major impact in the distribution of usage between internal and external users. In Year 6, 36% of user hours were external, compared to 23% pre-pandemic (i.e. Year 4). With development of safety measures and overall relaxation of pandemic restrictions, SDNI's training of new users also reached over 90% of pre-pandemic numbers.

Overall, during Year 6, SDNI served users from 79 external institutions and 85 UCSD internal academic groups. The breakdown of external user institutions is: 12 non-UCSD US academic, 4 state/federal government, 47 small companies, 14 large companies, 2 international. Averaging Years 1-6, SDNI annually has served 72 external institutions (9 non-UCSD US academic, 3 state/federal government, 43 small companies, 16 large companies, 1 international) and 92 UCSD internal academic groups.

Research Highlights and Impact

Scientific impact: SDNI has continued to heavily contribute to fundamental and applied research in high priority areas. For fundamental research, we helped the Berkeley team to demonstrate the first quantum Hall coherent light sources with designed orbital angular momenta. In applied research, we supported the groundbreaking work of an integrated, multimodal physical/biochemical wearable sensor demonstrated by scientists from UCSD Center for Wearable Sensors. The work was published in *Nature Bioengineering* and the senior authors (Professors Sheng Xu and Joseph Wang from the Nanoengineering Department) were elected to be the most cited scholars in 2021.

For technology advancement, we are pleased to work with engineers from TSMC and Stanford to develop the nanofog technology to create the first carbon nanotube transistor with Al_2O_3/HfO_2 gate oxide, a major step towards development of deeply scaled Si ICs. The work was highlighted by the IEEE, the world largest professional organization. For translational research, our staff supported a major NASA project led by a team including UC Irvine, UCLA, JPL, and Cal Poly. The goal of the project is to advance the technology of impulse electrospray thrusters for SmallSat propulsion. The SDNI staff provided full services in device fabrication and integration by working closely with the multi-organizational team. Here we describe two examples for our contributions to the advances in science and technology.

Fundamental Research: *Photonic quantum Hall effect and multiplexed light sources of large orbital angular momenta (Published in Nature Physics, 2021).* Using heterostructures based on structured semiconductors on a magnetic substrate, the Berkeley group led by Prof. Kante introduced compact and integrated coherent light sources of large orbital angular momenta based on the photonic quantum Hall effect. The photonic quantum Hall effect enables generation of coherent orbital angular momenta beams of large quantum numbers from light travelling in leaky circular orbits at the interface between two topologically dissimilar photonic structures. The work produces quantum light sources with unlimited choices of orbital angular momenta for communication and imaging applications.

Applied Research: *Integrated Blood Pressure-Chemical Sensing Epidermal Patch (published in Nature Biomedical Engineering 2021).* In collaboration with the affiliating companies of the Center for Wearable Sensors, UCSD Professors Joseph Wang and Sheng Xu developed a multimodal wearable sensor that can sense both hemodynamic and metabolic signals from the human body simultaneously. The multichannel signals give the health provider a holistic view of the physiological processes in the human body. This work presents the first demonstration of an integrated wearable sensor that monitors the blood pressure and heart rate via ultrasonic transducers, along with parallel non-invasive electrochemical detection of biomarker levels, such as glucose, lactate, caffeine, and alcohol, in sweat and interstitial fluid. Such simultaneous non-invasive blood-pressure/chemical sensing was implemented by monitoring the dynamic effects of everyday activities, such as exercise and intake of food and drinks, upon the user's physiological states. Such multimodal blood-pressure/chemical wearable sensor offers a collection of previously unavailable information towards enhancing our understanding of the body's response to common activities and holds considerable promise for remote, telemetric, and personalized healthcare with improved medical outcome. The fabrication, heterogeneous integration, and assembly of the devices were produced in the SDNI facilities, with the assistance of the SDNI equipment and engineering team.

Cutting-edge nanotechnology development: Scaled-Down Carbon Nanotube Transistors Closer to Silicon Abilities. As the world recognizes the strategic importance of semiconductor technologies, the research team of Taiwan Semiconductor Manufacturing Company (TSMC) (Greg Pitner), University of California San Diego (Andy Kummel), and Stanford University (Philip Wong) has made major advances in carbon nanotube (CNT) devices to bring the technology closer to silicon's abilities, highlighted by *IEEE Spectrum*. Carbon nanotube needs to use HfO_2 gate dielectrics, but CNTs do not offer nucleation sites for the atomic layer deposition (ALD) process to initiate the deposition of the HfO_2 film. The TSMC/UCSD/Stanford team invented an intermediate-dielectric-constant material (Al_2O_3) using a process called *nanofog*. Like water vapor condenses to form fog, the Al_2O_3 condenses into clusters that coat the nanotube surface. The atomic-layer deposition of HfO_2 can then begin using this interfacial dielectric as a foothold. The resulting device has similar on/off current ratio characteristics to those of silicon CMOS devices. SDNI plays a crucial role in this effort by providing the ALD and transmission electron microscopy capabilities that are critical to the development of the *nanofog* process.

Translational Research: *Variable Specific Impulse Electrospray Thrusters for SmallSat Propulsion*. Funded by a major NASA grant, Professor Manuel Gamero's team at UC Irvine is leading a project that involves JPL, UCLA and Cal Poly to use the SDNI facility to advance an innovative technology, electrospray thruster for primary propulsion of a 12U CubeSat, from a low TRL level to TRL5.

The proposed electrospray propulsion (ESP) system exhibits ideal characteristics for the propulsion of SmallSats and CubSats. ESP is based on the electrostatic acceleration of the charged droplets and ions emitted by an electrospray. The propellant is a dielectric liquid, most commonly an ionic liquid, which is atomized and ionized without the need for creating a plasma. Both charged droplets and molecular ions can be emitted. The suitability of electrospraying for propulsion was first recognized in the 60's, and after a long hiatus, interest resurfaced lately with the arrival of SmallSats that require an efficient micropropulsion system. However, one downside of electrospray ionic liquids is that the thrust remains little. To generate higher thrust, one strategy is to miniaturize the emitters in electrospray and organize them in large emitter arrays. The miniaturization and higher density of emitters in an electrospray thruster can provide an electric propulsion system with high and adjustable thrust.

Translational Research: *Enhancing Interferometric Color Display View Angle Performance Using a Nanofiber Array.* The SDNI engineering team has produced prototypes for the most advanced color display designed by Qualcomm and used by hundreds of millions of users worldwide. Viewing angle dependent color shift presents a fundamental challenge to all interferometric displays, including Qualcomm's MirasolTM displays. A unique solution was proposed by Qualcomm engineers to use a fiber array fabricated in a polycarbonate film via nano embossing to reduce the color shift.

The design of using a fiber array for color angle shift control calls for a transparent layer composed of an array of optical fibers with the following properties: 1) there is inherent randomness in the lengths of the fibers, on the order of a wavelength so that the light exiting from the fibers in the array can be considered to be mutually incoherent, 2) the core and cladding refractive indices are chosen in such a way that the numerical aperture of the each fiber is a designed number to support a clear viewing angular range. When these requirements are met, light carried in each fiber, excited by light entering the entrance face at a particular angle, emerges from each fiber at the exit face as a cone of light which matches the numerical aperture of the fiber. When the incidence angle is changed, the speckle pattern may change but the angular extent of the distribution of the light does not. As a result, a constant color vs viewing angle can be achieved.

Contributions to economy: Throughout its participation in the NNCI, SDNI has helped many companies raise hundreds of millions of dollars in investment and to develop cutting edge technologies into high value products. During Year 6, one such company, Roswell Biotechnologies, announced the developed of a CMOS integrated molecular biochip with 16,000 individual sensors for single molecule detection that can be a platform to be used for a wide range of medical applications. The first commercial market the company is targeting is in drug discovery, but the chips could also dramatically lower the cost of whole-genome sequencing.

The electric field generated by the sensor nano-electrodes (10nm gap), through dielectrophoresis, pulls molecules to the vicinity of the electrode gap, increasing the limits of sensitivity to single molecule levels. Staff at SDNI's Nano3 facility, especially in the area of electron-beam lithography, has been instrumental in enabling the development of the chip.

SDNI has continued its support for small and large companies (e.g. Qualcomm, TSMC, Dexcom, Illumina) during Year 6 in the areas of wearable sensors, night vision, imaging, optical communications, quantum sensing, genetic engineering, pharmaceuticals, health monitoring, artificial intelligence, robotics, semiconductors, etc. to develop prototypes for proof of concept and commercialization.

Education and Outreach Activities

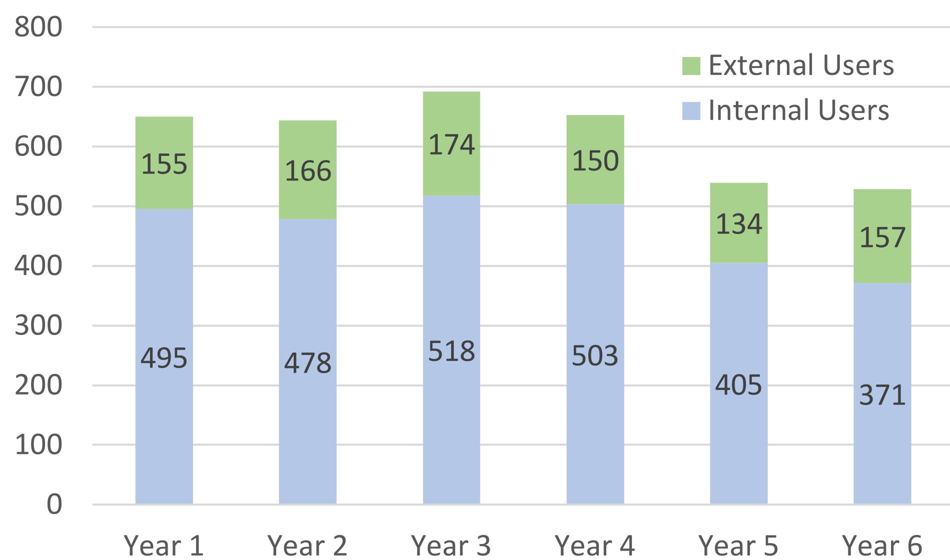
SDNI's strong commitment to education and outreach was also impacted by the pandemic. In 2020, our REU and RET programs were cancelled and our annual education/outreach symposium had to be delayed. However, during Year 6, we implemented the first 8-week fully remote REU program for 9 REU students from 5 states across three time zones. 60% of the REU students were underrepresented minority students. The program consisted of daily lectures by prominent faculty and hands-on labs, where material was sent to student residences and mentors worked remotely with the students on projects related to blood clotting, 2D materials, nanoparticle drug delivery. SDNI replaced the RET program with a one-week online Nanotechnology Summer Institute where 22 science teachers participated, each developing nanoscience curricula. SDNI also organized an online education/outreach symposium where science teachers, 7 other NNCI sites, and NNI and state officials attended the presentations and panel discussions.

SDNI has continued to offer Remote Scanning Electron Microscopy Sessions during Year 6 to introduce STEM subjects to K-12 students. We have expanded the footprint of this effort by offering sessions to schools in Northern California and Oregon. As of early 2021, SDNI held the record for holding the most remote sessions of the Remotely Accessible Instruments for Nanotechnology (RAIN) network, which allows students to access and control microscopes.

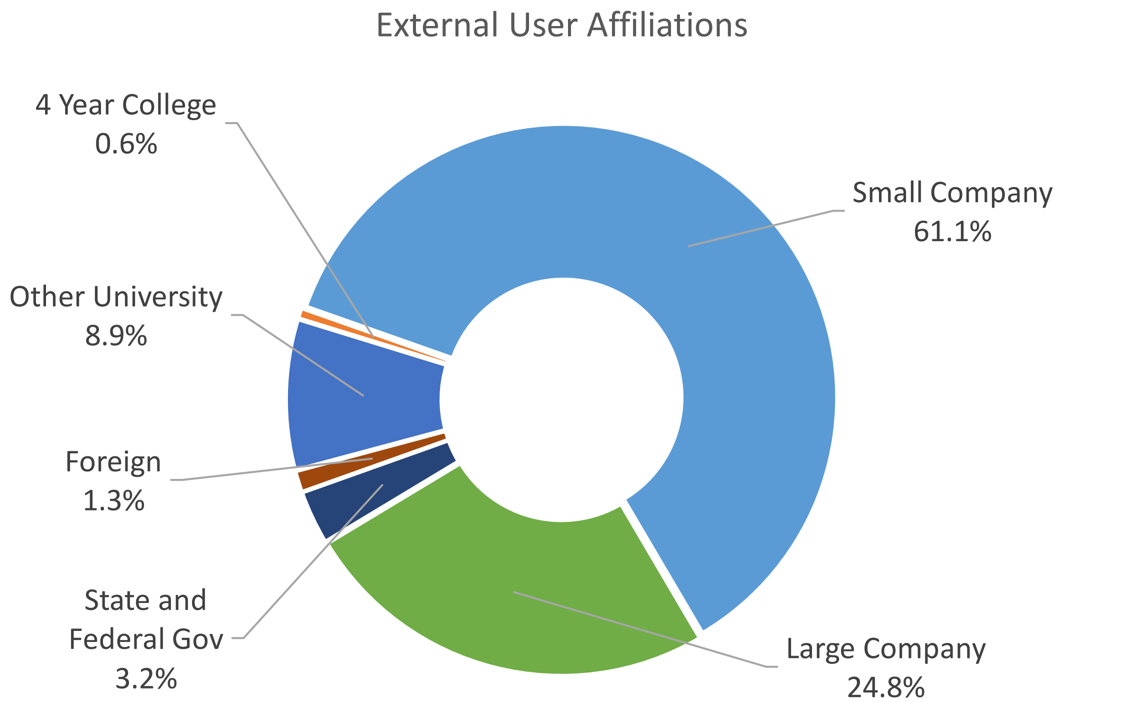
SDNI's Chip-Scale Photonics Facility (CSPTF) was engaged in the education and outreach activities by developing a pilot curriculum for the ongoing integrated Photonic Education Kit (IPEK) project, the first plug & play didactic toolkit that enables hands-on experimental integrated photonics for education institutions.

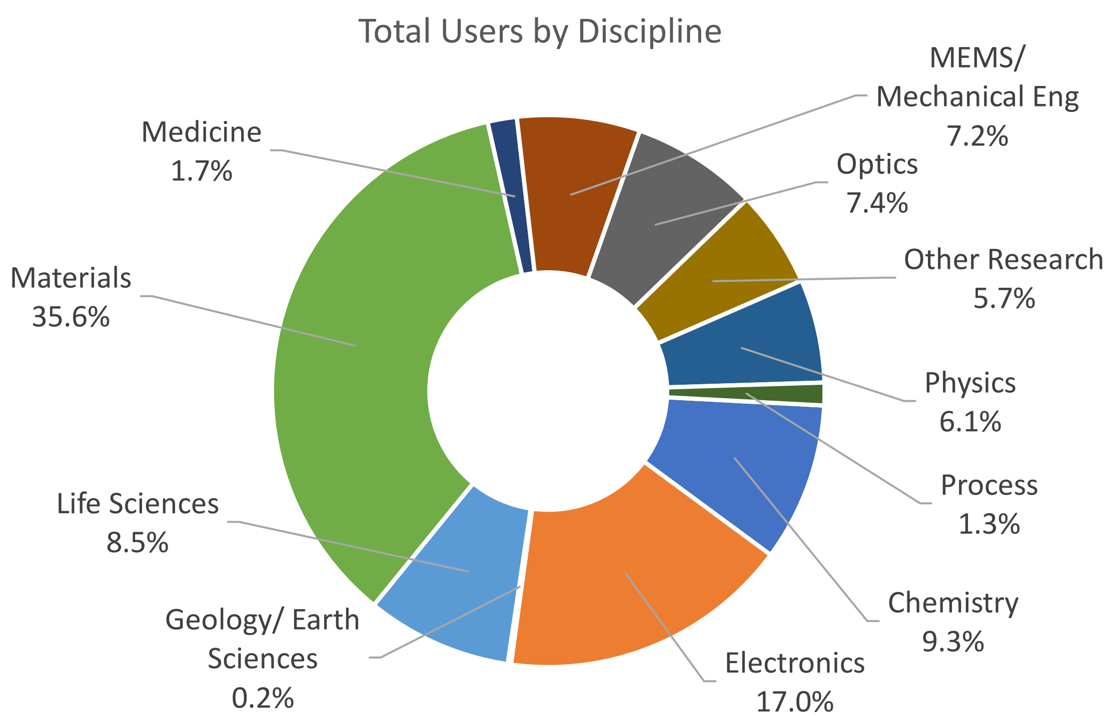
SDNI Site Statistics

Yearly User Data Comparison						
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**
Total Cumulative Users	650	644	692	653	539	528
Internal Cumulative Users	495	478	518	503	405	371
External Cumulative Users	155 (24%)	166 (26%)	174 (25%)	150 (23%)	134 (25%)	157 (30%)
Total Hours	47,893	50,497	49,519	69,367	53,667	61,111
Internal Hours	40,890	38,890	39,372	56,393	41,316	44,969
External Hours	7,003 (15%)	11,607 (23%)	10,147 (20%)	12,974 (19%)	12,352 (23%)	16,142 (26%)
Average Monthly Users	290	285	300	296	229	234
Average External Monthly Users	49 (17%)	56 (20%)	54 (18%)	50 (17%)	46 (20%)	53 (23%)
New Users Trained	183	210	225	202	169	152
New External Users Trained	34 (19%)	50 (24%)	46 (20%)	40 (20%)	36 (21%)	18 (12%)
Hours/User (Internal)	83	81	76	112	102	121
Hours/User (External)	45	70	58	86	92	103



SDNI Year 6 User Distribution





12.13. Soft and Hybrid Nanotechnology Experimental (SHyNE) Resource

SHyNE Resource is a nonprofit joint initiative between Northwestern University and University of Chicago. Our mission is to provide to the members of the global scientific, academic, and industrial communities open access to the nanotechnology facilities, technology expertise, and educational resources of both universities. Our nanotechnology facilities are open access resources which are open to all users. We offer our users advanced nanofabrication equipment, expertise, and education. Our expert technical staff are ready to assist our facility users with all their scientific research and technology development needs. We can train our users to do the work themselves using our equipment, or we can do the work for them as a service. We are dedicated to the education of young people. We facilitate the success of university students, and K-12 school students, with their personal enrichment, education, and career development. We are a global community center dedicated to serving educators, students of all ages, scientists, engineers, and entrepreneurs. We work to form strategic partnerships with various scientific, academic, and industrial institutions from all around the world.

The key capabilities of SHyNE Resource include (but are not limited to) the following.

- Electron Microscopy of Hard Material
- Electron Microscopy of Soft Biological Material
- Crystallography and X-Ray Characterization
- Pulsed Laser Deposition
- Bio-Nanotechnology and Molecular Engineering
- Nanofabrication of Microelectronics
- Nanofabrication of Bioelectronics

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

SHyNE Resource (www.shyne.northwestern.edu) includes 7 main facilities. One of these facilities is NU*ANCE*, which in itself includes 5 distinct facilities. All together there are a total of 11 distinct facilities within SHyNE.

1. SQI https://sqi.northwestern.edu/
2. NUCAPT https://mrsec.northwestern.edu/facilities/nucapt/
3. XRD https://mrsec.northwestern.edu/facilities/xray/
4. IMSERC http://imserc.northwestern.edu/
5. PLD https://sites.northwestern.edu/pldcore/
6. NU*ANCE* (NU*ANCE* includes 5 facilities) - www.nuance.northwestern.edu
    a. EPIC http://www.nuance.northwestern.edu/epic/index.html
    b. BioCryo http://www.nuance.northwestern.edu/biocryo/index.html
    c. Keck-II http://www.nuance.northwestern.edu/keck-ii/index.html
    d. SPID http://www.nuance.northwestern.edu/spid/index.html
    e. NUFAB https://www.nufab.northwestern.edu/
7. PNF https://pnf.uchicago.edu/

SHyNE facilities are actively engaged in acquiring and upgrading key equipment, and adding new staff members, through a combination of internal and external funding mechanisms.

- **SQI** - Simpson Querrey Institute teams of Peptide Synthesis Core and ANTEC cleanroom added a new staff member, Mr. Mark Seniw, who joined the team in the capacity of the Scientific Illustrator.
- **XRD** - The Jerome B. Cohen X-Ray Diffraction group, acquired in June 2021 a high resolution 2D Rigaku Hypix 3000 pixel array detector with a large active area of ~ 30 cm^2 and a small pixel size of 100 x 100 μm^2. The detector is installed on the 9 kW Rigaku Smartlab Gen 2 diffractometer and allows for measurements in 0D, 1D and 2D modes. The 2D measurement mode allows rapid (10X faster than previous 0D detector) pole figure measurements for texture analysis of polycrystalline films and reciprocal space mapping of single crystal samples. The accompanying upgraded Studio II software stitches the images from this 2D detector and allows for quick visualization of the pole figures and reciprocal space maps.
- **IMSERC** - Integrated Molecular Structure Education and Research Center group established the following capabilities and tools at its facility: high throughput DSC for the thermal analysis of polymers, and other types of solids, Karl-Fischer titration unit with furnace for solids for the quantification of water in materials, Agilent 6545/6546 LC/QTOF Mass Spectrometer for the characterization and quantification of ionizable molecules. Additionally, Dr. Nathaniel Barker joined the IMSERC group in the capacity of a postdoctoral scholar.
- **NU*ANCE*-EPIC** - Electron Probe Instrumentation Center's SEM group upgraded the EBSD and EDS systems on the Quanta 650 FEG SEM to an Oxford Symmetry2 CMOS detector and 40 mm^2 SDD EDS detector. The group is also adding a new Gatan Murano Heating stage for the Quanta 650F SEM. Additionally, the EPIC-TEM group purchased an Atmosphere 210 in situ Gas Cell System and AXON Core System Controller Platform. Dr. Kunmo Koo joined the group this year in the capacity of a Research Associate.
- **NU*ANCE*-BioCryo** - Biological Cryogenic Electron Microscopy group purchased and installed a Thermo Scientific Pathfinder Mountaineer Dual EDS System. They are in the process of adding a JEOL 3200 in-column energy filter 300kV TEM to their laboratory.
- **NU*ANCE*-Keck-II** - Keck-II Surface Science group purchased a new ToF-SIMS (ION-TOF M6) with external funds and also purchased a new XPS (Thermo Nexsa G2) with internal funds. The Keck-II hired a postdoctoral research associate, Dr. M Arslan Shehzad, in 2021.
- **NU*ANCE*-SPID -** Scanned Probe Imaging and Development group, through successful NSF-MRI funding, is acquiring NanoRaman system integrated with atomic force microscopy (AFM) that can provide physical sample information on the nanometer scale, including topography, near-field optical techniques (SNOM or NSOM), altogether with the chemical information obtained from Raman spectroscopy and Photoluminescence. The result is a more comprehensive sample characterization in one versatile instrument, for fast simultaneous co-localized measurements, tip-enhanced Raman Spectroscopy (TERS), and tip-enhanced Photoluminescence (TEPL).
- **NU*ANCE*-NUFAB** - NUFAB group acquired High-Performance E-Beam Writer, Raith VOYAGER 100. Dr. Sung Oh Woo joined NUFAB as a Research Associate in 2021.
- **PNF** - University of Chicago's Pritzker Nanofabrication Facility purchased in June 2021 the Heidelberg MLA 150, High Resolution lithography tool (500 nm features). Also in June 2021, PNF group purchased the new high-power laser upgrade on current MLA 150

to provide better throughput. Mr. Jered Feldman joined the PDF group as a process engineer and Mr. Joshua Kirks joined the PNF group as an equipment engineer.

User Base

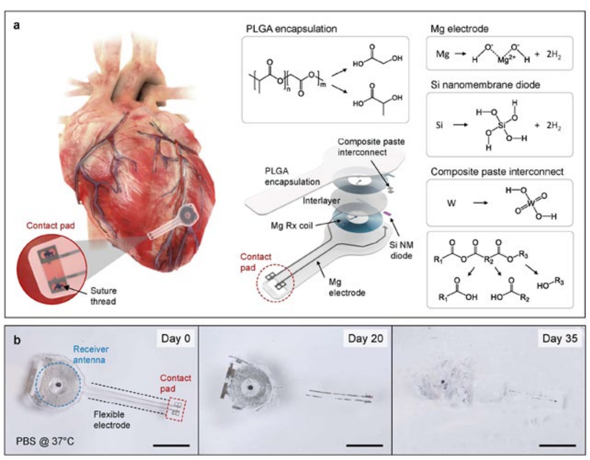
SHyNE facilities served over 1500 unique users who logged nearly 160,000 hours of instrument time generating $4.5M in revenue. Northwestern University and University of Chicago shut down in the Spring of 2020 for nearly 3 months in response to the Coronavirus pandemic. In the Fall of 2020, the Northwestern labs opened to external users in a restricted manner, with adequate safety measures in place. University of Chicago opened to external users in the Fall of 2021. Prior to the shutdown and the restricted operations, SHyNE was on pace to continue double-digit annual growth. In Year 6, external users represented 14% of the total users and 13% of the total revenue. In Year 6, the users of SHyNE facilities published more than 370 publications.

SHyNE actively engages local and regional companies, colleges, universities, non-profit research organizations, and governmental agencies to recruit new users. This is accomplished by several communication strategies including: exhibitions at conferences and trade shows, production of web portals, marketing videos and promotional materials, networking with alumni, coordination with university-wide corporate engagement and media relations offices, and an active social media presence. In Year 6, SHyNE continued managing a SEED (SHyNE External Experiment Development) funding program to recruit new external users by providing start-up grants for up to $2500 in facility usage. Two proposals were funded for new users from the University of Illinois at Chicago and the Chicago Botanic Garden. In Years 7-10, the primary programmatic focus will be on recruiting additional external academic users through a combination of efforts, including: an active marketing campaign, redevelopment of our web presence, and expansion of SEED program.

Research Highlights and Impact

1. Materials and Device Designs for Bioresorbable, Wireless Pacemakers

Temporary cardiac pacemakers provide critical functions in pacing through periods of need during post-surgical recovery. The percutaneous leads and externalized hardware associated with these systems represent, however, risks of infection and for myocardial damage and perforation during lead removal. Our advances in bioresorbable electronic materials serve as the basis for wireless and fully implantable cardiac pacemakers capable of post-operative control of cardiac rate and rhythm during a stable operating timeframe, followed by complete dissolution and clearance via natural biological processes. A combined set



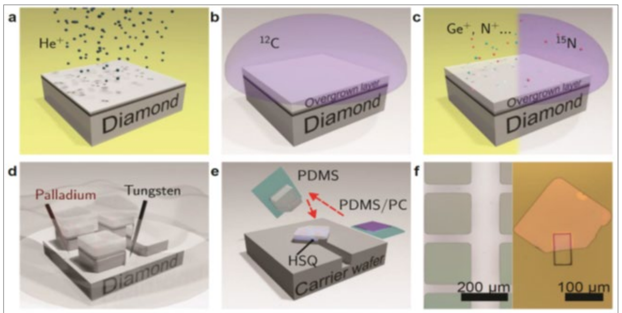
John A. Rogers and co-workers, Northwestern University. This work was supported by NSF Award # ECCS-123456. “Fully Implantable and Bioresorbable Cardiac Pacemakers Without Leads or Batteries,” Nature Biotechnology 39, 1228-1238 (2021). National Research Priority/NSF 10 Big Idea - Rules of Life

Figure 1 - (a) Schematic illustration of a device mounted on the myocardial tissue, the device configuration and the materials chemistry. (b) The device dissolves via hydrolysis in simulated biofluids.

of studies across mouse, rat, rabbit, canine, and human cardiac models demonstrate that these devices provide an effective, battery-free means for pacing as a new type of biomedical device technology.

2. Tunable Diamond Membranes for Integrated Quantum Technologies

Color centers in diamond are widely explored as qubits in quantum technologies. However, challenges remain for the effective and efficient integration of these diamond-hosted qubits in device hetero-structures. Here, nanoscale-thick uniform diamond membranes are synthesized via “smart-cut” and isotopically purified overgrowth. These membranes have tunable thicknesses, are deterministically transferable, have bilaterally atomically flat surfaces and bulk-diamond-like crystallinity. Color centers are synthesized via both implantation and in-situ overgrowth incorporation. Individual Ge-vacancy centers exhibit stable photoluminescence. The spin coherence of individual nitrogen-vacancy centers shows coherence times as long as 400 μs. This platform enables the straightforward integration of diamond membranes that host coherent color centers into quantum technologies.



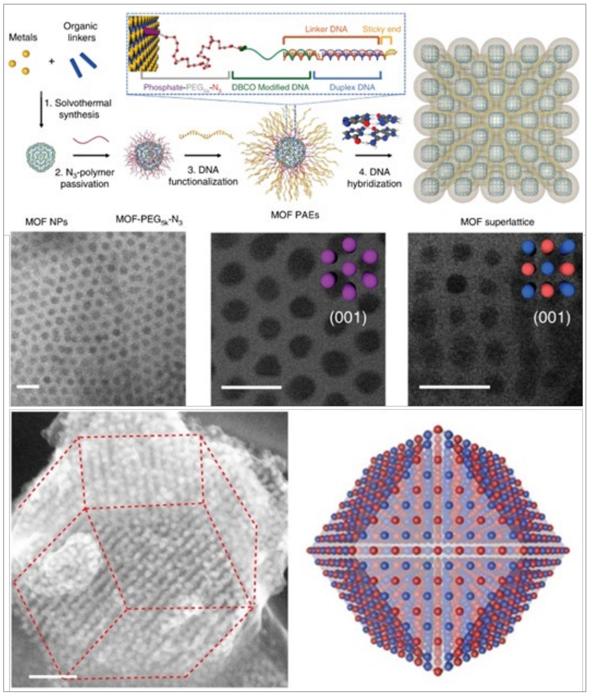
Worked was done at the Pritzker School of Engineering, University of Chicago.

X.H. Guo, N. Delegan, J.C. Karsch, Z.X. Li, T.L. Liu, R. Shreiner, A. Butcher, D/ D. Awschalom, F.J. Heremans, A. A. High. This work was supported by DOE, NSF MRSEC, and NSF NNCI. arXiv 2109.11507. National Research Priority/NSF 10 Big Idea - Quantum Leap

Figure 2 - Schematic of the diamond membrane fabrication process. (a) He+ implantation with subsequent annealing to form the membrane (light gray on the top) and the graphitized layer (dark grey underneath). (b) Isotopically purified PE-CVD diamond overgrowth. (c) Color center incorporation via ion implantation (left) or in-situ doping (right). (d) Diamond membrane undercut via EC etching. (e) Membrane transfer and back etching. The membrane is picked up by the PDMS/PC stamp (green/purple), flipped onto another PDMS stamp (green), and bonded to the carrier wafer by HSQ resist. (f) Microscope images of patterned overgrown membranes (left) and a transferred and multi-step etched membrane on a fused silica wafer (right).

3. Colloidal crystal engineering with metal-organic framework nanoparticles and DNA

Colloidal crystal engineering with nanoparticles (NPs) has emerged as a powerful tool to design materials from the bottom up. When NP building blocks are combined with nucleic acids, they may behave as programmable atom equivalents (PAEs) and can be assembled in a sequence-specific fashion into crystalline arrangements driven by a combination of DNA complementarity and their unique nanoscale architectural features. Colloidal crystal engineering with nucleic acid-modified nanoparticles is a powerful way for preparing 3D superlattices, which may be useful in many areas, including catalysis, sensing, and photonics. Here, we show that metal–organic framework nanoparticles (MOF NPs) densely functionalized with oligonucleotides can be programmed to crystallize into a diverse set of superlattices with well-defined crystal symmetries and compositions.



Worked was done at Northwestern University by Shunzhi Wang, Sarah S. Park, Cassandra T. Buru, Haixin Lin, Peng-Cheng Chen, Eric W. Roth, Omar K. Farha & Chad A. Mirkin.

Work was supported by NSF Award # ECCS-123456. Nature Communications volume 11, Article number: 2495 (2020) National Research Priority/NSF 10 Big Idea - Rules of Life

Figure 3 - New material and new methods of development allow colloidal crystal engineering with DNA. Metal-organic framework (MOF) nanoparticles are functionalized with DNA and can be programmed to form crystals with well-defined symmetries and compositions

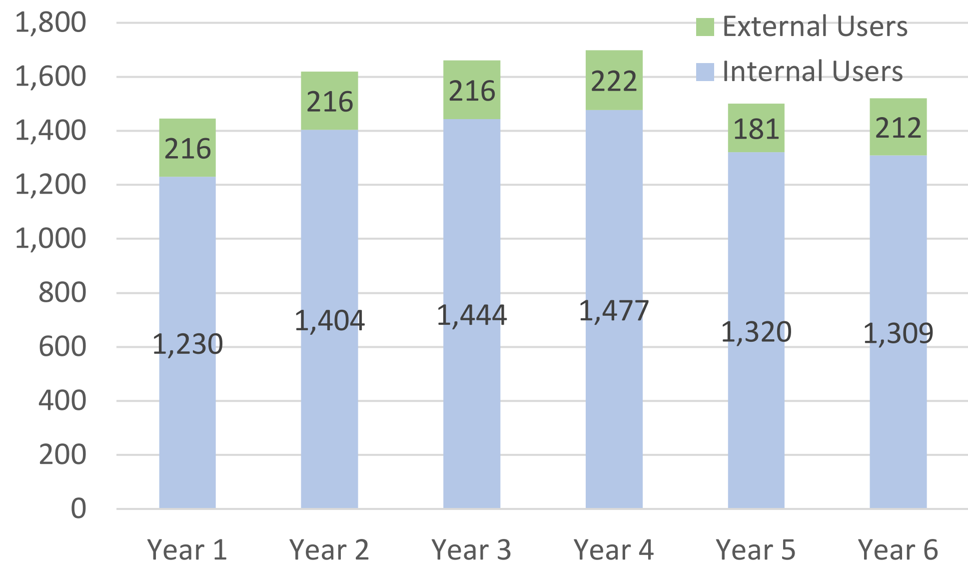
Education and Outreach Activities

Educations and Outreach activities included academic courses with laboratory components, monthly user meetings, Research Experience for Undergraduates (REU) and Research Experience for Teachers (RET) programs, hands-on workshops, seminars, vendor symposia/demos, facility tours/demos (K-12, higher-ed, public) and related web and social media communications. We held over 25+ events, reaching a total of 1,279 participants. There were 25 courses with 1400+ students. SHyNE sponsored five REU students and held a collaborative NNCI RET program, sponsoring four RET teachers from the local area, including two teachers from the Chicago public schools

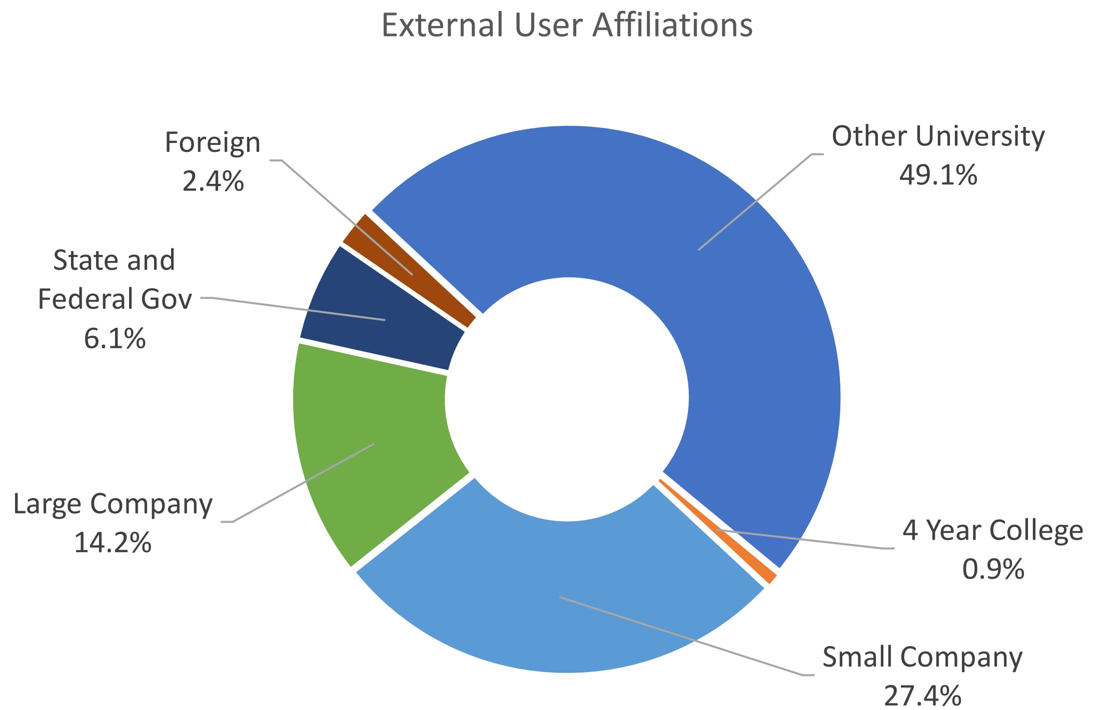
Technical lectures and seminars were held through our Tech Talk series. This year also included our inaugural Women in Microscopy conference with over 125 attendees from across the US. Workshops and demos were held, including a workshop on 4D Stem in collaboration with Gatan company. This workshop was attended virtually by over 450+ attendees. SHyNE also presented a Silvaco TCAD Workshop and demo through our NUFAB facility to educate users on this new software. SHyNE also implemented a new program, Magnifying Minds, in collaboration with Science in Society (SiS), a Northwestern University research center dedicated to science education and public engagement. This program focuses on middle school students and held summer programming in coordination with the Boys & Girls Clubs of Chicago. The program included the assembly of a foldscope, a video created by SHyNE along with a live Q&A session with our technical staff. In an effort to extend our presence in social media and engage with the broader community, SHyNE has built a YouTube channel, launched successful campaigns including our "Women in Nano" campaign, Earth Day week-long campaign highlighting SHyNE facility users who focus on environmental research and our annual image contest.

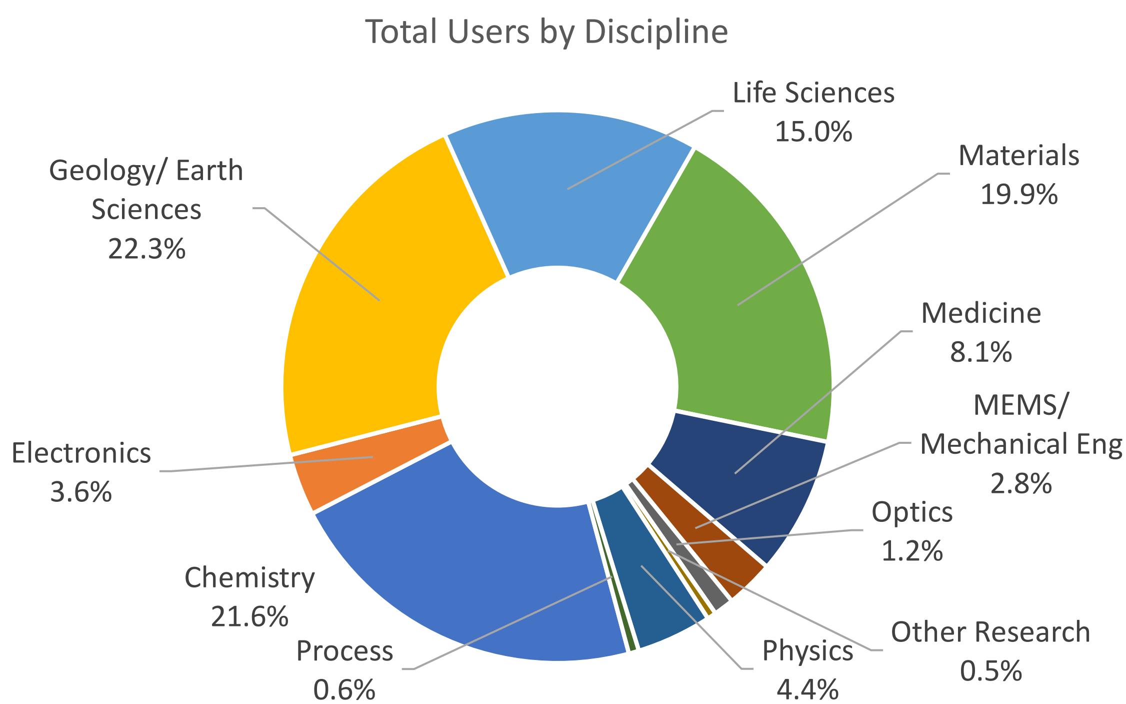
SHyNE Site Statistics

Yearly User Data Comparison						
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**
Total Cumulative Users	1,446	1,620	1,660	1,699	1,501	1,521
Internal Cumulative Users	1,230	1,404	1,444	1,477	1,320	1,309
External Cumulative Users	216 (15%)	216 (13%)	216 (13%)	222 (13%)	181 (12%)	212 (14%)
Total Hours	138,000	132,673	137,375	202,844	139,175	159,720
Internal Hours	128,838	127,127	131,206	192,434	132,177	150,425
External Hours	9,162 (7%)	5,545 (4%)	6,169 (4%)	10,410 (5%)	6,998 (5%)	9,294 (6%)
Average Monthly Users	679	802	797	829	606	693
Average External Monthly Users	54 (8%)	54 (7%)	52 (7%)	61 (7%)	41 (7%)	54 (8%)
New Users Trained	699	698	605	649	340	597
New External Users Trained	152 (22%)	140 (20%)	86 (14%)	120 (18%)	66 (19%)	121 (20%)
Hours/User (Internal)	105	91	91	130	100	115
Hours/User (External)	42	26	29	47	39	44



SHyNE Year 6 User Distribution





12.14. Southeastern Nanotechnology Infrastructure Corridor (SENIC)

Facility, Tools, and Staff Updates

SENIC continues to facilitate the "3 universities, 2 locations, 1 site" mindset and partnership between the Georgia Tech Institute for Electronics and Nanotechnology (IEN) and the Joint School of Nanoscience and Nanoengineering (JSNN). Our strategic goals, as developed with the help of our advisory board and expressed in our NNCI renewal proposal in 2020, are to (1) develop and serve a diverse user base, (2) develop strong synergies between partners, (3) expand capabilities based on future research trends, (4) develop education and outreach and societal and ethical implications programs targeting the SE, and (5) assist the NNCI Network in becoming more than the sum of its parts.

During NNCI Year 6, IEN's Micro/Nanofabrication Facilities added a Research Engineer II to assist external research users, perform baseline testing, and support direct write nanolithography activities. The IEN Micro/Nanofabrication Facilities have added additional 3D printing capabilities that support a wide range of materials for applications such as microfluidics, microneedles, electronics, and biomedicine. The Materials Characterization Facility (MCF) at Georgia Tech adjusted to the constraints of working under COVID by increasing video-based training options and performing more remote work for offsite users. The MCF also added a new research scientist to replace a longtime staff member who departed to pursue a Ph.D. Finally, the MCF was able to expand and upgrade its capabilities by adding a new FIB/SEM, which repairs the weak link in our TEM sample analysis chain, installing an X-ray Emission/X-ray Absorption Spectrometry system that is the first of its kind in the US, adding a new Variable-Pressure SEM with EDS for elemental analysis of non-conducting samples, and contributing to a new optical profiler for mm–nm automated 2D and 3D measurements. JSNN continued to strengthen its Facility and Technical Support team, with the addition of a User Program Manager and two part-time staff members (in Cleanroom and Analytical lab) to help meet the growing demand in fabrication, microscopy, analytical chemistry and remote service requests. This team is also responsible for providing user consultation, training, process and characterization support, remote jobs and data analysis, if requested by the user. JSNN has created special project spaces to address specific user/research needs, such as a battery research lab, a hydroponics lab, and a custom wet processing bay in the cleanroom to address one of its industry user's specific needs.

During the past project year, SENIC has continued to add new tools/capabilities and upgrade existing tools at both Georgia Tech IEN and JSNN although the pace of this activity has slowed. Normally new or upgraded tools are not obtained using SENIC funds; however, Year 1-5 No-Cost Extension funds were used for some purchases this past year. University support of core facility equipment benefits the goals of SENIC and NNCI in making state-of-the-art nanofabrication and characterization tools accessible to a broad and diverse user base. New tool purchases and upgrades include:

Lithography/Direct Patterning: 3DGence F350 3D Printer (photo right), BMF MicroArch S140 3D Printer, Nanoscribe Photonic Professional GT2 (upgrade), Heidelberg MLA150 (upgrade)

Deposition: Veeco Fiji Plasma-Enhanced ALD

Etching: Unaxis RIE, Plasma Etch PE25-JW Plasma Cleaning System

Imaging and Metrology: JEOL JEM-2100 Plus w/ Oxford Max80 Aztec EDS,

X-ray Emission Spectroscopy/X-ray Absorption Spectroscopy (XES/XAS), Thermo Helios 5 CX FIB/SEM, Thermo Axia VP-SEM, Zeiss EVO LS Environmental SEM (upgrade), Agilent 920 HPLC (upgrade), Keyence VK-X3000 3D Surface Profiler, KLA Zeta™-20 Optical Profiler and 3D Surface Topography System

Support Tools: Disco Dicing Saw, EVG-520 Wafer Bonder (photo left), CEM Mars 6 Microwave Digestion System

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 is performing the work on behalf of the user rather than the user doing the work on site. Seed grant programs seek to address the **affordability** challenge, and SENIC continues to support the IEN Facility Seed Grant Program and the Catalyst Program.

Marketing of SENIC continued through the website as well as promotional and communication efforts through email and social media, with SENIC-specific efforts on Facebook, LinkedIn, and Twitter. A periodic SENIC newsletter, initiated in 2018, is emailed to over 3,000 current and potential users along with other stakeholders. Year 6 issues were sent in October 2020 and May 2021. The SENIC website (http://senic.gatech.edu/) alerted users over the past year to the open/closed status of the SENIC facilities due to COVID-19, as well as announce the variety of online programs being offered during this period. Other content recently added to the website include user interviews and updated information on education and outreach activities (REU, RET, Teacher Workshop).

Started in 2018, the Southeastern Nano Facility Network (SENFN), a regional network of nanotechnology facilities, addresses all issues of awareness, accessibility and affordability. More than 30 nanoscale fabrication and characterization facilities located at universities in the southeast US (GA, SC, NC, FL, TN, AL, LA, and AR) comprise the network. The third annual meeting was hosted by Georgia Tech virtually on December 9, 2020. Topics of discussion included operational, financial, and personnel challenges in the COVID-19 era.

In support of its vision to strengthen and accelerate discovery in nanoscience and nanoengineering across the US, the SENIC Catalyst Program provides researchers limited (up to $1000) free access to the SENIC facilities to aid in research, obtain preliminary data, conduct proof-of-concept studies, or for educational purposes. Since the start of the program (2019), 28 projects have been funded, with several currently waiting for facility access. During NNCI Year 6, new Catalyst awards were made to researchers from University of Georgia, Louisiana State University, Morehouse College (HBCU), Georgia State University (PBI), Kennesaw State University, and Mercer University.

During the sixth year of the NNCI program (Oct. 2020 - Sept. 2021), the SENIC facilities have served 1221 individual users, including 250 external users (21% growth since Year 5) representing 96 companies, 24 colleges and universities, and 7 other institutions. Several users have accessed capabilities at both SENIC locations with minimal difficulty. Most users access the facilities on-site, although 199 users obtained services remotely, and some users operated in both on-site and remote fashions. Monthly users averaged 499 (a 34% increase compared to Year 5), and on average 38 new users were trained each month (453 total during the reporting period).

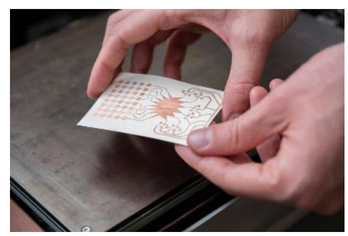
Research Highlights and Impact

Notable new academic users of the SENIC facilities this past year come from the University of Pennsylvania while new industry users include Sognef, Nclear, Boviteq, StethX, HZO, Hoowaki, Fredericks Company, Gilbarco, R&S Chemicals, to name a few. Some example research highlights include:

Low-cost, Fast Production of Solid-state Batteries for Electric Vehicles (G. Yushin, Georgia Tech)

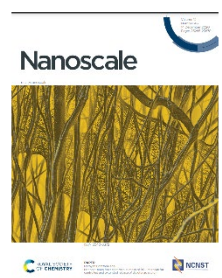
Materials science researchers have developed a melt-infiltration technology to produce high-density composites for solid-state automotive lithium-ion batteries. This research was supported by Sila Nanotechnologies Inc., a Georgia Tech startup company, and published in *Nature Materials*.

Powering Internet-of-Things using the 5G Network (M. Tentzeris, Georgia Tech)



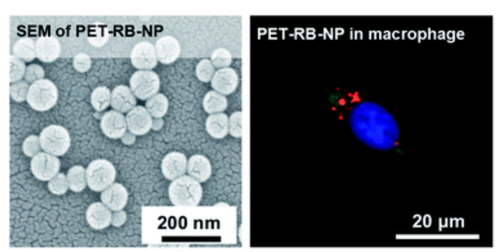
A method to use 5G networks as a "wireless power grid" for IoT devices that typically use battery power was developed. The device is based on a flexible Rotman lens-based rectifying antenna (rectenna) for energy harvesting in the 28-GHz band. This research was supported by the Air Force Research Laboratory and the NSF-Emerging Frontiers in Research and Innovation program and published in *Scientific Reports*.

Controlled Drug Release from Nanonet-Nanofibers (N. Bhattarai, NCA&T State Univ.)



Researchers using JSNN facilities synthesized nanonet-nanofiber electrospun meshes (NNEMs) of polycaprolactone (PCL)–chitosan (CH) for high payload delivery and controlled release of a water-soluble drug, Diclofenac Sodium (DS). DS-NNEMs also enhanced cell adhesion, viability, and proliferation in the nanonet-nano fiber network through the controlled release of DS. This work was published in *Nanoscale*.

PET Nanoparticles with Fluorescent Tracers for Studies in Mammalian Cells (L. Johnson, RTI International)



Fluorescent nanoparticles (NPs) comprising polyethylene terephthalate (PET) were synthesized using a bottom-up approach. The group studied concentration-dependent uptake and cytotoxicity of PET NPs in macrophages. The fabrication of well-characterized NPs, derived from highcommodity polymers, will support future studies to assess effects on biological systems. This work was published in *Nanoscale Advances*.

Scholarly impact can be measured indirectly with more than 660 publications, presentations, and patents benefiting from SENIC facilities in CY2020. Using a Google Scholar search, approximately 220 of these 2020 publications (and nearly 600 publications 2015-2020) acknowledged the SENIC NSF award number (ECCS-1542174 or ECCS-2025462). Furthermore, the SENIC SEI program produced an analysis of 444 publications (2016-2021) acknowledging SENIC funding downloaded in March 2021 from the Web of Science database (see more below).

Additional impact of SENIC is indicated by centers and other large programs that are enabled by the supported core facilities. Support continues to be provided by Georgia Tech for the **Atlanta Center for Microsystems Engineered Point of Care Technologies** along with **RADx (Rapid Acceleration of Diagnostics)**, both funded by NIH. JSNN is a collaborative partner in the newly-funded NSF STC **Science and Technologies for Phosphorus Sustainability Center (STEPS)** lead by NC State Univeristy as well as the NSF AccelNET program **International Network for Researching, Advancing, and Assessing Materials for Environmental Sustainability (INFRAMES)** lead by Duke University. In addition, SENIC participated in the NNCI funding sources analysis, which indicated that SENIC users (Oct. 2019-Sept. 2020) were supported by 526 research awards to 227 principal investigators, including 133 awards from NSF (113 PIs).

While economic impact can be difficult to quantify, select examples from Year 6 indicate that SENIC supported startup companies are achieving success:

- **MedShape, Inc** (medical implants based on shape memory alloys) was acquired by DJO in April 2021.
- **Nextinput** (MEMS force sensor) was acquired by Qorvo in May 2021.
- **Axion Biosystems** (microelectrode array technology) was acquired by Summa Equity in July 2021.
- SBIR/STTR awards were made to **Kampanics** (harsh environment sensors and oscillators), **Kepley BioSystems** (pathogen typing and antibiotic sensitivity test), and **Minerva Litthium** (nano-mosaic filter technology).

In addition, the SEI group conducted an economic impact analysis of 13 Georgia-based companies that used IEN facilities. While the results are limited, they indicated that these companies resulted in $50M+ added to the state economy, along with 275 jobs as well as non-monetized impacts. This analysis was also documented as a case study and toolkit and shared with the wider NNCI community (more details below).

Education and Outreach Activities

SENIC's vision for education and outreach is focused on the development of a strong workforce capable of meeting the needs of a growing nanotechnology-enabled economy. This year through our programs, we reached more than 3,400 individuals from young children through adults. The COVID-19 pandemic continues to affect the programming being offered with the number of people reached still less than pre-pandemic numbers.

JSNN is home to the NIH Maximizing Access to Research Careers (MARC) Undergraduate Student Training in Academic Research (U-STAR) Fellowship program. This program annually offers 2 students underrepresented in biomedical sciences a research opportunity, focused workshops and courses to prepare them for graduate school. Additionally, JSNN hosted 2 interns this past year (less than the normal 4/year) from Forsyth Technical Community College's Nanotechnology and Biotechnology programs. Georgia Tech, inspired by JSNN's program, started their own paid, technical college internship in spring 2020. Due to the pandemic, the first students to participate in-person will start in January 2022. While canceled during summer 2020, the NSF-supported Southeastern Undergraduate Internship in Nanotechnology at Georgia Tech hosted 12 students from southeastern institutions on campus during summer 2021; SENIC NCE funds were used to support two of these students. These students participated in the virtual NNCI REU Convocation. In addition to these internships, SENIC provides opportunities to students through work in the facilities as assistants. This past year, 33 undergraduate students worked in Georgia Tech nanotechnology facilities.

Each academic year, JSNN hosts a weekly seminar and IEN hosts a bi-monthly seminar series entitled Nano@Tech. Both seminar series pivoted to virtual formats in response to COVID-19 and have now transitioned to hybrid mode. JSNN also began hosting a virtual journal club. Georgia Tech's NanoFANS Forum, a biannual symposium at the intersection of life sciences and nanotechnology, was held as a series of webinars in October 2020 ("Point-of-Care Technology in Healthcare") and May 2021 ("Nanotechnology in Vaccine Delivery").

SENIC has been active in providing outreach to K-12 students, educators, and the general public. SENIC at Georgia Tech is the lead site (with MINIC, SHyNE, and NNF) of the NSF-supported Research Experiences for Teachers across the National Nanotechnology Coordinated Infrastructure collaborative program. While the first summer of the program was canceled due to the pandemic, all four sites were able to welcome high school teachers and community/technical college faculty to campus, 5 at each site, for in-person research during summer 2021. In addition to research, all of the teachers participated in regular virtual meetings and a nano-careers webinar series featuring industry speakers who are also users of site facilities. The summer 2021 Nanotechnology Summer Institute for Middle School Teachers (NanoSIMST) program was again conducted virtually. A new cohort of 15 teachers from across North Carolina participated in 4 hours/day of virtual instruction for 5 days. In addition, 15 teachers selected by nano@Stanford also participated in SENIC's virtual NanoSIMST. Classroom supplies were mailed to teachers in advance to facilitate hands-on activities. Teachers also participated in a virtual cleanroom tour, listened to guest speakers, and alumni of the program shared their implementation strategies. SENIC at JSNN started a partnership with the Guilford County School System and provided two days of professional development lessons to high school teachers. In response to the ongoing pandemic, new virtual activities have been introduced. JSNN, working with Hitachi, is borrowing a table-top SEM and offering remote sessions to both students and teachers. Georgia Tech is continuing to offer virtual hour-long class trips for middle and high school students. Staff are invited to join a teacher's virtual classroom and present an introduction to nanotechnology with demonstrations and hands-on activities; teachers receive the materials prior to the virtual class trip. Lastly, in honor of National Nanotechnology Day, JSNN hosted the 2021 NanoImpacts Conference with a presentation on "Strengthening Partnerships for University-Industry Research," a Nanotechnology Art Exhibit, and science demonstration event for K-12 students.

Societal and Ethical Implications Activities

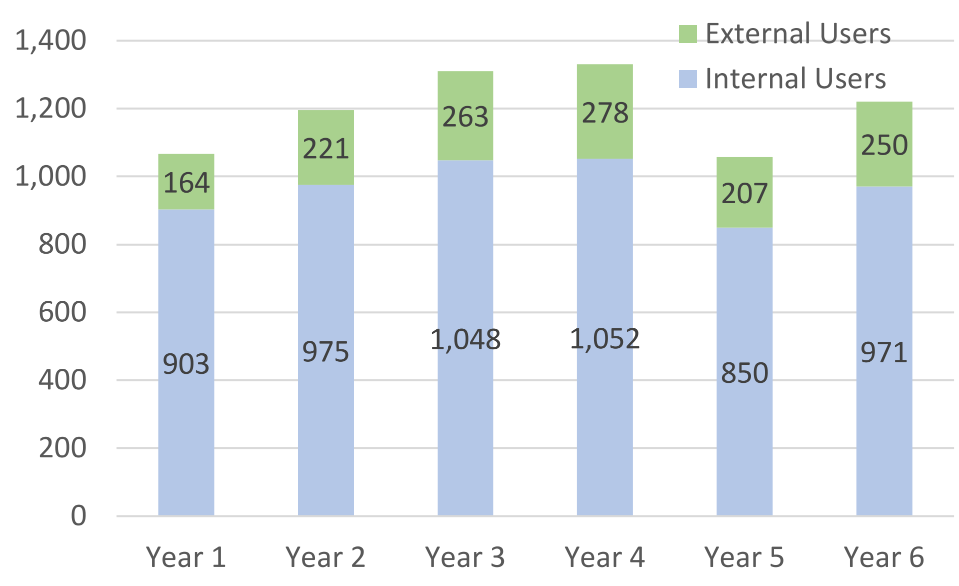
The aim of the SEI work at SENIC is to develop tools and techniques to measure the impact of SENIC on societal sectors. The results are designed to provide SENIC with information about its impact and facilitate replicability across the NNCI network by forming the basis for toolkits that other NNCI sites can use to replicate this work. We created two impact toolkits in NNCI Year 6.

"Economic Impact of NNCI-Funded Nanofabrication and Characterization Facilities: A Case Study and Toolkit" was based on interviews with 13 private sector users of the Georgia Tech SENIC facilities. The results described in the toolkit are organized around three types of companies based on the ways in which their use of the facility leads to economic impacts: (1) access to the facility is central to the company (Type 1 companies), (2) the facility serves as a primary business resource (Type 2 companies); and (3) the facility is used for one line of business (Type 3 companies). The total impact of use of the Georgia Tech facilities across these companies on the Georgia economy is at least $51 million based on direct impacts of nearly $24 million from the company users. Nearly all this impact comes from Type 1 companies, many, although not all, of which are start-ups. Other important non-monetizable impacts were time savings, quick market entry, and ability to retain custody of the product. The toolkit highlights five steps for other facilities interested in replicating the Georgia Tech approach: (1) identification of an economist or other social scientist with economic impact expertise to serve as a partner, (2) company selection, (3) interview requests, (4) questions by type of company, and (5) analysis and results. The second toolkit, "Mapping Research Outputs: A Case Study and Toolkit," presents a case study of how to analyze Web of Science publication records linked to SENIC through the NNCI grant number. The analysis of 444 publication records found 1427 authors from SENIC partner organizations, external organizations, or a mix. These articles were concentrated in traditional materials science and chemistry journals but also journals in nontraditional fields such as environmental science and bioscience. These works attracted 3446 citations and 14,810 downloads. Steps for other facilities to replicate the Georgia Tech analysis involve partnership identification, selecting relevant publications, determining software programs to use for the analyses, and communicating the results to key stakeholders.

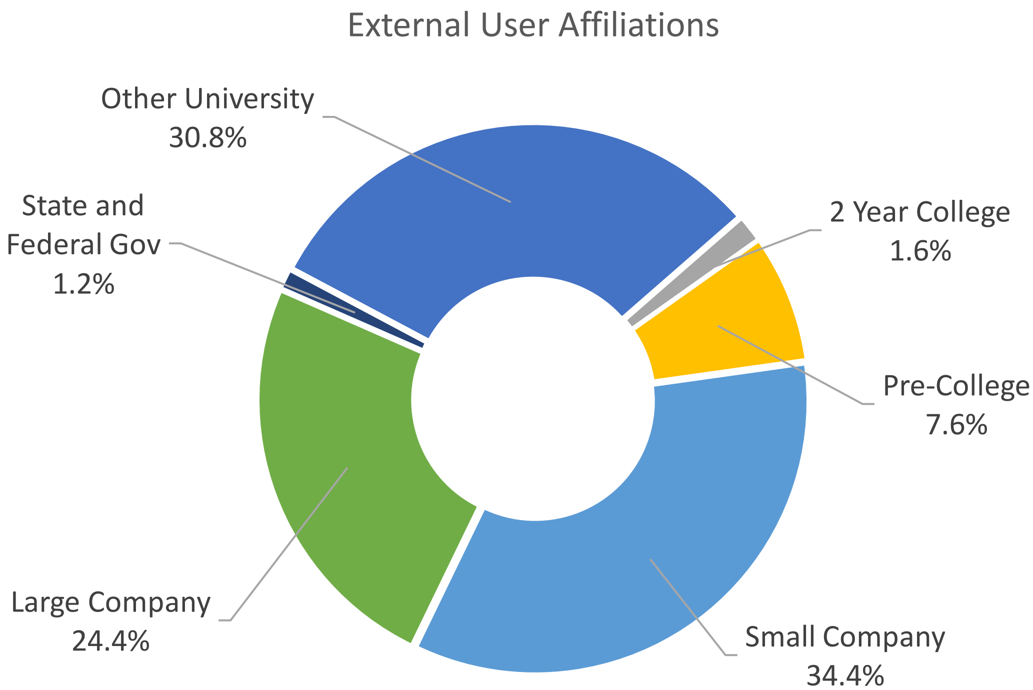
SENIC Site Statistics

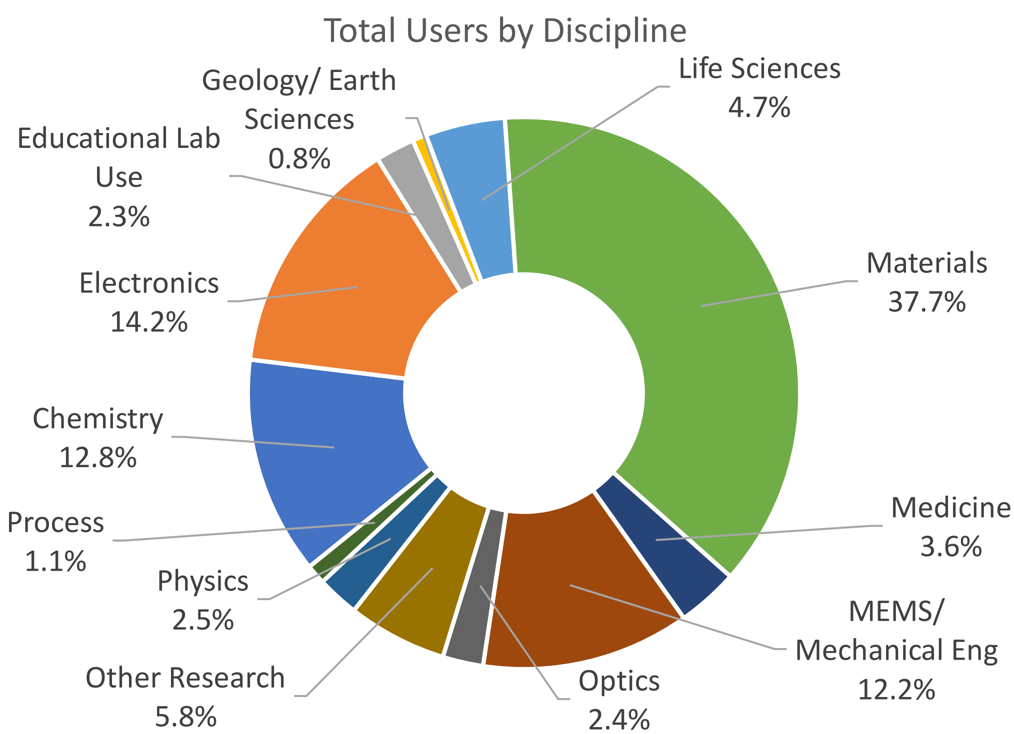
Yearly User Data Comparison	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Total Cumulative Users	1,067	1,196	1,311	1,330	1,057	1,221
Internal Cumulative Users	903	975	1,048	1,052	850	971
External Cumulative Users	164 (15%)	221 (18%)	263 (20%)	278 (21%)	207 (20%)	250 (20%)
Total Hours	79,581	85,275	99,118	101,571	66,611	92,998
Internal Hours	71,659	73,499	85,730	88,282	58,620	80,751
External Hours	7,922 (10%)	11,733 (14%)	13,388 (14%)	13,289 (13%)	7,991 (12%)	12,247 (13%)
Average Monthly Users	447	498	546	576	373	499
Average External Monthly Users	60 (13%)	63 (13%)	83 (15%)	89 (15%)	51 (14%)	75 (15%)
New Users Trained	313	313	386	502*	248	453
New External Users Trained	67 (21%)	110 (35%)	123 (32%)	132 (26%)	45 (18%)	80 (18%)
Hours/User (Internal)	79	75	82	84	69	83
Hours/User (External)	48	53	51	48	39	49

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



SENIC Year 6 User Distribution





12.15. Texas Nanofabrication Facility (TNF)

Facility, Tools, and Staff Updates

The Texas Nanofabrication Facility (TNF) at the University of Texas at Austin (UT) is composed of the Microelectronics Research Center (MRC), the Texas Materials Institute (TMI), and nanomanufacturing fab (nm-Fab). NNCI-TNF has 22,000 sq. ft. cleanroom space (class 100 and 1000) and 20,000 sq. ft. of labs. The MRC cleanroom provides extensive nanofabrication capabilities, TMI provides state-of-the-art metrology tools, while the nm-Fab has developed and provides novel nanomanufacturing tools in the areas of roll-to-roll manufacturing (deposition and etch), and high speed, large area nanoimprinting. TNF is well positioned geographically in the Austin high-tech hub, within the Dallas/Fort Worth-Houston-San Antonio triangle, with no competing universities having comparable infrastructure in nanotechnology in this region of the country. Since Texas, in general, and Austin in particular, have a strong industry base in nanotechnology, TNF has a large external user cohort, especially in terms of small companies. We also serve academic institutions in Texas, and the neighboring states. We also have users from other parts of the US, and the rest of the world. We have enabled and fostered breakthrough nano-innovation in the areas of electronics, healthcare and energy – all of which have significant presence in the South West; while establishing educational activities in nanotechnology directed at engaging underrepresented minorities (URM), particularly Hispanics and women.

Tools: TNF MRC has recently invested heavily in advanced plasma etching, deposition, and metrology tools. NASCENT has installed a novel roll-to-roll atomic layer deposition system on flexible substrates. A roll-to-roll etch system has been installed in 2020. MRC invested in a new atomic force microscopy system, and an ion milling system for metal etching for spintronic applications. Midas toxic gas monitors from Honeywell installed at the same time will maintain the highest safety standards as per industry protocols.

Major Tool Acquisitions and Upgrades:

- JEOL Aberration Corrected TEM (funded by Univ. of Texas) ($3M): Installed
- Kurt J Lesker PVD E-beam evaporator ($290k)**:** Installed and operational
- Bruker Dimension Icon AFM ($167k): Installed and operational
- VK-X1100 Optical profilometer for TMI facility ($120k): Installed and operational
- Park NX10 Atomic force microscopy tool for TMI facility ($100k): Operational
- JEOL E-Beam Stage and Laser ($86k)

Staff: The highly skilled TNF training staff provide user support for both standard and advanced fabrication or characterization techniques. They propose innovative and unique solutions to solve user's complex scientific challenges. With over 800 unique users utilizing the shared facilities each year, training sessions are organized every weekday. 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). Three of the technicians and three of the Ph.D.s are funded by NNCI.

User Base

TNF, prior to the COVID-19 shutdown, hosted ~685 unique users, averaging 5430 Lab hours/month for a revenue of ~ $111 K/month through user fees. The lab hours and the revenue both had generally increased from Year-to-Year. TNF had ~ 23% outside users (year 4 and 5), prior to the shutdown in March 2020. TNF started opening up to internal users since July 2020, with outside users allowed in from August 2020, albeit with severe restrictions. In the past 5 years, TNF has served 100+ users from different companies, two-thirds of whom are still part of the user base in 2021.

1. In Year 6, TNF hosted 372 unique users, averaging 3656 Lab hours/month for a revenue of ~ $94 k/month through user fees even with the imposed restriction of 50% re-opening. The external new users percentage went down due to the COVID.
2. Diversity of users (disciplines, affiliations, and demographics):

   User profiles including demographics and research fields (i.e. disciplines) are reported voluntarily through an online survey by each user during the orientation session. Half of the TNF users self-declared their research project to be related to Materials (26%) or Electronics (21%) disciplines. The TNF shared facilities are utilized significantly by women (23%). The number decreased due to the COVID lockdown. The cumulative number for year 6 shows some improvement. The percentage of External Users in year 6 is 24%, consistent with year 4 as well as year 5.

Research Highlights and Impact

TNF had 24% average outside users in the sixth year. The external institutions include 26 companies (small and large) as well as 3 academic institutions from outside UT Austin. More than half of the current companies which benefit from the TNF shared facilities were already users at TNF in past years. This shows that a good and lasting relationship between TNF and their users has been established and demonstrates the usefulness of the NNCI financial and scientific model.

Work done at TNF has led to multi-institution, and multi-NNCI site high impact papers in Nature and Science. NNCI has also enabled technology development by small companies, many supported by SBIR and STTR grants from NSF, DoD, etc. Several of these address the NSF Big 10 Ideas, or other federal initiatives. Approximately 150 papers were published each year by the internal and external users of TNF, many of them in high impact journal such as Nature and Nature group, Science, Phys. Rev. Letters, Phys. Rev. B, PNAS, Nano Letters and ACS Nano. This year the publication count dropped to 108 because of COVID.

The successes of TNF in the past year include:

- *Science to Scalability:* Integrated MRC (nanodevice prototyping) with TMI (state-of-the-art characterization) and nm-Fab (nanodevice manufacturing) to facilitate innovation in seed stage, as well as small and mid-size companies (SMCs) by building on our track record of technology incubation in Texas. The nm-Fab did prototyping and small-scale manufacturing for outside companies.
- *Innovation Ecosystem:* Focused on enhancing commercial success of SMCs by connecting them to an innovation ecosystem including the Longhorn Startup undergraduate entrepreneurship course at UT, the Austin Technology Incubator (UT's official startup incubator), and NSF I-Corps program, for which UT is an official node.
- *Engaged URM in NNCI-TNF*: Since Texas has a large Hispanic population, and Oklahoma has a large Native American population, we targeted these populations as part of our effort to engage underrepresented minorities and women. We are focusing on a year-round REU program through Austin Community College. Students get class credit for working in the TNF cleanroom.

- *Leveraged the Dell Research Hospital:* We started a collaboration with the medical research groups in Houston, Dallas and San Antonio areas by partnering with the Dell Medical Research Hospital established in 2014, in the area of healthcare electronics and nanomedicine.

Education and Outreach Activities

1. A Zoom video workshop and a virtual tour of MRC was conducted by TNF Site Coordinator, Dr. Majumder, for the Central Texas STEM Youth Explorers ranging from 6th grader to 9th grade students. The video link can be found at: https://vimeo.com/422622146.
2. Girl Day, February 27, 2021, hosted by TMI. Targeted audience was 5th, 6th, and 7th graders. This link below provides the video of the program: https://girlday.utexas.edu/activity-uttmi-grow-alum-crystals.
3. Microscopy Workshop on Energy Materials, October 14, 2020. The details of a few of the talks are given below:
    a. Multiscale Imaging Solutions for Lithium Battery Development
    b. Dr. Zhao Liu, ThermoFisher Scientific marketing development manager at Thermo Fisher Scientific focused on Next Generation Battery Technologies
    c. Dr. Arumugam Manthiram, UT-Austin, is the Cockrell Family Regents Chair in Engineering and Director of the Texas Materials Institute at the University of Texas at Austin. He spoke about advanced batteries.

    The workshop was attended by 50 participants.
4. TMI also organized a TEM workshop for prospective users of the newly installed aberration corrected TEM.
5. There were virtual tours of the TMI and the MER facilities for the MS&E prospective graduate students and the prospective faculties.

We have started 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 have started bringing these ACC from Fall 2021 after COVID restrictions were relaxed.

Societal and Ethical Implications Activities

Prof. Lee Ann Kahlor, a risk and science communication expert at the University of Texas at Austin leads the societal and ethical implications (SEI) team. This year, TNF-SEI focused on building a TNF-SEI website as part of our SEI outreach efforts (http://sites.utexas.edu/nnci-sei/). This website covers introductory information about NNCI, TNF, and SEI, including the training module we developed in prior years. It also provides nano-ethics related local and online educational resources for our audience(s). We anticipate that this website will serve as an information hub for NNCI-SEI related projects, resources, and news for Texans; however, we are still collecting data to determine our ideal audience(s).

After the soft launch, our team conducted the first round of usability tests. Each usability test was a combination of a 30-minute in-depth interview and a 10-minute monitored user task performance test. Participants were recruited from the UT campus and the general audience in Austin. Participants' feedback on the content, user flow, web design, and overall user experience was collected for the usability test. We also sought professional advice from NNCI-SEI network members to improve the website. Based on the feedback, our team is currently updating the website to enhance audiences' experiences across all aspects including increasing content richness, improving usability, optimizing user journey flow, and fixing existing errors.

TNF-SEI Pilot Website Usability: Building on the preliminary data collected from the usability test, our team is conducting a qualitative study exploring college students' motivation and barriers to gaining nano-ethics-related information. Using Kahlor's (2010) Planned Risk Information Seeking Model as a guide, this study seeks to understand college students' knowledge levels of nano-ethics related issues, major concerns of nano-ethics, types of nano-ethics information required, and the reasons behind nano-ethics information engagement or avoidance. With a deeper understanding of audiences' knowledge levels and information needs of nano-ethics topics, this study can also provide additional inspirations to our website project and suggest practical recommendations on nano-ethics education and outreach campaigns. This project is still in data collection.

Ethical Leadership: Prior research related to data collected from our training module also is still producing output: Moon, W. & Kahlor, L. "Ethical Leadership: How Scientists Who Work at the Nanoscale Think about Ethics in the Workplace". In revision at *Journal of Responsible Innovation*.

Nanotechnology in Consumer Applications: Our team also produced three quantitative studies to understand people's risk perceptions of and responses to the environmental impacts of nanotechnology. Two studies explored people's cognitive and affective evaluations of nanotechnology applications and related information behaviors (Wang, Kahlor, Atkinson, 2020; Wang, Atkinson, Kahlor, 2021). The third one explored people's attitudes towards nanotechnology and its corresponding purchase decisions on nanotech-enabled consumer products. This manuscript is under review at the National Communication Association Annual Convention.

<u>Computation Activities</u>

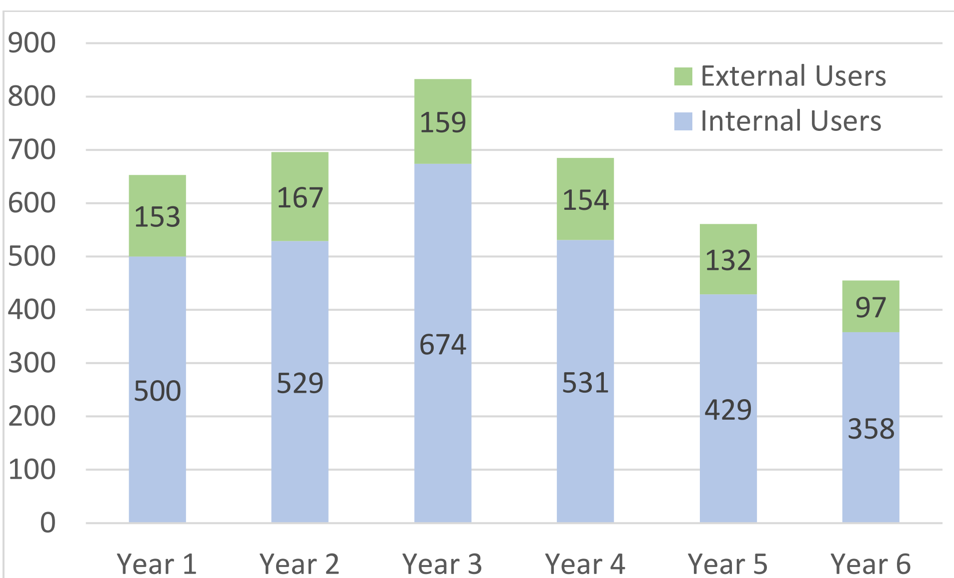
Modeling and simulation efforts performed with, in part, NNCI support have focused on understanding guiding subsequent experimental efforts planned within our NNCI facilities, and, recently, in collaboration with colleagues at sister sites, developing a series of seminars on modeling and simulation of interest to the NNCI community.

Prof. Leonard Register is working with Prof. Azad Naeemi at Georgia Tech and Prof. Dragica Vasileska at Arizona State University to a present a series of talks on modeling and simulation. Prof. Register of UT-Austin presented a talk focused on the essential physics of charge transport in nanoscale devices, as illustrated by quantum-corrected semiclassical Monte Carlo modeling of scaling of and alternative materials for nanoscale n-channel MOSFETs. These talks will help us gauge the communities' interests. Moving forward, we plan to then invite appropriate speakers from academia, government research labs, and industry to present talks accordingly.

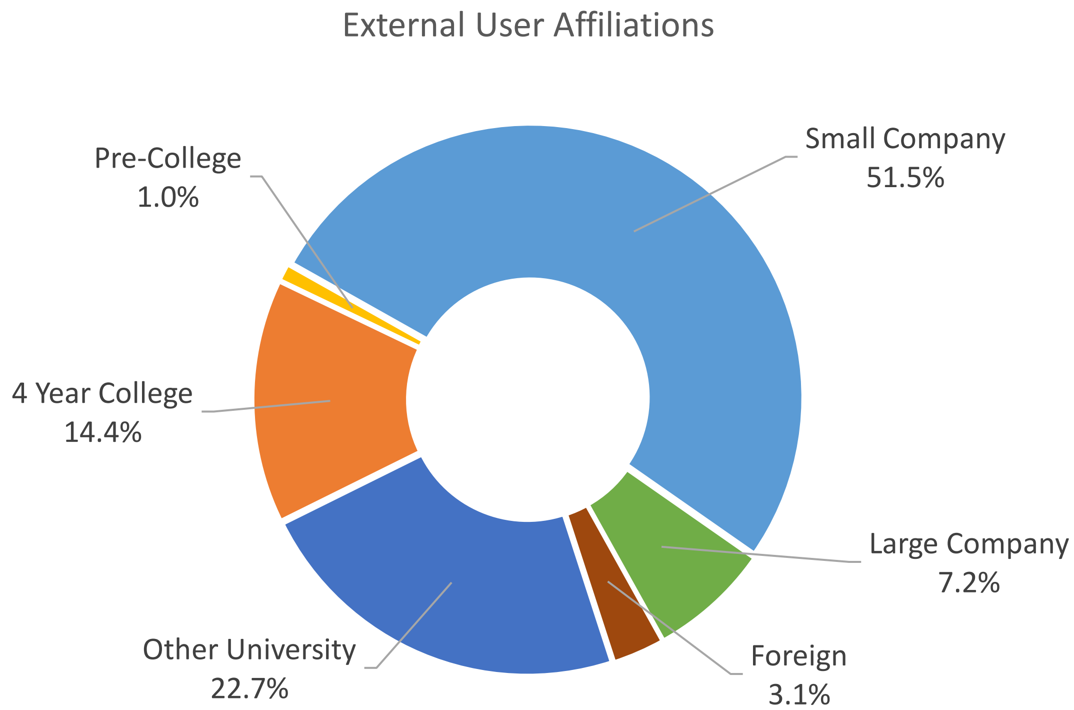
In addition, at UT Austin, supported in part with NNCI funding, we have and are performing modeling and simulation to better understand and guide the development of, in particular, spintronic materials and devices as a guide to ongoing and future experimental work on these systems within our NNCI supported facility. Examples include Density Functional Theory (DFT)-based first-principles predictions of magnetic material systems for hosting nano-scale room-temperature skyrmions to both fundamental theory and simulation of charge current to spin current conversion and vice-versa in topological insulator (TI) based systems, for application to low-power magnetic memory and perhaps even neuromorphic computing. Among other articles, we have just completed a review article on the extensive experimental work performed to date to understand these TI and related systems, including with a review of the basic theory on which not only the systems but also the measurements are based.

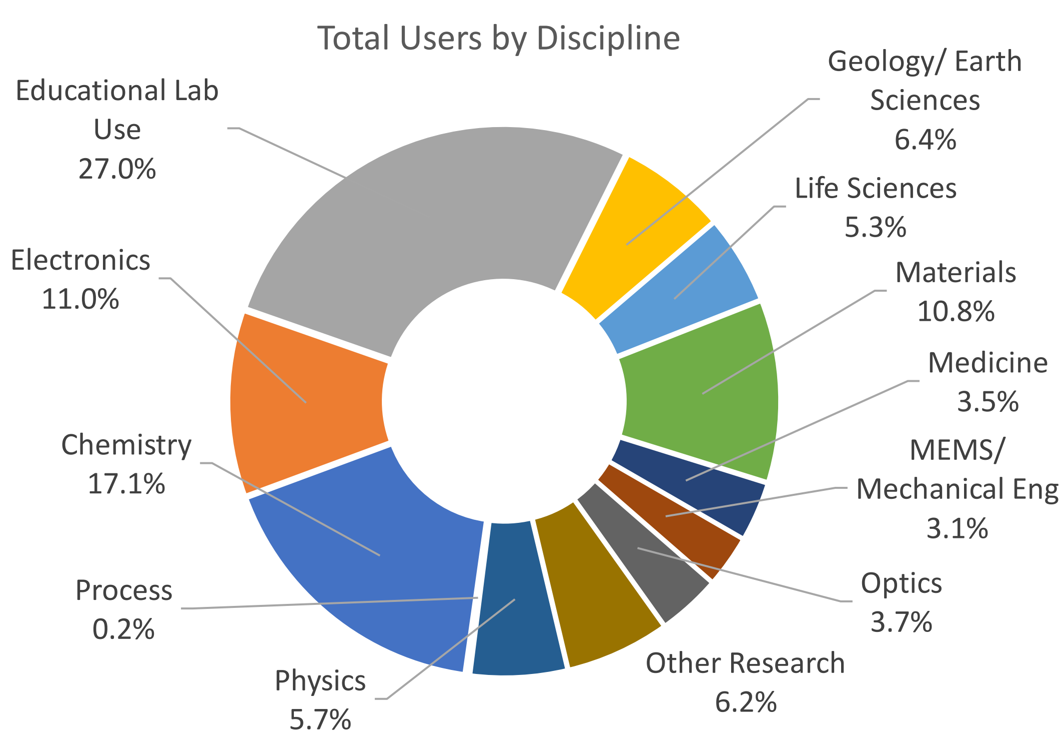
TNF Site Statistics

Yearly User Data Comparison						
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**
Total Cumulative Users	653	696	833	685	581	455
Internal Cumulative Users	500	529	674	531	429	358
External Cumulative Users	153 (23%)	167 (24%)	159 (19%)	154 (22%)	132 (24%)	97 (21%)
Total Hours	67,570	58,354	63,645	65,166	38,229	53,901
Internal Hours	53,484	45,952	46,464	48,254	28,263	41,159
External Hours	14,084 (21%)	12,402 (21%)	17,181 (27%)	16,912 (26%)	9,966 (26%)	12,742 (24%)
Average Monthly Users	244	272	287	315	216	246
Average External Monthly Users	45 (18%)	50 (19%)	59 (21%)	65 (21%)	45 (21%)	53 (22%)
New Users Trained	99	193	80	62	34	38
New External Users Trained	48 (48%)	45 (23%)	33 (41%)	29 (47%)	16 (47%)	10 (26%)
Hours/User (Internal)	107	87	69	91	66	115
Hours/User (External)	92	74	108	110	76	131



TNF Year 6 User Distribution





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

Facility, Tools, and Staff Updates

In March 2021, Marc Michel graciously agreed to step up into the Deputy Director role to support the center. In this role he works with the NanoEarth Executive Committee to support the day-to-day operation of NanoEarth. Marc's geoscience expertise and role as Division Leader for Virginia Tech's Nanoscience and Nanomedicine programs make him an excellent addition to NanoEarth's leadership team.

Previous Deputy Director Linsey Marr had to step down from this role due to additional duties related to being a leading expert on airborne transmission of viruses during a global pandemic. She remains actively engaged with NanoEarth as a coPI and environmental science expert.

To better support non-traditional users in Earth and environmental sciences, NanoEarth developed an online user portal to provide information on available instrumentation. The portal allows potential users to determine which instrument may be useful for their research project based on what type of samples they have and what information they are interested in gathering. The portal is live on the NanoEarth website (www.nanoearth.ictas.vt.edu) and additional content and resources will continue to be added. Components of the portal include:

- Overview of an instrument with typical applications and limitations.
- Detailed technical specifications of instrumentation available at NanoEarth.
- Highlights of Earth and environmental projects completed using a particular technique.
- Selected publications from NanoEarth supported users.
- Additional resources including educational videos and documents, typical sample preparation techniques, and links to other related NNCI content.

User Base

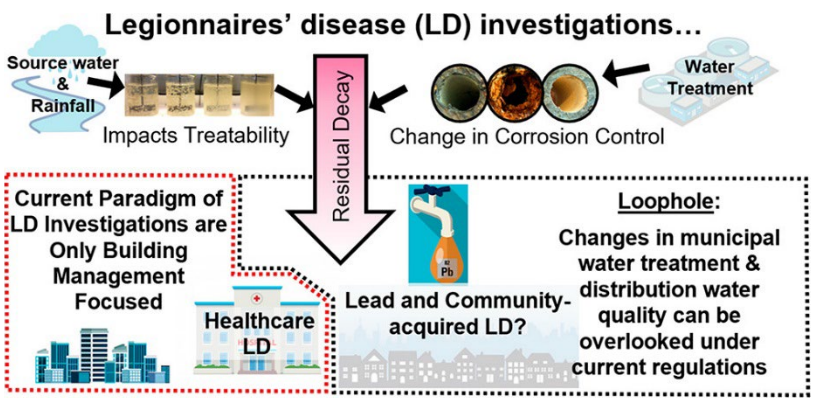
NanoEarth is designed for users in the Earth and environmental sciences and engineering fields, but many other scientists and engineers accomplish important research in related fields using our labs and instrumentation. In the case of NanoEarth, Earth and environmental science and engineering related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

NanoEarth's MUNI (Multicultural and Underserved Nanoscience Initiative) provides financial support for individuals engaging with NanoEarth for research or educational purposes. Due to the pandemic, in our sixth year, the focus was on remotely supporting ongoing MUNI user projects and expanding the NTEC program.

Research Highlights and Impact

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

Leading Academic Highlight – ***Legionella*** **Contamination and the Municipal Water System**: Fifty-eight people were sickened and 12 died from a Legionnaires' disease (LD) outbreak in Quincy, IL, in 2015. The outbreak was widely publicized and politicized and the official outbreak investigation identified deficiencies at the Illinois Veteran's Home (IVHQ) as the precipitating cause of the outbreak. However, we discovered in our analysis that the conclusions of the investigation did not account for four community-acquired cases that occurred concurrently with no IVHQ exposure. In our study published in *Environmental Science & Technology Letters*, we broadened the investigation to assess whether municipal drinking water supply deficiencies could have potentially contributed to a community-wide outbreak. In doing so, we comprehensively evaluated seven lines of evidence, including publicly available records on the operation and maintenance of the Quincy city water system. Notably, 3–6 months prior to the outbreak, we found that the primary disinfectant was changed and corrosion control was interrupted, causing a sustained decrease in disinfectant residuals throughout Quincy's distribution system. We hypothesize this created more favorable conditions for growth of *Legionella*, the bacteria that cause LD, growth throughout the system. There was also an increase in lead levels in the drinking water. These municipal system deficiencies were not identified in prior investigations of the outbreak, but their impacts on public health outcomes are consistent with those of the 2014–2016 Flint Water Crisis. However, they occurred in Quincy without any legal violations in the municipal water system or public acknowledgment of community-wide health risks. This study supports the critical need for improved data collection during changes in municipal water treatment. Additional regulatory and communication requirements can better protect public health from both LD and lead.



The current paradigm of Legionnaires' disease investigations allows changes in municipal water treatment and distribution water quality to be overlooked under current regulations.

Leading Industry Highlight – Developing a nano-enabled solution for separating oil and water: NanoEarth spent much of 2021 supporting innovators and entrepreneurs like Professor Jamie Lead and his start-up, GeoMat, LLC. GeoMat is commercializing a multifunctional nanoparticle platform that has broad utility separating oil from water (see a video demonstration here). The particles were developed by professor Lead at the University of South Carolina Center for Environmental Nanoscience & Risk (CENR). Professor Lead and his research team have published extensively on the technology (e.g., see Palchoudhury and Lead, 2014) and have been

GeoMat one year later. The start-up wins innovative technology award, additional funding to apply oil remediation technique in Alaska

awarded various university-owned patents. NanoEarth has been proud to leverage its unique "nanotechnology innovation ecosystem" to support the efforts of professor Lead and GeoMat as a partner on the team's NSF I-Corps program and, most recently, their very first NSF SBIR award! For more information on GeoMat's success, see:

https://www.sc.edu/study/colleges_schools/public_health/about/news/2021/geomat_award_sbir.php

Education and Outreach Activities

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

- NanoEarth continues our partnership with Jim Metzner (multiple radio media major-award winner, plus multiple NSF, Grammy Foundation, and Fulbright grants) with 5 new shows developed for ***Pulse of the Planet*** this year about nano-related research and technology, and how it is changing the world, very much built for public consumption in a highly constructive format. *Pulse of the Planet* highlights the most interesting projects that come to us from external users, local site researchers, and impactful research at other NNCI sites with those individuals personally interviewed for each episode. This year's episodes featured Maya Trotz a Civil and Environmental Engineering Professor at the University of South Florida discussing coral reefs. *Pulse of the Planet* is heard on over 265 NPR radio stations by 1.1M listeners per week and are available as podcasts on Sticher and iTunes. A full list of episodes with links to each program, which credit the National Science Foundation by name, are available on the NanoEarth website.
- **HBCU/MSI Research Summit**: NanoEarth participated in the virtual 2020 HBCU/MSI Research Summit organized by Virginia Tech's Office of Recruitment and Diversity Initiatives. The summit provides an opportunity for faculty, students, and administrators to explore research opportunities and potential collaborations between historically black colleges/universities (HBCUs), minority serving institutions (MSIs), and Virginia Tech. Through these partnerships we seek to enhance the quality of research and graduate education by placing equity, diversity, and inclusion at the forefront of our pursuit of excellence. Our goals in hosting the annual research summit include: 1) Research: fostering cross-institutional research partnerships between HBCUs, MSIs and Virginia Tech; 2) Recruitment: Providing current HBCU and MSI students with a preview of Virginia Tech's graduate programs, allowing Virginia Tech graduate programs a key opportunity to recruit prospective students; and 3) Shared Degrees: Facilitate discussions about the feasibility of shared degree programs between the HBCUs and MSIs and Virginia Tech programs.
- Once again, NanoEarth sponsored the Spring 2021 **NanoTechnology Entrepreneurship Challenge (NTEC)**, which kicked off on March 19, 2021. The NTEC program aims to accelerate innovative nanotechnology transfer from the university to the private sector. The NTEC program encourages diverse, student-led teams to apply nanotechnology-based ideas to sustainability challenges in areas like public health, agriculture, clean water, and renewable energy. Winning teams receive seed funds to help develop their idea, as well as business development assistance and mentorship. The seven week "pre-I-Corps" program culminates in a virtual "Launch Lunch" in May, where invited guests from the local entrepreneurship ecosystem review the NTEC program and vote to select the top NTEC team. The objectives of

NTEC program, which has supported more than two dozen student entrepreneurship teams since 2014, are to:

- Encourage entrepreneurship through diverse, student-led teams,
- Provide seed funding to help student-led teams advance innovative nanotechnologies towards solving real-world problems in society,
- Encourage commercialization of nanotechnologies available through Virginia Tech Intellectual Properties (www.vtip.org)
- Educate students on the technology transfer process
- 2021 Impact: 9 student-led teams; 2 teams lead by students from HBCUs; 3 teams led by female entrepreneurs

- Along with the other members of the Nano Earth Systems Research Community, NanoEarth hosted a virtual workshop on May 24-26, 2021. The workshop had 20 invited speakers, included break-out "listening" sessions for the NNCI to get community feedback, and hosted "office hours with experts" to provide high-quality interaction between NNCI labs and new users to design new research and build collaborations. Workshop goals included:
  - Introducing the geoscience community to new advances and opportunities to do research in nanoscience through the National Nanotechnology Coordinated Infrastructure (NNCI) program.
  - Helping participants stay current about data, tools, services, and research related to nanoscience.
  - Addressing the "big science questions" related to nanoscience: nanomaterials in the Earth system, impacts on biogeochemical processes, characterization of nanomaterials and their chemical properties at the nanoscale, impacts of nanomaterials (natural and incidental) on the environment and human health.
  - Building collaborations; developing research networks to facilitate nanoscience research in the Earth and Environmental Sciences.
  - Introducing education outreach efforts for nano-ES

  The workshop had 150 registrants and feedback was overwhelmingly positive with a significant post-workshop evaluation completed by the Science Education Research Center. Workshop materials and recording are available online: https://serc.carleton.edu/nnci_spring2021/index.html.

- The Virginia 4-H State Congress was held June 25-27, 2021. This annual statewide 4-H gathering, which was held as a hybrid mix of in person and online components, included collaboration with NanoEarth. NanoEarth hosted an online learning event which was live via Zoom and broadcast to approximately 100 youth per session. The session included a short presentation titled "Intro to Nano & Importance of Sunscreen" and two hands-on activities related to UV Light and the value of sun protection. The event also featured "Ask a Scientist" where graduate students entertained questions from the groups as the attendees completed the sunscreen activities. Each of the 4-H classrooms participating received materials so they could follow along at their sites.

Innovation and Entrepreneurship

NanoEarth continued to operate its core innovation and entrepreneurship (I&E) programs including the industry seminar series, the NanoTechnology Entrepreneurship Challenge (NTEC), and the Entrepreneur-in-Residence (EiR) program. Additionally, NanoEarth supported multiple ongoing collaborative projects with industry partners GeoMat, LLC, and Micronic Technologies, Inc. One program, the Research AND Entrepreneurship Experience for Undergraduates (REEU) did not occur this summer as the collaborating REU program based at Virginia Tech has ended. NanoEarth is currently working to identify another REU program through which to administer its REEU module. Following is a summary of NanoEarth I&E highlights since October 1, 2020:

- NanoEarth hosted Lawrence Mayhew, Regenerative Agriculture Consultant, for a NanoEarth Industry Seminar on April 27th, 2021. Mr. Mayhew discussed a humification index using UV-visible light spectroscopy. Following his talk Mr. Mayhew initiated a collaborative laboratory validation study with NanoEarth, which was led and successfully completed by Dr. Weinan Leng.
- During March through May 2021, NanoEarth ran its annual NTEC program, which is highlighted in this report.
- New industry engagements this reporting period included Hymag'in (Grenoble, France), Mycologics LLC (Alexandria, VA), and Hoover Color – with Prof. Marc Michel (Hiwassee, VA).
- Ongoing industry engagements included Natural Immunogenics (Sarasota, FL), GeoMat LLC (Columbia, SC – see included highlight) and Micronic Technologies (Bristol, VA). GeoMat LLC was awarded their first NSF SBIR Phase I award, which included a consulting role for NanoEarth. Dr. Hull is currently working with GeoMat to prepare for an upcoming Phase II SBIR submission. Dr. Hull accepted a role to serve as chair of Micronic's External Scientific Advisory Committee for 2020-2021.
- Through his role as EiR, Dr. Hull mentored three senior professionals (two faculty members and one government employee) who are considering start-ups and contributed to the mentorship of 14 entrepreneurial students via the NTEC challenge.

Societal and Ethical Implications Activities

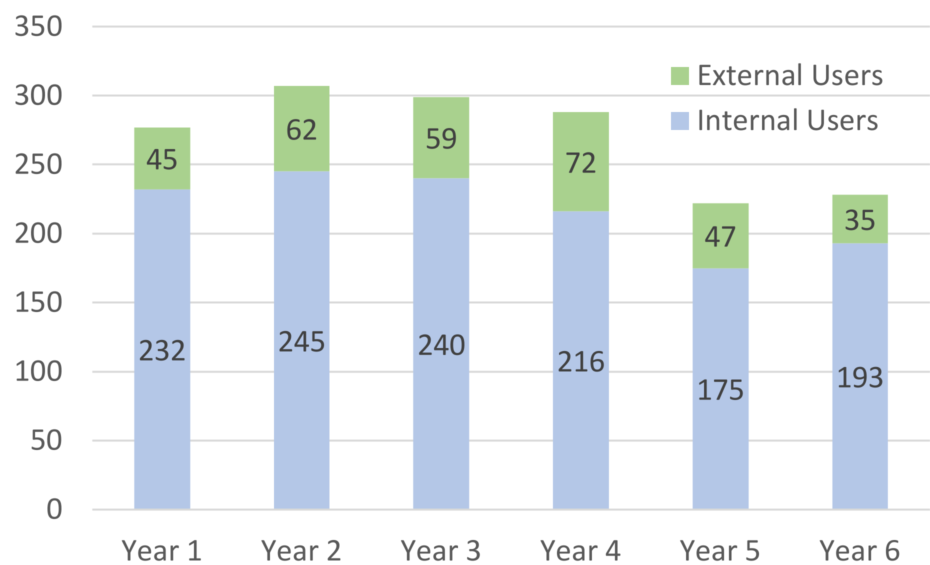
NanoEarth participates in Societal and Ethical Implications (SEI) of nanotechnology activities that are coordinated across participating NNCI nodes under the direction of Professor Jamey Wetmore of the Nanotechnology Collaborative Infrastructure Southwest (NCI-SW) node. SEI activities initiated within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

Computation Activities

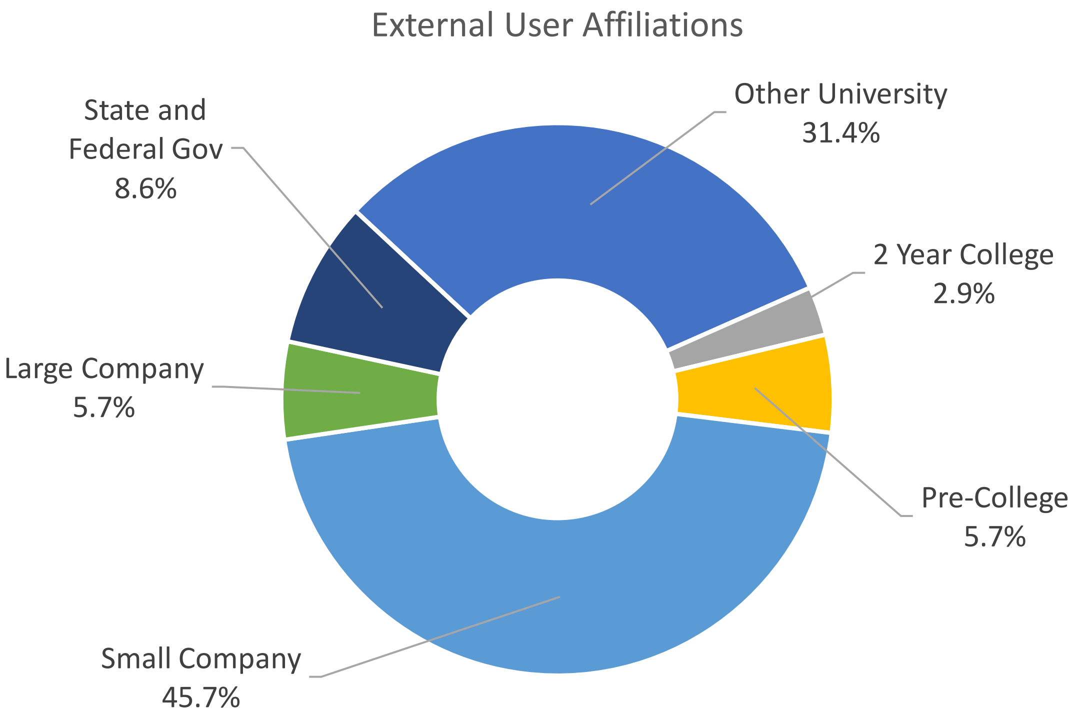
NanoEarth Associate Director for Innovation and Entrepreneurship Matthew Hull led the re-development of the Nanotechnology Consumer Products Inventory (CPI) (www.nanotechproject.org/cpi/), and until 2020, managed requests for users seeking access to the CPI. While the inventory no longer receives funding support from the Pew Charitable Trusts, NanoEarth faculty, staff, and students have played a vital role in sustaining this critical nanoinformatics resource. These efforts led to the publication of a highly cited (more than 1600, as of Dec. 2021) manuscript entitled *Nanotechnology in the real world: redeveloping the* *nanomaterial consumer products inventory* (https://www.beilstein-journals.org/bjnano/content/pdf/2190-4286-6-181.pdf). As of 2020, the resource has been transferred to the oversight of David Rejeski at the Environmental Law Institute (https://www.eli.org/bios/dave-rejeski) and NanoEarth oversight of the resource has ended.

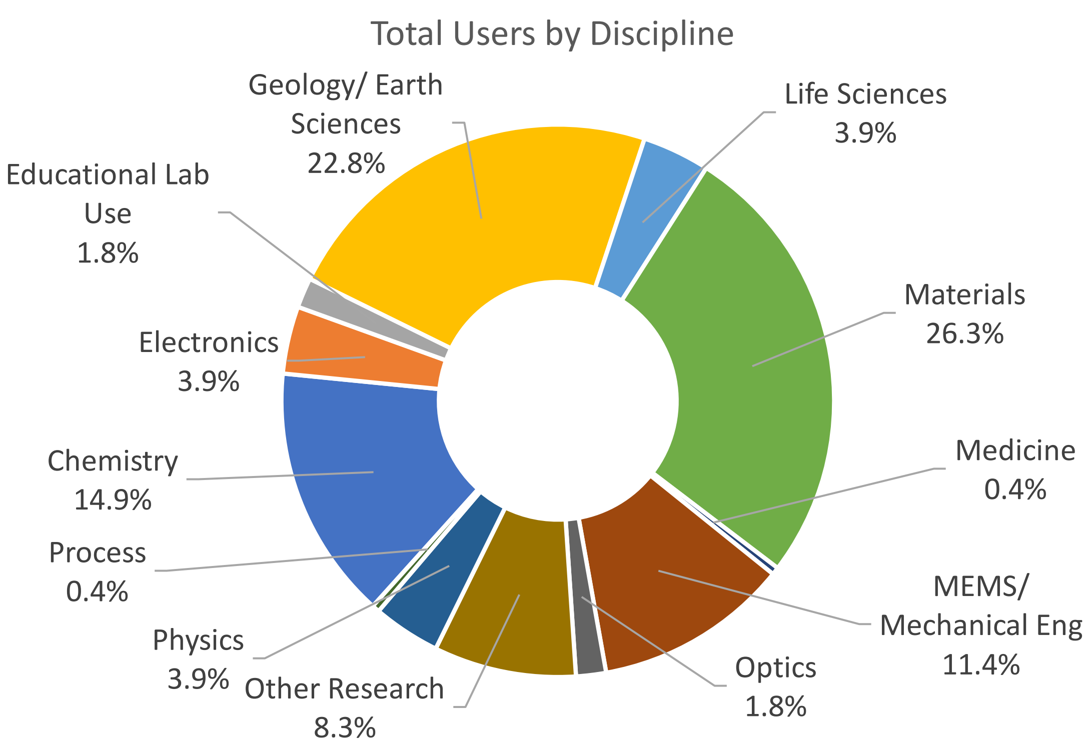
NanoEarth Site Statistics

Yearly User Data Comparison						
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**
Total Cumulative Users	277	307	299	288	222	228
Internal Cumulative Users	232	245	240	216	175	193
External Cumulative Users	45 (16%)	62 (20%)	59 (20%)	72 (25%)	47 (21%)	35 (15%)
Total Hours	7,627	18,056	16,455	15,291	10,710	11,706
Internal Hours	6,196	14,277	14,073	11,622	8,174	9,748
External Hours	1,431 (19%)	3,779 (21%)	2,382 (14%)	3,669 (24%)	2,536 (24%)	1,958 (17%)
Average Monthly Users	78	90	93	91	61	83
Average External Monthly Users	9 (12%)	14 (15%)	13 (14%)	18 (20%)	10 (16%)	13 (16%)
New Users Trained	277	134	94	80	49	72
New External Users Trained	45 (16%)	27 (20%)	0 (0%)	0 (0%)	0 (0%)	3 (4%)
Hours/User (Internal)	27	58	59	54	47	51
Hours/User (External)	32	61	40	51	54	56



NanoEarth Year 6 User Distribution





13. Program Plans for Year 7

Year 6 marked the start of the 5-year renewal of the NNCI. However, many of the programs for the Coordinating Office (see Section 2 for details) remain the same as in the first five years. The Coordinating Office will continue to: (1) promote and market the NNCI and its sites, (2) assist users in finding appropriate resources across the network and beyond, (3) coordinate site activities and share best practices across the network and beyond, (4) assist the sites wherever possible, and (5) serve as the main interface with the NSF. Thereby, the overarching goal remains to ***make the network greater than the sum of its parts*** to the benefit of our user communities.

The roles of the Coordinating Office (CO) were defined in the NSF program solicitation:

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

Starting in Year 6, the CO added a fourth Associate Director, Dr. Matt Hull from Virginia Tech, to initiate and coordinate network wide activities in the area of innovation and entrepreneurship. The other three Associate Directors of the CO will continue to coordinate activities in Education & Outreach, Societal and Ethical Implications, and Computation across the network.

In Year 7, the CO will continue to support Subcommittees and Working Groups, the NNCI website, the NNCI Annual Conference, as well as the new Research Communities, which are a new network-wide effort for Years 6-10. In prioritizing its programs in view of the limited resources, the CO considers recommendations from the NSF, the NNCI Advisory Board, the NNCI Executive Committee, as well as the NNCI Subcommittees, Working Groups and Research Communities. The CO appreciates the strong support from all sites in making the network more than the sum of its parts and counts on continued site support for Year 7.

A number of specific activities planned for Year 7 are highlighted below:

- *Associate Director for Innovation and Entrepreneurship:* In Year 7, the Associate Director for Innovation and Entrepreneurship (I&E) will continue to work with the I&E working group to roll out and expand on network-wide I&E activities. An example is the NNCI Nanotechnology Entrepreneurship Challenge (NTEC), which is being launched in Spring 2022.
- *NNCI Website*: The CO will continue to add new and revise existing content to the nnci.net webpage. Such content includes new pages for the Innovation Ecosystem.
- *NNCI Annual Conference:* The 7th NNCI Annual Conference will be hosted by CNF and held at Cornell University in Ithaca, NY, October 19-21, 2022. The current plan is that this year's conference will be a hybrid event with in-person events for those who can travel accompanied by live streaming for those who cannot. We will adjust our plans based on how the pandemic evolves during the year and specific national and local conditions.
- *REU Convocation*: The Year 7 REU Convocation will be hosted by KY Multiscale and held at University of Louisville in Louisville, KY, August 8-10, 2022. The current plan is that this year's convocation will be an in-person event. We will adjust our plans based on how the pandemic evolves during the year and specific national and local conditions.
- *Research Communities*: The CO will continue to support the current five Research Communities: "Transform Quantum", "Understanding the Rules of Life", "Growing Convergence Research", "Nano Earth Systems" and "Nano for IoT". These research communities are described more fully in Section 9.2. Based on discussion at the Year 6 NNCI Conference, the CO will explore starting a 6th Research Committee on "Semiconductors" to support the federal emphasis on microelectronics and semiconductors as part of the Creating Helpful Incentives for Semiconductors (CHIPS) for America Act.
- *Staff Exchange Program*: Originally proposed by the Global & Regional Interactions Subcommittee, the CO will revisit the idea of a staff exchange program in Year 7 after staff exchanges were not possible in Years 5 and 6 because of the pandemic-related travel restrictions. Funds to support this program have been included in the CO renewal budget.
- *NNCI Staff Awards:* The CO plans to continue the successful NNCI-wide staff awards program started in Year 3 to promote staff and recognize excellence in areas of user support, technical activity, and education and outreach.
- *Workshops*: The CO will continue incentivizing sites to collaborate via symposia and workshops. A budget has been established to financially support workshops that involve and benefit multiple NNCI sites (see also Subcommittees and Working Groups).
- *User Survey:* The CO will administer this survey again in summer 2022.

- *Data Collection and Reporting:* The CO will continue to collect statistical data on network usage and report these data to the NSF as part of the annual reporting. In Year 7, the collection of data on funding sources supporting research done at NNCI will be repeated, as well as the collection of information on degrees awarded to NNCI users (started in Year 6).
- *NNCI Impact:* The CO will continue to work with the Metrics and Assessment Subcommittee to define NNCI societal and economic impact metrics, collect those metrics and disseminate them as appropriate. The goal is to better showcase, using quantitative and qualitative data, the societal and economic impact of the NNCI and, thus, complement the data collected on the scientific and scholarly impact of the network.
- *NNCI National and International Connections:* As a focus effort for Years 6-10, the CO will work with NNCI sites and the Global and Regional Interactions Subcommittee to connect with other nationally-funded as well as international "nano" networks and facilities supported by government, the private sector, and international partners. The goal is to promote capabilities, improve user support, share best practices and develop strategies for future infrastructure programs.
- *Prioritization of NNCI CO Funds:* With more and more requests for financial support from the CO, the CO will review how it spends its annual budget and, together with the Executive Committee, prioritize its resources to impact the programs that help the network be more than the sum of its parts.