

The Research Triangle Nanotechnology Network

Convergence Nanotechnology Hub



Executive Committee: Jacob Jones (NC State), Nan Jokerst (Duke), Jim Cahoon (UNC), David Berube (NC State), Mark Walters (Duke), Phil Barletta (NC State), Bob Geil (UNC), Maude Cuchiara (NC State)



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**NSF Big Idea:
Convergence**

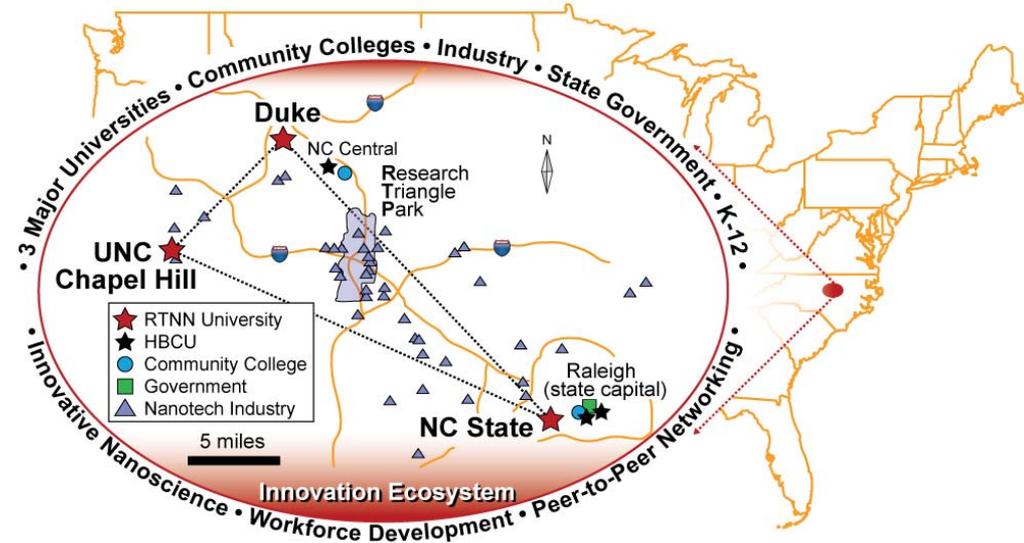
Anchored by 3 Research-1 Universities, 2 Community Colleges, and 3 HBCUs



RTP cities rank in the top 10 in concentration of STEM professionals

Significant number of high-tech, nano-tech and start-up companies

Research Triangle Park (RTP) is the largest and the most prominent research park in the U.S., currently hosting **250 companies** and institutes with **~50,000 employees**



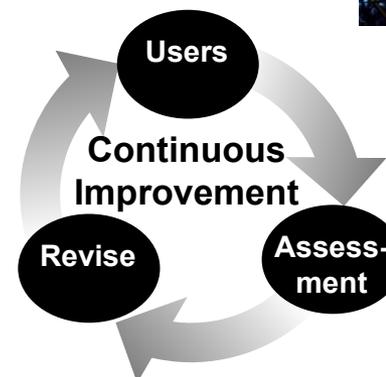
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NSF Big Idea:
Convergence

Distinguishing RTNN Goals

- 1. Facilitate convergence using infrastructure:** Enhance cross-disciplinary access to university nanotechnology tools, create “bump-in” collisions, and grow interdisciplinary research
- 2. Innovate programs:** Develop new nanotechnology tools, spaces, education, outreach, and workforce training programs to lower barriers of entry, e.g. cost, distance, and awareness
- 3. Deeply assess socio-technical integration:** Evaluate user experiences and programs to enhance the future of work at the human-technology frontier



RTNN: New Facilities, Tools, and Personnel

*>230 characterization and fabrication tools across >40,000 ft.² of space,
>45 new/upgraded tools (>\$12.6M value) since RTNN start*

Highlight:

PE-ALD and E-beam evaporation tools with unique functionalities

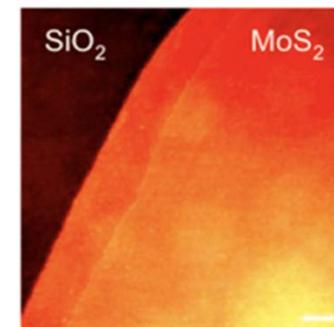
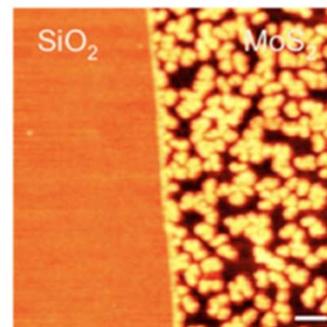
Tools linked through ultra-high vacuum loadlock

Allows research on new class of heterogeneously integrated thin films



ALD

PE-ALD

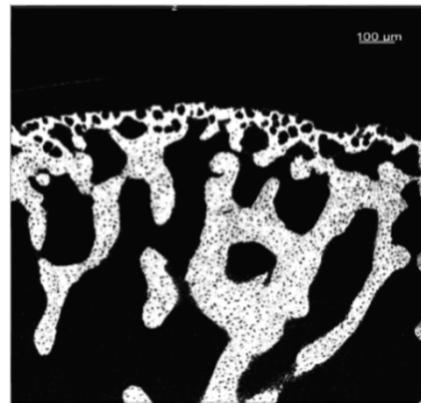
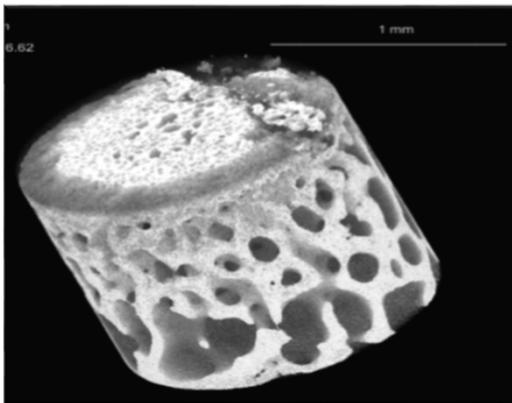


Atomic force microscopy images of 10 nm Al₂O₃ ALD growth onto two-dimensional MoS₂

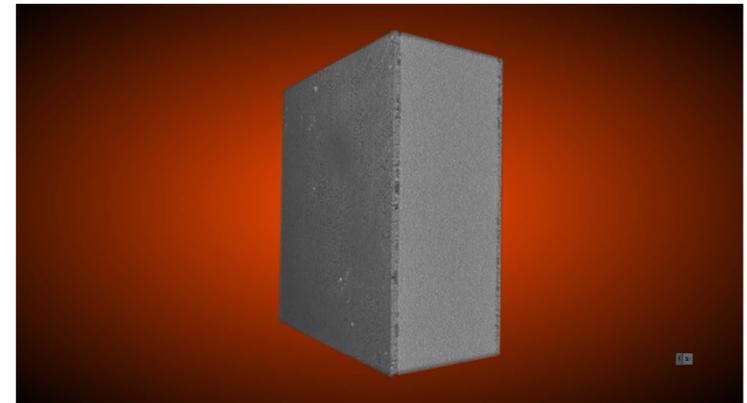
RTNN: New Facilities, Tools, and Personnel

Highlight: Zeiss Xradia 510 Versa X-ray Nano-microscope (nano-CT) System

MRI award (Aug. 2018) led by Prof. Jacques Cole (NC State-UNC Chapel Hill, Joint Dept. of Biomedical Engineering)



Examination of microstructural defects in cortical bone due to brachial plexus birth injury



SiC Wafer exposed to extreme temperature, pressure, and moisture

RTNN: New Facilities, Tools, and Personnel

60+ technical staff members

100+ faculty working in related nanotechnology areas

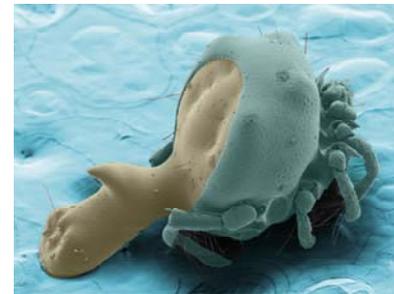
New site staff and facility leadership

Shadow Huang, Associate Director of the Analytical Instrumentation Facility, Associate Professor of Mechanical and Aerospace Engineering



Aaron Bell, Bio Electron Microscopy Staff Scientist

New personnel support strategic growth in one of our four technical focus areas, ***Nanomaterials for Biology and Environmental Assessment***



SEM Image of a Water Mite



Leica Freeze Fracture System

RTNN: Research Highlight: *Nanoplumbing of DNA with 2D Materials*

NSF Big Idea:
Rules of Life

Known: **DNA can be manipulated in nanofluidic channels** for, e.g., genetic mapping applications and interrogation of DNA-protein interactions

Contribution: Nanofluidic devices were designed with a **distributed network of channel junctions**, fabricated using e-beam and optical lithography, to enable the **fundamental study of dynamics of DNA transport and manipulation in confined nanochannels**

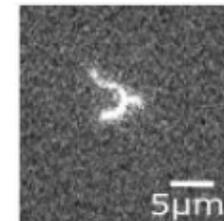
Impact: Work enabled the development of a universal, **dynamic model for DNA behavior** in confined nanofluidic channels

Dangi, S. and Riehn, R. Small, 15 (2019).

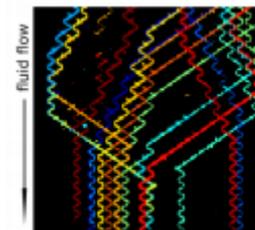
**Work performed at RTNN and SENIC*



A junction of two nanochannels induces folded configurations of DNA molecule



A fluorescence micrograph of a DNA molecule at a nanochannel junction



Overlaid collection of multiple DNA molecules' transport through large-area device

RTNN: Research Highlight: *Nanocells for Targeted Heart Repair*

NSF Big Idea:
Rules of Life

Known: Limitations of stem cells in cardiovascular therapy include poor cell retention and targeting ability

Contribution: **Platelet-inspired Nanocells (PINCs)** with **therapeutic core** (cardiac stromal cell-secreted factors encapsulated in poly(lactic-co-glycolic acid) with **shell** (platelet membrane decorated with prostaglandin E2 (PGE₂) to target damaged tissue)

Impact: In experiments on live mice, PINC therapy restored heart's pumping function better than the control

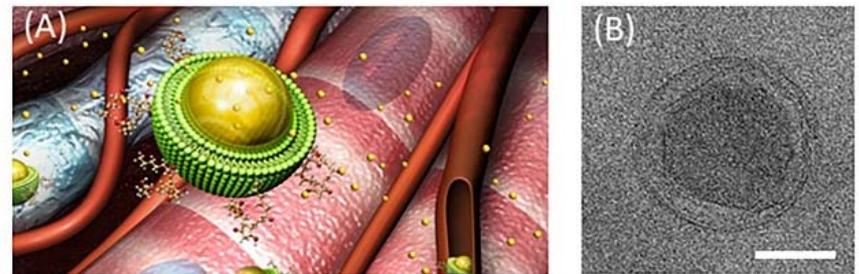
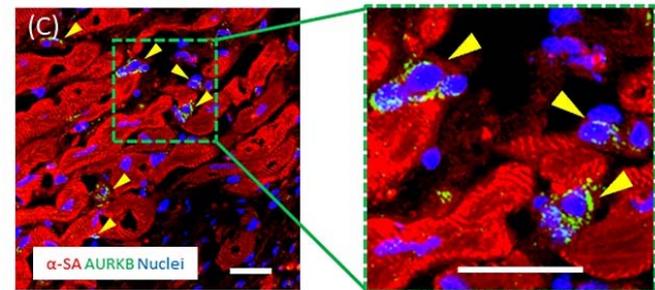


Illustration (A) and transmission electron micrograph (B) showing PINC structure. *Scale bar: 100 nm*



Fluorescent micrographs of cardiac muscle cells stained for cytokinesis marker (AURKB) in damaged regions of PINC-recipient mouse hearts. *Scale bar: 20 μm*

Su, T. et al. *Adv. Funct. Mater.*, 29, (2019).

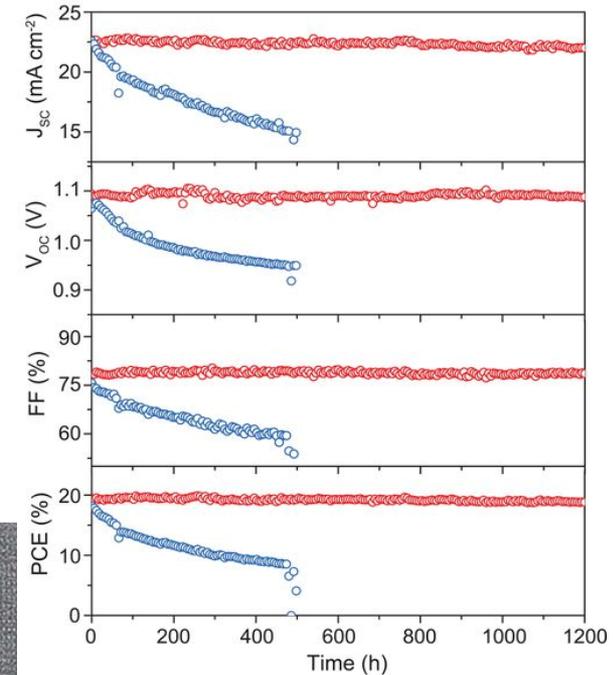
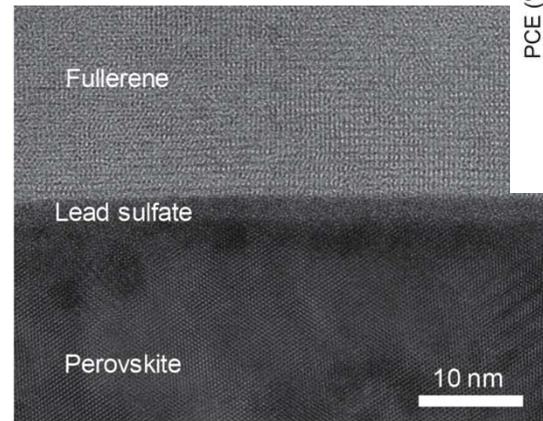
RTNN: Research Highlight: *Stabilizing Perovskite Surfaces of Solar Cells*

NSF Big Idea:
Quantum Leap

Known: Perovskite solar cells **face long-term instability issues** under operating conditions

Contribution: Surfaces of lead halide perovskite were passivated with **water-insoluble lead (II) oxysalts**, e.g. PbSO_4 , to passivate surface and bulk material

Impact: Enhanced water resistance and reduced defect density; Boosted and maintained efficiency of solar cells to $\sim 21\%$



Stability test of encapsulated solar cell devices based on **control** and **sulfate-treated** perovskite active layers

Cross-section HR-TEM image of perovskite device

Yang, S. et al. *Science*. 365, (2019).

RTNN: Research Highlight: *Nanoflake Inks for Flexible Electronics*

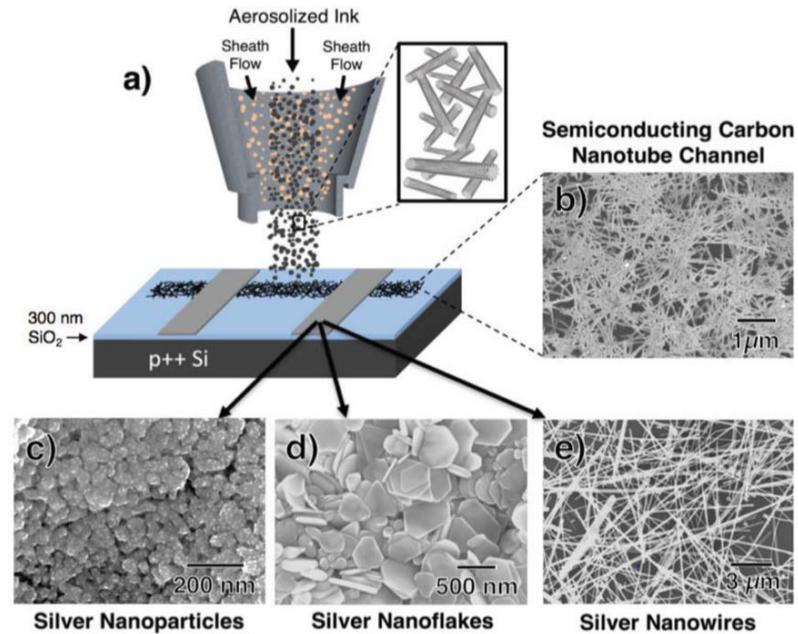
NSF Big Idea: Future of Work at the Human-Technology Frontier

Known: Silver nanoparticles are a widely used **conductive material in printed electronics**, but interfaces with CNTs in thin film transistors are suboptimal

Contribution: **three distinct silver morphologies** were compared including nanoparticles, nanoflakes, and nanowires

Impact: **Nanoflake inks** yielded best electrical performance, but with tradeoffs of print resolution and process temperature

Cardenas, J. et al. *Adv Funct Mater.* 1805727 (2019)



Many RTNN researchers utilize RTNN facilities for their work at the **Human-Technology Interface**.



NC State's ERC, ASSIST, focuses on the design of self-powered, wearable devices for health monitoring

RTNN: Education and Outreach Highlight: *Girls STEM Day at Duke*

NSF Big Idea:
NSF INCLUDES

Girls participate and earn Girl Scout badges through hands-on STEM activities in topics of DNA, robotics/AI, and chemistry of cosmetics
Includes parent-focused activities (e.g. financial sessions) for supporting girls' trajectory in the STEM pipeline

Two years running (2018-2019)

>140 girls and their families participated (2019)

Collaboration between many partners with volunteers from STEM professions (43 companies/institutions represented)

Assessment

98% were satisfied or very satisfied with their experience

81% felt the event had a great or a lot of impact on them

85% were extremely or very likely to attend next year

All 2019 E&O Events

**Participants: >3,500 in-person,
>5,000 on-line**

60% of on-site participants were women and under-represented minorities in STEM



RTNN: Education and Outreach Highlight: *Community college educator workshop*

NSF Big Idea:
NSF INCLUDES

Hands-on nanotechnology experiences and teaching materials for community college educators

Held annually (2016-2019)

Educators ran several processes in the clean room to fabricate blue LEDs (InGaN/GaN quantum well structures) using lithography, e-beam evaporation, and etching.

Resulted in integration of nanotechnology tools into *Intro to Engineering* and other courses at Durham Tech

Catalyzed a successful Collaborative RET Site Award: Atomic Scale Design & Engineering

Initial 5 week program Summer 2019

11 participants annually



"This is the best workshop I have attended. I have heard about clean rooms but having live experience is awesome"

RTNN: Education and Outreach Highlight: *Nanotechnology: A Maker's Course*

NSF Big Idea:
NSF INCLUDES

Massive Open Online Course on Coursera platform,
providing education in nanofabrication and nano-
characterization

Lectures and in-lab demonstrations of equipment
in RTNN labs by RTNN faculty and staff from
diverse backgrounds

Launched September 2017

coursera



> 13,500 enrolled & utilized some aspect of the course

> 1,700 completed all course components

> 64,500 visitors

High satisfaction, e.g. course materials rated 6.4 on a scale
with 7 being the highest

> 90% of respondents “likely” or “very likely” to recommend
course

*“I hope I can be a
scientist like her.”*

*“Gracias...me divertí
mucho en este curso
y definitivamente con
mas ganas de seguir
aprendiendo.”*

RTNN: SEI Goals & Highlights

Goals: Leverage the RTNN team and user base to:

- 1) enhance the instruction and understanding of how humans engage with nanotechnology (future of work at the human-technology frontier), and
- 2) study governance involving multiple stakeholder groups

Representative Outcomes:

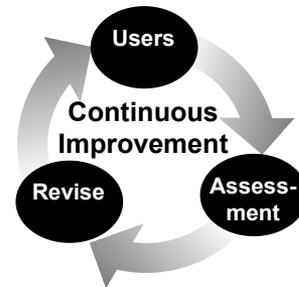
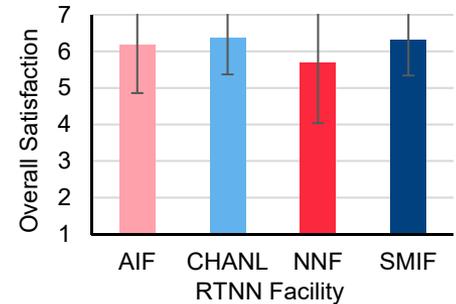
Deep assessment of users and programs (IRB-approved)

Regular surveys of users and many programs (N=1451)

Structured interviews of users; content analysis

Data informed decisions on resources and staff changes

New social media programs to study how social networks influence nanotechnologists' decision making



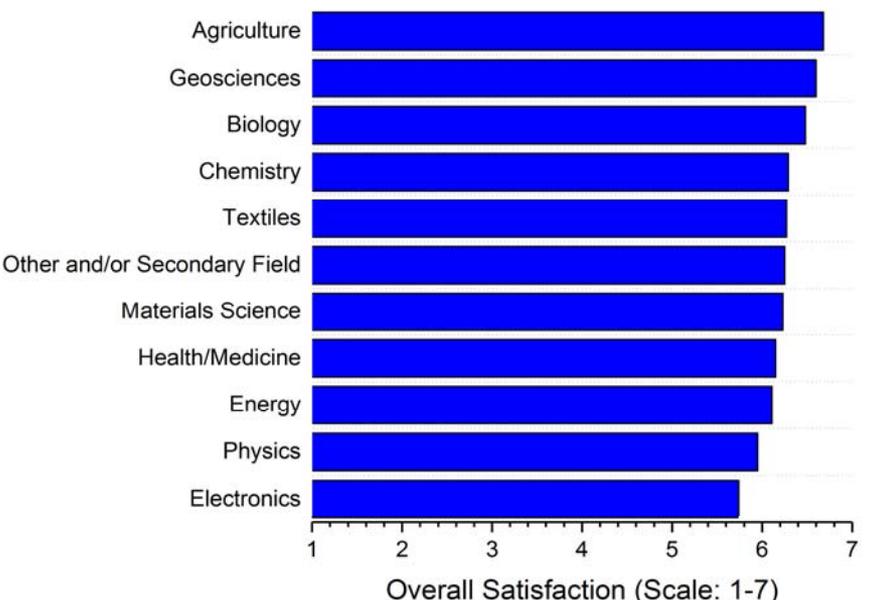
RTNN: SEI Goals & Highlights

Goals: Leverage the RTNN team and user base to:

1) enhance the instruction and understanding of how humans engage with nanotechnology (future of work at the human-technology frontier)

Example Data:

Overall satisfaction example, Years 1-4
All RTNN Facilities



Research Questions:

How do individuals from different backgrounds, experiences, disciplines, and demographics experience our facility differently?

How do we make laboratories **more usable and increase satisfaction?**

Research in socio-technological integration will influence staffing, leadership, process, and tool acquisition decisions

Charge: 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

Committee members: 8 individuals from 8 different sites who care passionately about this topic

Major 2019 activities:

1. ***Assessment of diversity*** of site leadership, site staff, institutional characteristics of NNCI sites and universities, and site user institutional characteristics (disseminated to sites in June 2019)
2. ***Staff diversity climate survey*** (disseminated to sites in August 2019)

Diversity Assessment Highlights:

NNCI users from 241 external academic institutions: 36 HBCUs or MSIs and 16 Emerging HSIs

Seven recommendations were provided to site directors

Staff Diversity Climate Survey Highlights:

Survey designed with input from multiple sources including IRB, Site Directors, Coordinating Office, LGBT centers, etc.

262 responses with participation by all sites

Site-specific data sent to each site director

Recommendations included **discussing best practices** with site staff, **ensuring harassment-free workplaces**, and mechanisms for **non-escalating reporting**



RTNN: Infrastructure with Impact (Highlights)

Patents (2018 data)

12 awarded, 39 filed, 40 invention disclosures

238 peer-reviewed publications (2018 data)

200 internal, 38 external

\$83 million in research activity (2018)

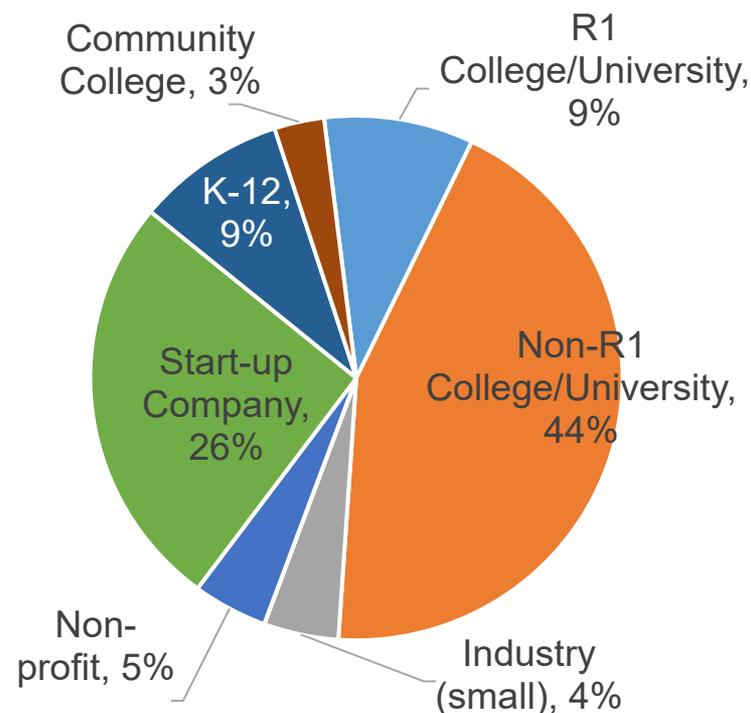
As defined by annual research expenditures for projects that utilized the facilities

Kickstarter Program (free use of facilities)

29% of participants from start-up companies

>40% of participants have returned to facilities with own financial support (>\$80,000 in facility fees)

Affiliations of Kickstarter Program Participants (66 total)



RTNN: Infrastructure with Impact (Highlights)

RTNN facilities provide a valuable service to start-ups and small companies

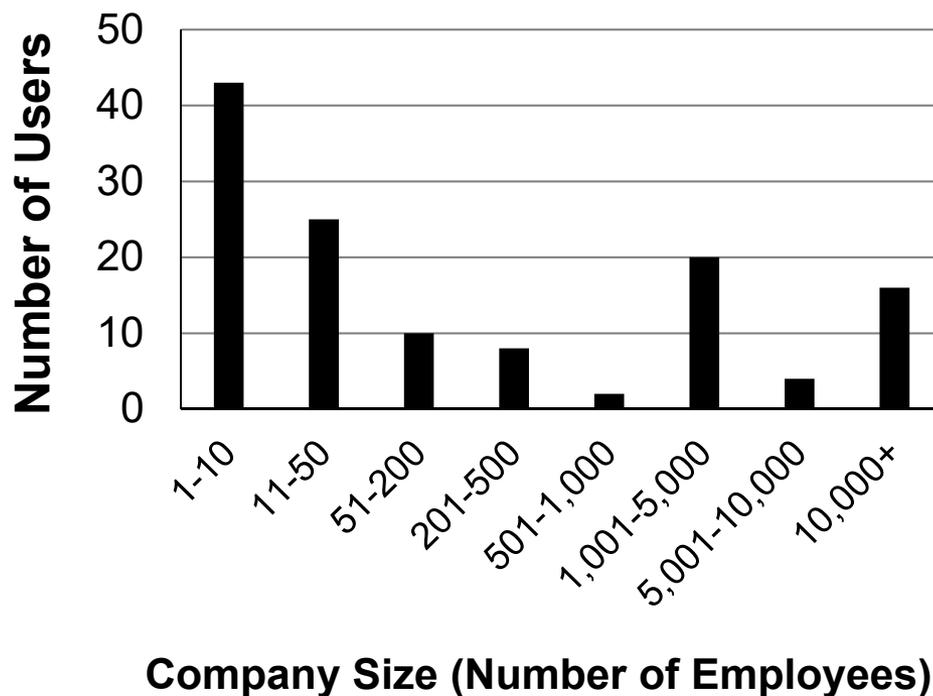
128 users from 98 companies

88 users from 64 small companies

40 users from 34 large companies

54% of industry users from companies with less than 50 employees

RTNN Industry Users

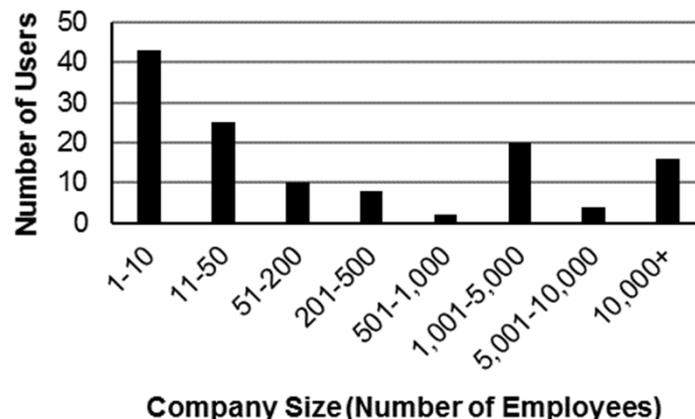


Panel Discussion: Measuring the Impact of the NNCI

Geographic impact: Co-authors of papers that cite the RTNN NSF award, evidencing intellectual impact (method: sort co-author addresses by state)



Economic impact: Annual patents awarded (RTNN: 12), patents filed (RTNN: 39), invention disclosures (RTNN: 40), industry users by company size (# employees)



Workforce development: Graduate degrees earned for research enabled by facilities (RTNN: 79), ideally by race, ethnic, and gender demographics (method: compare user lists to published commencement booklets, graduate dissertations, and graduate school lists)

RTNN Representation at the NNCI meeting



Jacob Jones
RTNN Director
Director of AIF
Professor of MSE
NC State University



Nan Jokerst
Executive Director
of SMIF
Professor of ECE
Duke University



David Berube
Professor of
Communication
NC State University



Jim Cahoon
Professor of Chemistry
Executive Director of
CHANL
UNC-Chapel Hill



Maude Cuchiara
RTNN Assoc. Director
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Holly Leddy
R&D and Outreach
Engineer
Duke University



Nicole Hedges
Business and
Education Manager
NC State University



Joe Magno
EAB Member
Advisor