Progress and Plans of National Nanotechnology Initiative (NNI) Agencies

January 2020

National Science Foundation (NSF)[1]

Summary

The National Science Foundation supports fundamental nanoscale science and engineering in and across all disciplines. NSF's nanotechnology research is supported primarily through grants to individuals, teams, and centers at U.S. academic institutions. The efforts in team and center projects have been particularly fruitful because nanoscale research and education are inherently interdisciplinary and increasingly translational pursuits, often combining elements of materials science, engineering, chemistry, physics, and biology.

The NSF nanotechnology investment in fiscal year (FY) 2019 supported about 5,500 active projects, over 30 research centers, and several infrastructure networks for device development, computation, and education. This investment impacted over 10,000 students and teachers. Approximately 150 small businesses were funded to perform research and product development in nanotechnology through the Small Business Innovation Research (SBIR) and Small Business Technology Transfer Research (STTR) programs. NSF sponsors an annual nanoscale science and engineering (NSE) grantee conference to assess progress in nanoscience and nanotechnology and facilitate identification of new research directions.

Several new directions planned for FY 2020 are nanotechnology using artificial intelligence for smart materials and systems, quantum systems, the human-technology frontier, nanoplastics, and sustainability in the urban environment. NSF's nanotechnology investments continue to include research on highly energy-efficient systems and intelligent cognitive assistants; nanobiomanufacturing and nanobiomedicine, including cell technology; chromatin and epigenetic engineering and its nanoscale environment; semiconductor synthetic biology for information processing and storage technologies; food-energy-water processes such as nanostructured membranes and point-of-use nanofiltration; nanomodular materials and systems by design, including hierarchical three-dimensional nanoscale materials; advanced communication quantum information research in engineering; and emerging aspects of nanoelectronics, photonics, and neuroscience. NSF has sponsored the "Generation NANO—Communication Competition" for high-school students,[2] and "Quantum Matters—Communication Competition" for undergraduate and graduate students, both nationwide, with the participation of the Boston Museum of Science.[3]

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[2] https://www.nsf.gov/news/special_reports/gennano/

[3] https://www.mos.org/quantum-matters-competition

In FY 2021, NSF support will increase focus on convergence research and education activities in confluence with other priority areas such as: the Networking and Information Technology Research and Development (NITRD) program; the National Quantum Initiative (NQI); the artificial intelligence (AI) focus area; the Designing Materials to Revolutionize and Engineer our Future (DMREF) program; the Materials Genome Initiative (MGI); smart systems; quantum information science and engineering; and synthetic biology. Partnerships of the Nanosystems Engineering Research Centers (NERCs) with industry and small businesses in the areas of nanomanufacturing and commercialization will be strengthened while maintaining about the same level of NSF investment. An industrial internship program ("INTERN") in emerging technologies, including nanotechnology, will be expanded. NSF continues its contributions to translational innovation programs, including Grant Opportunities for Academic Liaison with Industry (GOALI); Industry/University Cooperative Research Centers (I/UCRCs); the NSF Innovation Corps (I-Corps™) program; and the Partnerships for Innovation (PFI) program, including the Technology Translation (PFI-TT) and Research Partnerships (PFI-RP) tracks. The NSF SBIR program has an ongoing nanotechnology topic. Nanotechnology research will contribute to and synergize in the future with eight of NSF's Big Ideas,[4] and particularly with: Quantum Leap, Understanding the Rules of Life, Future of Work at the Human-Technology Frontier, Harnessing the Data Revolution, and Growing Convergence Research. NSF will continue support for the National Nanotechnology Coordinated Infrastructure (NNCI) of user facility sites in nanotechnology, and for the Network for Computational Nanotechnology (NCN) and its Engineered nanoBIO and Hierarchical NanoMFG nodes, which provide computation, simulation, and education services to researchers, educators, students, and industry members of the nanoscience and engineering community worldwide. The Nanoscale Interactions program within the Engineering Directorate provides support for biological and environmental research. The program will provide supplementary support for U.S.-South Africa collaboration in research on environmentally sustainable nanotechnology.

The FY 2021 budget reflects that NSF has mainstreamed nanotechnology-related research, education, and infrastructure in core programs in several directorates.

Plans and Priorities by Program Component Area (PCA)

PCA 1. Nanotechnology Signature Initiatives and Grand Challenges

The first PCA encompasses the five Nanotechnology Signature Initiatives and a Grand Challenge. The Nanotechnology Knowledge Infrastructure NSI was completed in FY 2019. The Water Sustainability through Nanotechnology NSI began in FY 2016 and will continue in FY 2020 and 2021. The Nanotechnology-Inspired Grand Challenge for Future Computing began in FY 2017 and continues through 2020.

Special emphasis will be on the following:

- *Sustainable Nanomanufacturing.* Establishing manufacturing technologies for economical and sustainable integration of nanoscale building blocks into complex, large-scale systems by supporting product, tool, and process design informed by and adhering to the overall constraints of safety, sustainability, and scalability. This signature initiative specifically focuses on high-performance structural carbon-based nanomaterials, cellulosic nanomaterials, nanobiomanufacturing, and nanomodular systems. A Dear Colleague Letter, Supporting Fundamental Research to Enable Innovation in Advanced Manufacturing at Manufacturing USA Institutes,[5] was issued in 2017 and

[4] https://www.nsf.gov/about/congress/reports/nsf_big_ideas.pdf

[5] https://www.nsf.gov/pubs/2017/nsf17088/nsf17088.jsp

continues in 2021. It solicits proposals addressing critical fundamental research needs in advanced manufacturing, including nanomanufacturing and manufacturing across length scales, particularly projects that may enable innovations in the technical focus areas of one or more of the Manufacturing USA institutes. Such proposals leverage the facilities, infrastructure, and expertise of one or more institutes and member companies. Engineering biology at the nanoscale for advanced manufacturing activities in the Biological Sciences (BIO), Engineering (ENG), and Mathematical and Physical Sciences (MPS) directorates are being organized for 2020. Methods for nanomanufacturing design are in synergy with the Materials Genome Initiative. The Hierarchical Nanomanufacturing (NanoMFG) node of the NCN (nanoHUB) was launched in 2017 with a lifetime of five years, with a focus on modeling and simulation of manufacturing processes. Exploratory research directions are manufacturing of nanomachines and nanobiostructures, cellular nanobiomanufacturing, atomically precise manufacturing, and nanomanufacturing for quantum devices and sensors. The Advanced Manufacturing (AM) program, issued in 2018,[6] includes support for nanoscale fundamental research to enable innovation in advanced manufacturing at universities exclusively or in collaboration with industry (GOALI). The AM program encourages cross-disciplinary research.[7]

- *Nanoelectronics for 2020 and Beyond.* This initiative is aimed at discovering and using novel nanoscale fabrication processes and innovative concepts to produce revolutionary materials, devices, systems, and architectures to advance the field of electronics beyond Moore's Law. NSF plans ongoing collaboration with other agencies and industry in activities such as the Semiconductor Synthetic Biology for Information Processing and Storage Technologies (SemiSynBio) program, with awards continuing in 2021, and with a focus on Energy-Efficient Computing from Devices to Architectures (E2CDA). Real Time Machine Learning (RTML), a three-year program of NSF’s Computer and Information Science and Engineering (CISE) and ENG directorates,[8] started in FY 2019 in collaboration with the Defense Advanced Research Projects Agency ($10 million from each agency), and has a focus on chip design AI. NSF will increase coordinated research on its Quantum Leap and Future of Work at the Human-Technology Frontier “Big Ideas” priority areas.
- *Nanotechnology for Sensors and Sensors for Nanotechnology.* This NSI involves use of nanotechnology and nanoscale materials to build more sensitive, specific, and adaptable sensors, and the development of new sensors to detect engineered nanomaterials across their life cycles to assess their potential impacts. The initiative supports materials and technologies that enable novel sensing mechanisms for biological, chemical, and nanoscale materials, including sensors for nanotechnology-related environmental, health, and safety research. A dedicated program on nanobiosensing and biophotonics in ENG's Division of Chemical, Bioengineering, Environmental, and Transport Systems (CBET) will support this effort.
- *Water Sustainability through Nanotechnology.* The Water NSI takes advantage of the unique properties of engineered nanomaterials and systems to increase water availability; improve the efficiency of water delivery; and enable next-generation water monitoring systems. The NSF Innovations at the Nexus of Food, Energy and Water Systems initiative supports projects in nanotechnology. Besides core

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[6] https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505572

[7] as described in https://www.nsf.gov/pubs/2018/nsf18091/nsf18091.jsp

[8] https://www.nsf.gov/pubs/2019/nsf19566/nsf19566.htm

nanoscience-related programs on water filtration and applications, the NERC for Nanotechnology Enabled Water Treatment Systems (NEWT), led by Rice University and funded between 2015 and 2024, aims at developing high-performance water treatment systems that will broaden access to clean drinking water from a variety of unconventional sources (briny well water, seawater, wastewater), and enable industrial wastewater reuse at remote locations such as oil and gas fields.

- *Nanotechnology-Inspired Grand Challenge for Future Computing.* Planned research in support of this NNI Grand Challenge includes "Brain-like Computing" and "Intelligent Cognitive Assistants" (ICAs).[9] Two examples of active centers are the Science and Technology Center (STC) on Quantum Materials and Devices at Harvard University and the Materials Research Science and Engineering Center (MRSEC) on Quantum and Spin Phenomena in Nanomagnetic Structures at the University of Nebraska, Lincoln. Further collaboration is planned with industry groups developing hardware (with a focus on a "beyond Moore" system architecture and corresponding devices), software (with a focus on artificial intelligence), and implementation in various applications. The research will be conducted in collaboration with other agencies (e.g., National Institutes of Health, Defense Advanced Research Projects Agency).

PCA 2. Foundational Research (including ELSI)

The NSF FY 2021 Budget includes funding for the discovery and development of fundamental knowledge pertaining to new phenomena in the physical, biological, and engineering sciences that occur at the nanoscale. Also included is funding for research aiming to understand scientific and engineering principles related to nanoscale systems, structures, processes, and mechanisms; research on the discovery and synthesis of novel nanoscale and nanostructured materials including biomaterials and modular structures; and research directed at identifying and quantifying the broad implications of nanotechnology for society, including social, economic, ethical, and legal implications. About 60 percent of the MRSECs pursue NSE-related fundamental research.

PCA 3. Nanotechnology-Enabled Applications, Devices, and Systems

The FY 2021 Request is for research that applies the principles of nanoscale science and engineering to create novel devices and systems, or to improve existing ones. This includes the incorporation of nanoscale or nanostructured materials and the processes required to achieve improved performance or new functionality, including metrology, scale up, manufacturing technology, and nanoscale reference materials and standards. Core programs in the ENG, MPS, and CISE directorates support development of new principles, design methods, and constructive solutions for nanodevices. A special focus is on smart, autonomous nanoscale-based devices and systems.

PCA 4. Research Infrastructure and Instrumentation

The FY 2021 Request is for the establishment and operation of user facilities and networks; acquisition of major instrumentation; workforce development; and other activities that develop, support, or enhance the Nation's physical or human infrastructure for nanoscale science, engineering, and technology. This PCA includes research pertaining to the tools needed to advance nanotechnology research and commercialization, including next-generation instrumentation for characterization, measurement, synthesis, and design of materials, structures, devices, and systems. While student support to perform research is captured in other categories, dedicated educational and workforce efforts, ranging from

[9] https://www.nsf.gov/crssprgm/nano/reports/ICA2_Workshop_Report_2018.pdf

curriculum development to advanced training, are included here as resources supporting the human infrastructure of the NNI. NSF has funded an award of about $16 million per year for the NNCI sites for FY 2015–2024. An NNCI national coordination office was added in FY 2016. A five-year renewal of NNCI is planned for FY 2020. Other STCs, MRSECs, Engineering Research Centers (ERCs), and Centers for Chemical Innovation (CCIs) have a focus on supporting the NNI, including the Center for Cellular Construction at the University of California-San Francisco (annual award since 2016 of approximately $5 million), two NERCs, one each on nanobiotechnology and cell technology, and a CCI at the University of Wisconsin (annual award of $4 million per year) that investigates the fundamental molecular mechanisms by which nanoparticles interact with biological systems. NSF continues to sponsor nanotechnology education and related activities, such as student competitions, through the ENG and MPS directorates and NSF's Office of Legislative and Public Affairs, in cooperation with the National Nanotechnology Coordination Office.[10] NSF will increase coordinated research on its Mid-scale Research Infrastructure priority area.

PCA 5. Environment, Health, and Safety

In FY 2021, NSF will continue its funding for the Environment, Health, and Safety (EHS) PCA. Requests for research are primarily directed at understanding nano-bio phenomena and processes, as well as environmental, health, and safety implications and methods for reducing the risks of nanotechnology development. NSF continues to sponsor the Center for Sustainable Nanotechnology at University of Wisconsin.[11] ENG's Nano EHS program has changed its name to Nanoscale Interactions.[12]

Key Technical Accomplishments by NNI Goal

Goal 1. Advance a World-Class Nanotechnology Research and Development Program

The main contribution of NSF research is to create the foundational science and tools for nanoscience and nanotechnology, with contributions to all disciplines and areas of activity. The main progress is in modeling and simulation using specialized algorithms, artificial intelligence, and manipulation of large sets of data; better understanding of small living systems; creating new structures with motion (nanomachines, nanomotors) and dynamics at the nanoscale; assembling larger nanostructures; two-dimensional materials; and nanoscale neurotechnology, nanophononics, and brain-like cognitive systems. Representative research results achieved in each fiscal year are presented at the annual NSF Nanoscale Science and Engineering Grantees Conference in December.[13] A special area of focus has been on nanostructure assembly in synthetic cells that is a part of the NSF Big Idea, Understanding the Rules of Life, by predicting phenotype and tissue engineering.

Several specific examples are as follows:

- *Plasmonics to enable continuous patterning* (NSF award CMMI 1537440[14]).

Researchers at the University of Michigan have demonstrated a roller-based nanolithography system. Periodic structures of deep-subwavelength pitch were produced by using ordinary UV light but specially

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[10] www.nsf.gov/news/special_reports/gennano/index.jsp

[11] https://susnano.wisc.edu/

[12] https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505553

[13] www.nseresearch.org/2019/ for FY 2019

[14] https://nsf.gov/awardsearch/showAward?AWD_ID=1537440

designed plasmonic masks. High-resolution nanopatterning without resorting to million-dollar instruments open new opportunity for many practical applications (see Figure 1, below).

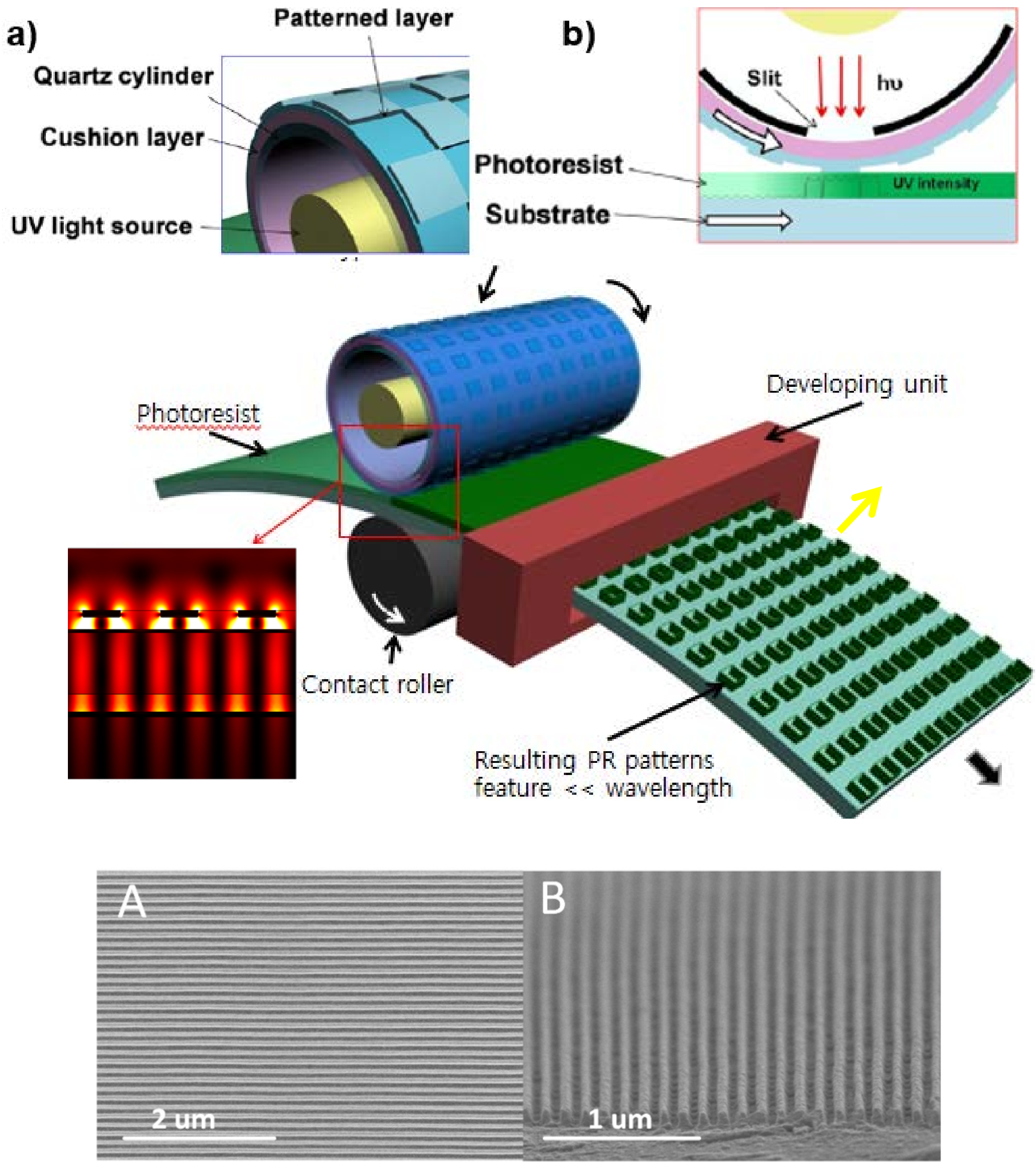

Figure 1. At 405 nm wavelength, the system achieved 61 nm half-pitch (l/7) and 100 nm thick patterns. Image credits: L. Jay Guo, the University of Michigan.

By making a flexible photomask with plasmonic materials in the roller system, deep sub-wavelength uniform patterns with high aspect ratios were printed continuously over a moving substrate coated with photoresist. In this plasmonic roller system using a 405-nm-wavelength light source, large-area periodic patterns with a half-pitch of 61 nm and a height of 100 nm were fabricated in a continuous fashion.

Key outcomes/achievements: This should be the first demonstration of a continuous plasmonic-based lithography system capable of good pattern quality with deep subwavelength features and high aspect ratio.

These experimental results at wavelength of 405 nm demonstrated that the feature size produced via the proposed lithography system can be as small as 1/12 of the period of the photomask, which is ~1/7 of the light wavelength, with thickness of 100 nm, and 1:2 aspect ratio. It also shows that the principle can be applied to 193 nm and produce 22 nm half pitch periodic structures without using double patterning or resorting to EUV lithography.

Comparison: Almost all previously reported plasmonic lithography results suffer from critical issues such as shallow pattern depth, and pattern non-uniformity even over small exposure areas, which limit the application of the technology.

- *Rational Design and Optimization of Nanostructures for Therapeutic Drug Delivery* (Figure 2; NSF awards CMMI 1350731[15] and CHE 1834750[16]).

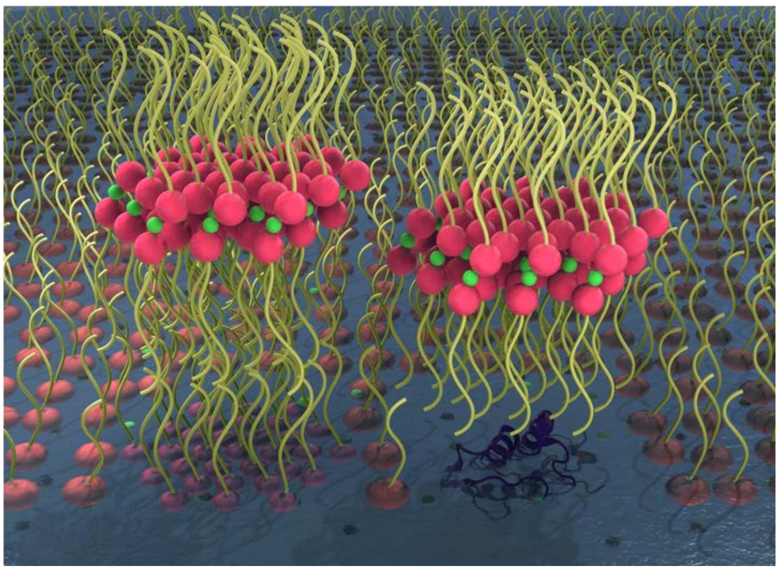

Figure 2. Published in *Soft Matter*, 2019, 15, 4068.[17] Image credit: Ying Liu, University of Illinois at Chicago (copyright Royal Society of Chemistry; re-used by permission).

Outcome: a scalable, continuous process to produce nanoparticles for targeted drug delivery and desired drug-release schedules. Designed molecular self-assembly enabled massive production of the nanoparticles with well-controlled properties. Advanced synchrotron x-ray techniques integrated with custom-made devices were established as a platform for studies of molecular packing, binding, degradation, and self-assembly.

[15] https://nsf.gov/awardsearch/showAward?AWD_ID=1350731

[16] https://nsf.gov/awardsearch/showAward?AWD_ID=1834750

[17] https://pubs.rsc.org/en/content/articlelanding/2019/sm/c8sm01154k

- *A multi-purpose, reprogrammable molecular computer* (Damien Woods et al., Maynooth University, support from NSF award CCF 1219274[18] and others, and from NASA).

The creation of "self-assembly molecular computers" uses molecular hardware in the form of artificial DNA, which sticks together to execute a computation (Figure 3). The research involves developing algorithms to perform programmable functions (like a standard computer) and create tiny objects—all at the nanoscale. Algorithmic self-assembly of DNA molecules carries out a Boolean logic circuit computation. Highlighted in green in the figure is the circuit diagram for sorting bits from the bottom left to the top right; below is an atomic force microscope image of a self-assembled DNA ribbon that carried out the same computation. In the background are other ribbons, with different barcode labels, that carried out different computations. The work was published in *Nature* (2019).[19]

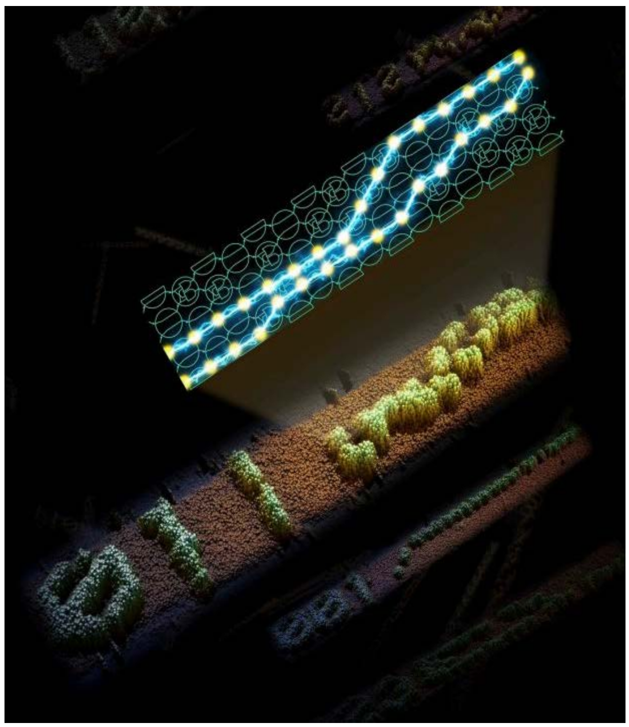

Figure 3. A traditional computer circuit (top) compared with a molecular circuit built using DNA. Image credits: Demin Liu (Molgraphics) and Damien Woods (Maynooth University; copyright Damien Woods).[20]

- *Biosensor technology for stem cell therapies* (NSF award CHE-1429062[21]).

An instrument developed at Rutgers University (Figure 4) may lead to safe stem cell therapies for treating Alzheimer's and Parkinson's diseases and other neurological disorders. To facilitate stem cell therapy-based treatment of neurological disorders, a large-scale homogenous substrate coupled with dual-enhanced Raman scattering was developed for sensitive gene detection and monitoring stem cell neuronal differentiation. This unique sensing platform is composed of a uniform gold-graphene hybrid nanoarray that orthogonally modulates both electromagnetic and chemical enhancement of Raman signals, thereby

[18] https://nsf.gov/awardsearch/showAward?AWD_ID=1219274

[19] https://www.nature.com/articles/s41586-019-1014-9

[20] https://www.irishtimes.com/news/science/monaghan-scientist-involved-in-molecular-computing-breakthrough-1.3832929

[21] https://nsf.gov/awardsearch/showAward?AWD_ID=1429062

improving reliability, selectivity, and sensitivity effectively toward next-generation gene sensing and biomarker detection in clinical stem cell therapeutics.

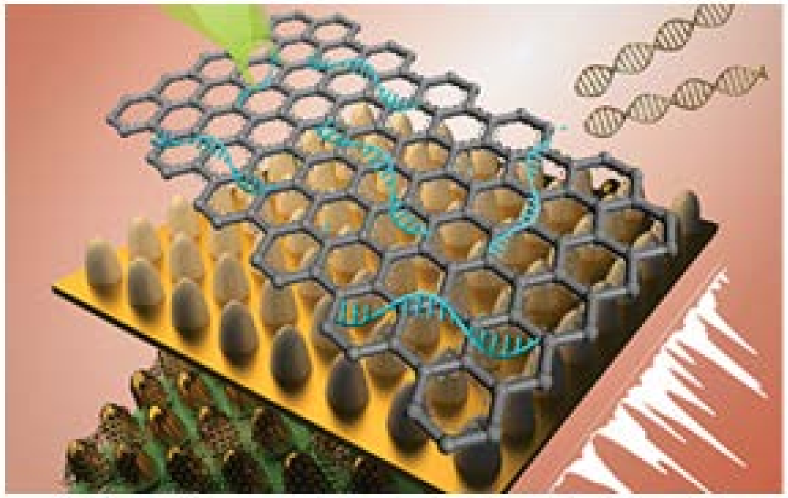

Figure 4. Biosensor technology created for stem cells. Work published in *Nano Letters* (2019).[22] Image credits: Letao Yang, KiBum Lee, Jin-Ho Lee, and Sy-Tsong (Dean) Chueng, Rutgers University.

Goal 2. Foster the Transfer of New Technologies into Products for Commercial and Public Benefit

The transfer of technology is carried out through publication of papers and patents, center activities and outreach, and dedicated programs in the NSF Division of Industrial Innovation and Partnerships, including SBIR and STTR programs. In 2021, the agency will continue its contributions to translational innovation programs, including GOALI, I/UCRC, I-Corps™, PFI, and its Technology Translation (PFI-TT) and Research Partnerships (PFI-RP) tracks. The NSF SBIR program has an ongoing nanotechnology topic with subtopics for nanomaterials, nanomanufacturing, nanoelectronics and active nanostructures, nanotechnology for biological and medical applications, and instrumentation for nanotechnology. NSF has provided strong support for the Nanoelectronics for 2020 and Beyond Nanotechnology Signature Initiative (NSI) through core programs and for the Nanomanufacturing NSI through the Advanced Manufacturing (including Scalable Nanomanufacturing) solicitation.[23] Other NNI-affiliated awards include Nanoscale Science and Engineering Centers (NSECs), the National Nanotechnology Coordinated Infrastructure, the nanotechnology-inspired ERCs (in the Directorate for Engineering), awards mapped into the Advanced Manufacturing program (in the Directorate for Engineering, Division of Civil, Mechanical and Manufacturing Innovation—CMMI), and Mathematical and Physical Sciences Directorate centers investments (MRSECs and CCIs).

Example of SBIR project

- *EUV materials for better integrated circuits* (NSF award IIP 1747341[24]). This project supports the development of new extreme ultraviolet (EUV) materials that are highly reflective at 13.5 nm and can deliver exponentially more light to the wafer (Figure 5), driving up the wafer throughput and rate of

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[22] https://pubs.acs.org/doi/10.1021/acs.nanolett.9b03402
[23] https://www.nsf.gov/pubs/2016/nsf16604/nsf16604.htm
[24] https://nsf.gov/awardsearch/showAward?AWD_ID=1747341

manufacturing of integrated circuits at 7 nm and smaller dimensions. The wafer throughput is increased by an order of magnitude.

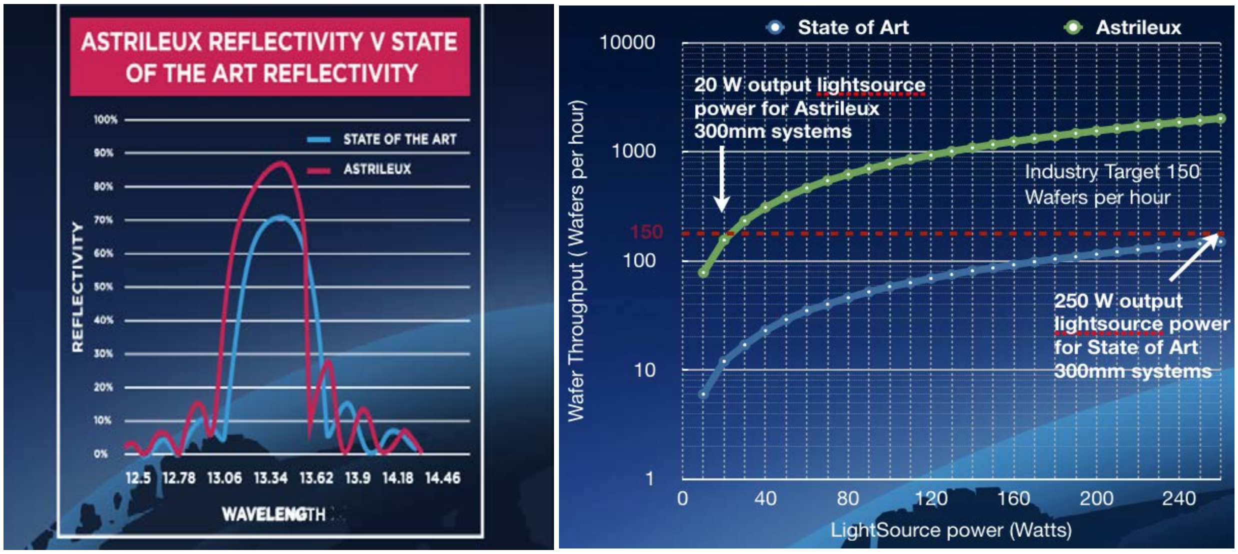

Figure 5. Image credits: Astrileux.

Examples of I-Corps awards

The program involves partnerships including nanotechnology projects with DOE, NIH, and NASA. Information on the NSF ICorps™ Teams program is posted on the NSF website.[25] Nine I-Corps nodes were active in 2019 nationwide:

1. Bay Area Regional I-Corps Node (BA)[26]
2. DC/MD/VA Regional I-Corps Node (DMV)[27]
3. I-Corps South Node (SOUTH)[28]
4. Innovation Node-Los Angeles (IN-LA)[29]
5. Midwest I-Corps Node (MWIN)[30]
6. New England Regional Innovation Node (NE I-Corps)[31]
7. New York City Regional Innovation Node (NYCRIN)[32]

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[25] https://www.nsf.gov/pubs/2018/nsf18515/nsf18515.htm
[26] http://bayicorps.com/
[27] http://www.dcicorps.org/
[28] http://icorpssouth.com/
[29] http://lanode.org/
[30] https://www.midwesticorps.org
[31] http://icorps.mit.edu/
[32] http://www.nycrin.org/

8. Southwest Innovation Corps (SWICORPS)[33]
9. UNY I-Corps Node (UNY)[34]

There were 36 new I-Corps awards related to nanotechnology in FY 2019 ($2,459,990), and 73 active awards ($2,559,986).

Goal 3. Develop and Sustain Educational Resources, a Skilled Workforce, and a Dynamic Infrastructure and Toolset to Advance Nanotechnology

The academic infrastructure supported by NSF is in more than 500 universities. In addition, there are centers for research, education, and technology transfer. Two representative examples are NNCI and NCN:

- *NNCI.* To advance research in nanoscale science, engineering, and technology, NSF has provided a total of $81 million over five years to support 16 sites and a coordinating office as part of the 2015–2019 National Nanotechnology Coordinated Infrastructure.[35] A five-year renewal of NNCI is planned for FY 2020. The NNCI sites 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.

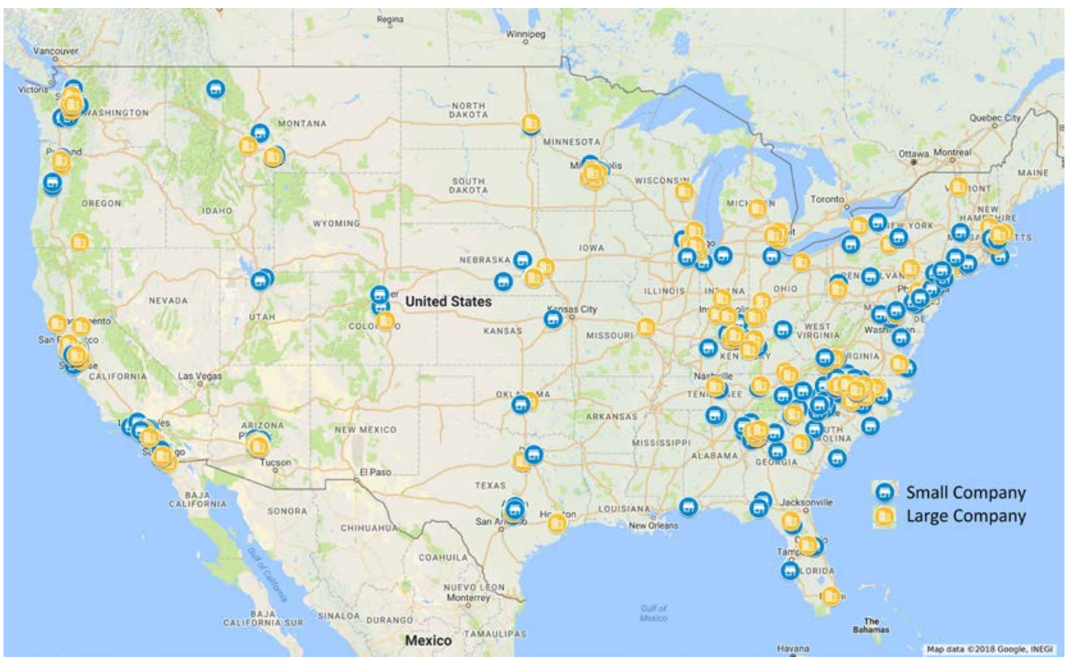

Figure 7. Industry partners of NNCI. Image credit: NNCI.[36]

- *nanoHUB (NCN)*. NCN's mission is to advance nanoscience and nanotechnology modeling, simulation and networking through nanoHUB.org, which has become a successful scientific end-to-end cloud

[33] https://www.swicorps.org/

[34] http://unyicorps.org/

[35] https://www.nnci.net/

[36] https://www.nnci.net/sites/default/files/inline-files/NNCI%20CO%20Annual%20Report%202019%20Web_0.pdf (p. 86)

computing environment, hosting over 3,000 resources for research, collaboration, teaching, learning, and publishing. NCN serves more than 1.6 million users annually,[37] in multiple domain networks.[38]

- *Nanotechnology Knowledge Infrastructure.* This signature initiative has been completed (FY 2012–FY 2019) and was aimed at activities surrounding the fundamental, interconnected elements of collaborative modeling and computer simulation, an interacting cyber-toolbox, and data infrastructure for nanotechnology. It was intended to provide a community-based, solution-oriented knowledge infrastructure for discovery, innovation, and nanoinformatics of research, education, and regulatory interest to NNI agencies. The program solicitation, Cyberinfrastructure for Sustained Innovation,[39] has been contributing to data infrastructure, software advances, and high-throughput computation. Going forward, NSF will increase coordinated research on the Harnessing the Data Revolution priority area.[40]

Goal 4. Support Responsible Development of Nanotechnology

Research in support of nanomaterials characterization and exposure is performed in NSF's core programs.

One example of public outreach in support of Goal 4 is the Generation Nano comic competition,[41] designed to inspire high school and middle school students to learn more about the science behind nanotechnology. The competition, a partnership between NSF and the NNI, has challenged students to imagine novel superheroes who use the power of nanotechnology to solve crimes or tackle a societal challenge. In 2021 a collaboration with the Boston Museum of Science is envisioned.

[37] https://nanohub.org/about/presskit

[38] https://nanohub.org/groups/ncn/

[39] https://www.nsf.gov/pubs/2018/nsf18531/nsf18531.htm

[40] https://www.nsf.gov/cise/harnessingdata/

[41] https://www.nsf.gov/news/special_reports/gennano/