NATIONAL SCIENCE FOUNDATION

FY 2021 Budget Request to Congress

February 10, 2020

NOTES

Table and Figure Notes

Numbers in the tables and figures may not add up to totals because of rounding.

Amounts for FY 2020 were not available at the time this Budget Request was published.

Common Acronyms Used in NSF's Budget Submission

Appropriation Accounts
- AOAM - Agency Operations and Award Management
- EHR - Education and Human Resources
- MREFC - Major Research Equipment and Facilities Construction
- NSB – Office of the National Science Board
- OIG - Office of Inspector General
- R&RA - Research and Related Activities

Directorates and offices
- BFA - Office of Budget, Finance, and Award Management
- BIO - Directorate for Biological Sciences
- CISE - Directorate for Computer and Information Science and Engineering
- ENG - Directorate for Engineering
- EHR - Directorate for Education and Human Resources
- GEO - Directorate for Geosciences
- MPS - Directorate for Mathematical and Physical Sciences
- SBE - Directorate for Social, Behavioral, and Economic Sciences
- OIRM - Office of Information and Resource Management
- OISE - Office of International Science and Engineering
- OPP - Office of Polar Programs
- OIA - Office of Integrative Activities [organizational unit]
- IA - Integrative Activities [budget activity]

NSF Big Ideas
Convergence Accelerator
- CA - NSF Convergence Accelerator

Research Big Ideas
- HDR - Harnessing the Data Revolution for 21st-Century Science and Engineering
- FW-HTF - The Future of Work at the Human-Technology Frontier
- NNA - Navigating the New Arctic
- QL - The Quantum Leap: Leading the Next Quantum Revolution
- URoL - Understanding the Rules of Life: Predicting Phenotype
- WoU - Windows on the Universe: The Era of Multi-messenger Astrophysics

Enabling Big Ideas
- GCR - Growing Convergence Research at NSF
- Mid-scale RI - Mid-scale Research Infrastructure

- NSF INCLUDES - Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science

NSF-Wide Investments
- GRFP - Graduate Research Fellowship Program
- INFEWS - Innovations at the Nexus of Food, Energy, and Water Systems
- IUSE - Improving Undergraduate STEM Education
- I-Corps™ - NSF Innovation Corps
- NRT - NSF Research Traineeship
- SaTC - Secure and Trustworthy Cyberspace
- UtB - Understanding the Brain
  - BRAIN Initiative - Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative

National Science and Technology Council Crosscuts:
- NITRD - Networking and Information Technology Research and Development
- NNI - National Nanotechnology Initiative
- USGCRP - U.S. Global Change Research Program

Other Frequently Used Acronyms
- STEM - science, technology, engineering, and mathematics
- R&D - research and development
- O&M - operations and maintenance
- AI - artificial intelligence
- QIS - quantum information science

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The *National Science Foundation Act of 1950 (Public Law 81-507)* sets forth our mission: "***To promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense...***"

On April 10, 2019, the first image of a black hole was released by the Event Horizon Telescope (EHT) team. This discovery was enabled by the significant investment from the National Science Foundation and the use of NSF funded telescopes and instrumentation including the Atacama Large Millimeter/submillimeter Array (ALMA), the Submillimeter Telescope operated by the Arizona Radio Observatory, the South Pole Telescope, and the Large Millimeter Telescope. After years of theoretical physics research and detector development, researchers coordinated eight telescopes on five continents to capture observations of a black hole 55 million light-years away by effectively forming an Earth-sized virtual telescope. This accomplishment, which was awarded the 2020 Breakthrough Prize in Fundamental Physics, was achieved after years of work involving international collaboration of over 300 researchers. This project emphasizes several unique aspects of the mission and work of NSF in its investment in projects that empower discoverers to ask the questions and develop the technologies that lead to the next big breakthroughs.

The success of EHT highlights several NSF programs that support the transformative research of high risk and potentially high reward. These programs include those that fund priority research areas, encourage partnerships and large-scale international collaboration, and empower early career scientists and students. As a data-driven discovery, the EHT project aligns with three of NSF's Big Ideas. Future astrophysical discoveries will also benefit from new hardware and software advances generated by Harnessing the Data Revolution, particularly development of new data cyberinfrastructure for timely handling, processing, analyzing and modeling of multi-messenger astrophysical data. By exploring new ways to probe the cosmos, Windows on the Universe continues to enrich our view of the universe, and Mid-Scale Research Infrastructure offers a new funding mechanism that is responsive to ambitious projects like EHT requiring dynamic and flexible investment.

Since the agency's founding in 1950, NSF has been the only federal agency dedicated to funding basic non-biomedical research across all areas of science and engineering. NSF has been on the forefront of the innovations that provide American prosperity and strength, and sustain the U.S. role as a global leader driving innovation in technological and scientific advancements. Additionally, NSF is committed to the development of a future-focused science and engineering workforce that draws on the talents of all Americans.

NSF's FY 2021 Request supports investments in the Administration's research and development priority area of Industries of the Future (IotF). These investments will continue NSF's focused support of the science, technology, innovation and workforce development to ensure that America remains at the forefront of scientific progress, national and economic security, and personal well-being, while continuing to serve as the standard-bearer for today's emerging technologies and innovations. NSF will support IotF through the research areas of advanced manufacturing, advanced wireless, artificial intelligence, biotechnology, and quantum information science. To achieve and complement NSF's IotF goals, NSF will make strategic investments across the agency to support the heart of NSF's mission, basic research, while helping to usher in the next generation of science and technology with convergence research that spans and integrates all areas of science and realms of human knowledge.

In FY 2021, NSF will make strategic investments in basic research, the STEM workforce, and research infrastructure that will advance the Nation's global competitiveness economically and scientifically. Federal investment in basic research and the STEM workforce is vital to the Nation's continued global leadership. These investments will fuel our Nation's economy for decades to come, produce high-paying jobs for American workers, improve American prosperity including our quality of life, and enhance our national security.

Innovations in basic research are dependent upon strategic investments in scientific infrastructure and instrumentation. Facilities and research infrastructure have long been a NSF priority. NSF will continue efficient and effective management of all research infrastructure and large facilities. NSF's FY 2021 investments will continue to prioritize the health and balance of its facilities portfolio, leveraging NSF's substantial investment in facilities to further support the scientific output of the communities they serve.

In FY 2021, NSF will continue oversight of the construction of the following projects in the Major Research Equipment and Facilities Construction (MREFC) account: Antarctic Infrastructure Modernization for Science (AIMS) project, the High Lumosity-Large Hadron Collider Upgrade (HL-LHC), and the Vera C. Rubin Observatory (formerly Large Synoptic Survey Telescope). Continued investment in the construction of major research infrastructure allows the U.S. to maintain international leadership in science and engineering by developing new capabilities to address the most challenging scientific questions.

NSF will continue to build, strengthen, and expand strategic multisector partnerships in order to enhance the impact of NSF's investments. Private industry, foundations, and non-profits, together with other federal agencies and international funding organizations, bring additional expertise, resources, and capacity to NSF-funded research. This, in turn, accelerates discovery and translation of research to products and services, and enhances preparation of the future workforce to benefit society and grow the American economy. However, entering into and maintaining these partnerships requires significant time and intellectual capital, as well as strategic foresight.

Within the global science and engineering enterprise, unprecedented competition exists for highly skilled, technical workers who will lead tomorrow's innovations. Continued U.S. leadership and support for basic research is critically important for the Nation. The JASON report, "Fundamental Research Security", released in December 2019 provides an opportunity for NSF to assess the policy impacts and frame the problems within the area of science and security. In collaboration with other federal agencies, colleges and universities, and other stakeholders in the U.S. science and engineering enterprise, this effort will ensure that America continues to attract and retain the best science and engineering talent globally, and uphold values of ethics and research integrity in science and engineering.

NSF's FY 2021 Budget Request is $7.74 billion, a $675 million increase above the FY 2020 Request level, a 5.0 percent decrease from the FY 2019 Actual level, and a 6.5 percent decrease from the FY 2020 Enacted level.

Industries of the Future

NSF's FY 2021 Request aligns with the Administration's Research and Development priorities by making critical investments in the Industries of the Future (IotF). As the only federal agency dedicated to funding basic non-biomedical research across all areas of science and engineering, NSF has long supported the science and technological innovations that create new industries. NSF plans to invest $868 million in artificial intelligence (+$403 million above FY 2019 Actual) and more than double our support of quantum information science to $226 million (+$120 million above FY 2019 Actual) in FY 2021.[1] All IotF investments support cross-cutting, convergent, and interdependent fields of research that collectively offer enormous economic potential and are critical to the Nation's long-term economic and national security. NSF's FY 2021 Request will ensure NSF continues to invest in the breakthrough discoveries and workforce development needed to draw on the talents of all Americans, as well as sustain America's globally preeminent innovation ecosystem.

Artificial Intelligence (AI) research is advancing rapidly and holds the potential to transform American lives through improved educational opportunities, increased economic prosperity, and enhanced national and homeland security. NSF investments in AI span fundamental research in machine learning, computer vision, and natural language processing, along with the safety, security, robustness, and explainability of AI systems; translational research at the intersection of AI and various science and engineering domains as well as economic sectors such as agriculture, manufacturing, and personalized medicine; and education and learning, including growing human capital and institutional capacity to nurture a next generation of AI researchers and practitioners. NSF FY 2021 investments in AI will include support for a set of National AI Research and Development (R&D) Institutes, which will further AI through multi-disciplinary, multi-institution teams to focus on larger-scale, longer-term challenges in both foundational and translational AI.

Quantum Information Science (QIS) examines uniquely quantum phenomena that can be harnessed to advance information processing, transmission, measurement, and fundamental understanding in ways that classical approaches can only do much less efficiently, or not at all. NSF will increase support for QIS research and development, which strongly aligns with the Administration's National Strategic Overview for QIS and the National Quantum Initiative Act to consolidate and expand the U.S.' world-leading position in fundamental quantum research and deliver proof-of-concept devices, applications, tools, or systems with a demonstrable quantum advantage over their classical counterparts.

Advanced Manufacturing investments support the fundamental research needed to revitalize American manufacturing to grow the national prosperity and workforce, and to reshape our strategic industries. NSF research accelerates advances in manufacturing technologies with emphasis on multidisciplinary research that fundamentally alters and transforms manufacturing capabilities, methods and practices. Investments in advanced manufacturing include research on highly connected cyber-physical systems in smart processing and cyber manufacturing systems, and activities that develop new methods, processes, analyses, tools, or equipment for new and existing manufacturing products, supply chain components, and materials. NSF's investments will enable new functionalities that will increase the efficiency and sustainability of the production of the next generation of products and services. These developments will yield advantages such as reduced time to market, new performance attributes, improved small-batch production, cost savings, energy savings, and reduced environmental impact from the manufacturing of products. NSF FY 2021 investments includes support for Future Manufacturing research, which will enable a new generation of manufacturing industries that do not exist today, will be compatible with human needs, and will make U.S. manufacturing competitive far into the future

[1] NSF IotF investments have funding overlap and thus should not be summed.

Advanced Wireless Research, including the Spectrum Innovation Initiative will advance knowledge gaps and innovate in areas critical to future generations of wireless technologies and networks, such as wireless devices, circuits, protocols, and systems; mobile edge computing; distributed machine learning and inference on mobile devices; human-machine-network interactions; and dynamic spectrum allocation and sharing. This work will offer new insights capable of making wireless communication faster, smarter, more responsive, and more robust, and more secure – with profound implications for science and society. Research in advanced wireless includes the support for passive uses of the spectrum, including advanced receiver design and interference mitigation techniques for radio astronomy and atmospheric science. NSF's leadership in wireless research has three intertwined components: supporting fundamental research enabling advanced wireless technologies; establishing advanced wireless research testing platforms, in collaboration with industry and other government agencies, to experiment on new approaches at scale; and catalyzing academic, industry, national scientific facility, and community leaders to work together to prototype innovative wireless approaches to address societal challenges.

Biotechnology investments support the data, research infrastructure, and innovation that enable an understanding of living organisms and their biologically-related processes at the level of the genetic code. Advanced biotechnology, including advanced sequencing, metabolic engineering, epigenetic modulation of gene expression, and gene editing, serve to both accelerate scientific discovery in biology and to enable the harnessing of biological systems for economic and societal benefit. Biotechnology is considered one of the key drivers of growth in the bioeconomy. NSF invests in biotechnology and related drivers of the U.S. bioeconomy through a multitude of programs in research, infrastructure, and education, including genomics, synthetic biology, bioinformatics, computational biology, engineering biology, tissue engineering, and the development of new types of biomaterials, bio-based microelectronics, and biomanufacturing. NSF's educational investments in these areas are essential to support the biotechnology workforce needed to grow the U.S. bioeconomy. NSF investments in research on ethical, legal, and environmental consequences of synthetic biology and other biotechnologies also support the bioeconomy through understanding of product adoption and socially responsible use.

For more information about NSF's investments in AI, QIS, and Advanced Manufacturing see the NSF-Wide Investments chapter.

Strategic Research Investments

In FY 2021, NSF will make investments that support the basic research that advances human knowledge and makes tomorrow's innovations possible. Additional investments will support research in the areas of microelectronics and semiconductors, spectrum innovation, coastlines and people, and strengthening American infrastructure. In FY 2021, NSF expects that over 90 percent of its annual budget will be used to fund research and education grants and research infrastructure in the science and education communities. New discoveries made possible through basic research investments will enable the Nation to overcome crucial scientific barriers for emerging technologies that will strengthen U.S. scientific leadership, economic prosperity, and national security.

Basic research forms the core of NSF's work and has led to discoveries and innovations that have been awarded Nobel Prizes, and changed humankind's conception of the known world. In FY 2021, NSF expects to invest $5.02 billion, or 65 percent of NSF's total budget, in basic research. Basic research is responsible for advancing our knowledge of the universe, as well as innovations like high speed internet, nanotechnology, and advances in robotics that require understanding of the fundamental laws that govern the physical world. NSF funds basic research in all of the agency's directorates and continues to fund research that transcends a single discipline.

Research in **Semiconductors and Microelectronics** ($84.16 million) is critical to future advances and security in several areas, including information technology, communications, sensing, smart electric grid, transportation, health, and advanced manufacturing. NSF will support research to address fundamental science and engineering questions on the concepts, materials, devices, circuits, and platforms necessary to sustain progress in semiconductor and microelectronic technologies. This investment will strengthen America's capabilities and capacity for revolutionary microelectronics design, architecture, and fabrication, as well as high-performance computing.

NSF's **Spectrum Innovation Initiative** ($17.0 million) will catalyze spectrum research, which addresses key challenges related to an increasingly congested radio frequency environment and outdated approaches to spectrum allocation. NSF is uniquely positioned to lead this effort with its mission to both protect and innovate in scientific uses of the spectrum and in the development of new technology (e.g., advanced wireless). FY 2021 funding will support three cross-cutting initiatives: (1) a novel mechanism for piloting, testing, and rolling out the most innovative approaches to dynamic spectrum sharing in specialized geographic regions, "National Radio Dynamic Zones"; (2) collaborative, center-scale institutes for sustained R&D in the most challenging areas to bring together diverse science and engineering perspectives; and (3) education and public outreach funding for the much needed workforce development specifically related to spectrum research.

FY 2021 investment of $16.0 million in **Coastlines and People (CoPe)** will support interdisciplinary research through establishment of virtual centers or research "hubs" aimed at improving prediction of coastal natural hazards, and understanding of the complex interactions between coastal hazards, people, ecosystems and the built environment. Coastal research offers compelling lines of scientific inquiry with potential for great societal and economic benefit. Research Hubs will address scientific questions that cross multiple disciplines and scales (time and space). These hubs will engage and involve stakeholders and local communities; exploring science that informs pathways to sustainability in changing coastal environments.

FY 2021 investments to **Strengthen American Infrastructure** ($6.0 million) will link experts on physical, computational, and material aspects of infrastructure design with scientists whose fundamental research explains how humans will—and will not—use infrastructure that we build. This approach to infrastructure is a critical component to building better, smarter, and more cost-effective roads, electric grids, and hospitals. Improving infrastructure in these ways spurs private-sector innovation, grows the economy, and is essential to national competitiveness.

Additional Research Priorities
In FY 2021, NSF will continue to emphasize ongoing investments that engage scientists and engineers from all STEM fields in creating private-public partnerships, protect the Nation's cyber assets, and expand the reach of NSF funding.

Ongoing NSF-wide Investments
A **NSF Innovation Corps (I-Corps™)** investment of $31.42 million in FY 2021 will prepare scientists and engineers to reduce the time and risk associated with translating promising ideas and technologies from the laboratory to the marketplace. I-Corps™ accelerates the economic and societal benefits of NSF-funded, basic research projects. In FY 2021, NSF will support I-Corps™ Teams and I-Corps™ Hubs to expand, utilize, and sustain a national innovation ecosystem that helps researchers and entrepreneurs effectively identify viable market opportunities and augments the development of technologies that benefit the Nation.

The **Secure and Trustworthy Cyberspace (SaTC)** investment, $124.91 million in FY 2021, aims to build the knowledge base in cybersecurity that enables discovery, learning, and innovation, and leads to a more secure and trustworthy cyberspace. Through a focus on long-term, foundational research, SaTC will develop the scientific foundations for cybersecurity research for years to come. SaTC also focuses on the training of the future cybersecurity workforce. SaTC aligns NSF's cybersecurity investments with the national cybersecurity strategy.

Ongoing Targeted Priorities
NSF's FY 2021 Request of $163.67 million for the **Established Program to Stimulate Competitive Research (EPSCoR)** will enhance the research competitiveness and strengthen the STEM capacity and capability of targeted jurisdictions

In FY 2021, the **Historically Black Colleges and Universities Excellence in Research (HBCU-EiR)** program ($9.50 million) supports basic research projects that enable STEM and STEM education faculty to further develop research capacity at HBCUs and to conduct research.

Through innovative programs like the **Small Business Innovation Research (SBIR)** and the **Small Business Technology Transfer (STTR),** NSF will continue to support the basic and early-stage applied research that provides the fundamental building blocks of technological advances. FY 2021 funding for SBIR/STTR, including operations, will total $209.25 million.

Strategic Infrastructure and Instrumentation

In FY 2021, NSF is dedicated to the support of research infrastructure and instrumentation. The Nation's science and engineering activities rely on instrumentation that is geographically and technically accessible, cost effective, and managed well. To ensure that the infrastructure needs of the entire community are met, NSF supports activities that ensure instrumentation and infrastructure can be designed, developed, acquired, or constructed through programs with focused oversight and investments.

Instrumentation and Infrastructure
The Major Research Instrumentation (MRI) program is responsible for catalyzing new knowledge and discoveries by helping STEM professionals acquire or develop the instrumentation needed at their institutions. MRI grants support instrumentation in all NSF-supported research disciplines. MRI makes awards of up to $4 million, for projects with total costs (including matching funding) as high as $6 million.

In the American Innovation and Competitiveness Act (AICA) of 2017, Congress directed the agency to develop a strategy for supporting research infrastructure with a total project cost above the upper limit for the MRI program and below the MREFC threshold. NSF responded by introducing the Mid-scale Research Infrastructure (Mid-scale RI) program. This dedicated activity implements a high-priority, agency-wide mechanism that includes upgrades to major facilities as well as stand-alone projects.

In FY 2021, NSF will continue funding the Mid-scale Research Infrastructure (Mid-scale RI) program through two tracks. Mid-scale RI Track 1 will support the acquisition or development of instrumentation in the $6 million to $20 million range. Mid-scale RI Track 1 funding is provided through the Research and Related Activities account, and awards will fund projects similar to those supported in FY 2019 such as Event Horizon Telescope 2.0, next generation atmospheric research aircraft, and neutron spin-echo spectrometer. Mid-scale RI Track 2 will make awards in the $20 million to $100 million range, and is funded through the MREFC account. Mid-scale RI Track 2 includes support for upgrades to major facilities and stand-alone projects.

Facility Operations and Maintenance
NSF's FY 2021 Request for facilities operations and maintenance is $867.42 million, all of which is provided through the R&RA account.

Major Research Equipment and Facilities Construction
Projects that require an investment of more than $100 million are supported by NSF's Major Research Equipment and Facilities Construction account.

The FY 2021 Request includes funding to continue construction of three projects—AIMS, the two detector upgrades at the HL-LHC, and the Vera C. Rubin Observatory, formerly Large Synoptic Survey Telescope (LSST)—as well as Mid-scale RI Track 2. The total request to support these projects and associated oversight costs is $229.75 million.

MREFC Account Funding, by Project

(Dollars in Millions)

	FY 2019 Actual	FY 2020 Enacted	FY 2021 Request
Antarctic Infrastructure Modernization for Science	$103.70	$97.89	$90.00
Daniel K. Inouye Solar Telescope	19.59	-	-
High Luminosity-Large Hadron Colliger Upgrade	-	33.00	33.00
Mid-Scale Research Infrastructure[1]	-	65.00	65.00
National Ecological Observatory Network	0.07	-	-
Regional Class Research Vessels	108.12	-	-
Vera C. Rubin Observatory	53.48	46.34	40.75
Major Facilities Administrative Reviews and Audits	0.32	1.00	1.00
Total	**$285.27**	**$243.23**	**$229.75**

[1] Mid-scale Research Infrastructure funding in the FY 2019 Actual is reflected in the R&RA account within Integrative Activities. Mid-scale projects in this table have a total implementation cost between $20 million and $100 million.

The **AIMS** ($90.0 million) construction project funding request will support the third year of the multi-year funding profile. Antarctica makes up nearly nine percent of the continental mass of Earth's surface. NSF manages all U.S. activities as a single, integrated program, making Antarctic research possible for scientists supported by NSF and other U.S. agencies. Funding for the AIMS infrastructure improvement project will protect U.S. interests on the continent. It will continue modernization of major facilities at the aging McMurdo Station, much of which was recommended by the U.S. Antarctic Program Blue Ribbon Panel in 2012, so that anticipated science support needs are met for the next three to five decades. When completed, AIMS will enable faster, more streamlined and cost-effective logistical and science support by co-locating or consolidating warehousing, skilled trades work, and field science support where field projects are prepared for movement into the field, into four buildings. AIMS will also provide necessary utilities to support these facilities.

The **LHC** ($33.0 million) is the world's largest and highest energy particle accelerator. Located near Geneva, Switzerland and operated by the European Organization for Nuclear Research (CERN), the LHC can accelerate and collide counter-propagating bunches of protons at a total energy of 14 tera-electron volts. A Toroidal LHC ApparatuS (ATLAS) and Compact Muon Solenoid (CMS) are two general purpose detectors used by researchers to observe these collisions and analyze their characteristics. Together, CMS and ATLAS represent the United States contribution to the LHC facility. In FY 2021, NSF funding together with our Department of Energy partner will support year two of the five-year project for the **HL-LHC Upgrade**. This investment will upgrade components of the of the ATLAS and CMS detectors, enabling them to function at much higher collision rates following an upgrade to the LHC to increase its luminosity.

The **Vera C. Rubin Observatory** ($40.75 million) will be an 8-meter-class wide-field optical telescope capable of carrying out surveys of the entire southern sky. It will collect nearly 40 terabytes of multi-color imaging data every night to produce the deepest, widest-field sky image ever. It will also issue alerts for moving and transient objects within 60 seconds of their discovery. FY 2021 will be year eight of its nine-year construction funding profile.

The **Mid-Scale Research Infrastructure** ($65.0 million) project has a dedicated funding line in the MREFC account for Track 2 awards. Individual projects will be selected through dedicated program solicitations and NSF's merit review process. Although funding will be allocated from the MREFC account, managing directorates will be responsible for award oversight.

Big Ideas and Convergence Accelerator

In 2021, NSF will continue to invest in its Big Ideas and the Convergence Accelerator, which support bold inquiries into the frontiers of science and engineering. These efforts endeavor to break down the silos of conventional scientific research funded by NSF to embrace the cross-disciplinary and dynamic nature of the science of the future. The Big Ideas represent unique opportunities for the U.S. to define and push the frontiers of global science and engineering leadership and to invest in fundamental research. This research will advance the Nation's economic competitiveness, security, and prestige on the global stage. For more information, see the NSF-Wide Investments chapter.

<u>About the Big Ideas</u>
Six of the Big Ideas are research ideas, which will build on the foundation of NSF-funded research over the last 70 years. The Research Big Ideas are complemented by Enabling Big Ideas, which are areas in which research endeavors to improve the way in which science is done, from impacting the workforce to developing the infrastructure that will drive the discoveries and aid the discoverers of tomorrow's science.

Research Big Ideas:

- **Harnessing the Data Revolution for 21st-Century Science and Engineering (HDR**) ($45.0 million): Engaging NSF's research community in the pursuit of fundamental research in data science and engineering, the development of a cohesive, federated, national-scale approach to research data infrastructure, and the development of a 21st-century data-capable workforce.

- **The Future of Work at the Human Technology Frontier (FW-HTF)** ($45.0 million): Catalyzing interdisciplinary science and engineering research to understand and build the human-technology relationship; design new technologies to augment human performance; illuminate the emerging socio-technological landscape; and foster lifelong and pervasive learning with technology.

- **The Quantum Leap (QL): Leading the Next Quantum Revolution** ($50.0 million): Exploiting quantum mechanics to observe, manipulate, and control the behavior of particles and energy at atomic and subatomic scales; and developing next-generation quantum-enabled science and technology for sensing, information processing, communicating, and computing.

- **Navigating the New Arctic (NNA)** ($30.0 million): Establishing an observing network of mobile and fixed platforms and tools, including cyber tools, across the Arctic to document and understand the Arctic's rapid biological, physical, chemical, and social changes, in partnership with other agencies, countries, and native populations.

- **Understanding the Rules of Life (URoL): Predicting Phenotype** ($30.0 million): Elucidating the sets of rules that predict an organism's observable characteristics. Advances in understanding life at the fundamental level of the genome will enable re-engineering of cells, organisms, and ecosystems, and innovative biochemicals and biomaterials that sustain a vibrant bioeconomy and strengthen society.

- **Windows on the Universe (WoU): The Era of Multi-messenger Astrophysics** ($30.0 million): Using powerful new syntheses of observational approaches to provide unique insights into the nature and behavior of matter and energy and to answer some of the most profound questions before humankind.

Enabling Big Ideas:

- **NSF INCLUDES** ($18.92 million): Transforming education and career pathways to help broaden participation in science and engineering and build a diverse, highly skilled American workforce.

- **Growing Convergence Research at NSF (GCR)** ($15.20 million): Merging ideas, approaches, tools, and technologies from widely diverse fields of science and engineering to stimulate discovery and innovation.

- **Mid-scale Research Infrastructure** ($97.67 million): Developing an agile process for funding experimental research capabilities in the mid-scale range, spanning the midscale gap in research infrastructure. This is a "sweet spot" for science and engineering that has been challenging to fund through traditional NSF programs.

About the Convergence Accelerator

The Convergence Accelerator (CA) is an organizational framework that stands separately from the NSF research directorates, with its own budget, staff, and initiatives. Each CA research track will be a time-limited entity focused on specific research topics and themes. Therefore, CA research tracks will evolve over time and will be informed by external stakeholder input. The CA will reward high-risk, innovative thinking by multidisciplinary teams of researchers who want to accelerate discovery and innovation. The CA is a way of achieving rapid lab-to-market or research outcomes. The FY 2021 CA funding is $70.0 million, or $28.61 million above the FY 2019 Actual. NSF anticipates external partners will begin contributing financially to the effort in FY 2021.

Education and STEM Workforce

NSF's education and STEM workforce investments are primarily housed in the Directorate for Education and Human Resources, but represent agency-wide investments in the education of tomorrow's scientists, engineers, and educators. NSF is committed to building and leveraging a diverse, highly skilled American workforce for the 21st century economy. This workforce must be capable of adapting to the increasingly technical nature of work across all sectors, which will require a greater emphasis on STEM education and literacy. NSF works to prioritize programs that will provide experiential learning opportunities, as well as programs that prioritize computer science education and reskilling. NSF's extensive broadening participation portfolio impacts minority serving institutions and rural communities. Priority STEM education activities to prepare America's future workforce in FY 2021 are:

The **Advanced Technological Education (ATE)** ($70.97 million) program focuses on the education of technicians for the high-technology fields that drive our Nation's economy. The program involves partnerships between academic institutions and industry to promote improvement in the education of science and engineering technicians at the undergraduate and secondary institution school levels. The ATE program supports curriculum development; professional development of college faculty and secondary school teachers; career pathways; and other activities.

The **NSF Research Traineeship (NRT)** ($61.87 million) program encourages the development and implementation of bold, new, and potentially transformative and scalable models for STEM graduate education training. The program is dedicated to effective training of STEM graduate students in high priority interdisciplinary or convergent research areas through innovative professional development activities that will educate the next generation of scientist. In FY2021, NRT will expand to include a special focus on traineeships in artificial intelligence and artificial intelligence engineering.

The **CyberCorps®: Scholarship for Service (SFS)** ($52.13 million) program supports cybersecurity education at higher education institutions. SFS also focuses on workforce development by increasing the number of qualified students entering the fields of information assurance and cybersecurity, which enhances the capacity of the U.S. higher education enterprise to continue to produce professionals in these fields to secure the Nation's cyberinfrastructure.

Computer Science for All (CSforAll): Researcher and Research Practitioner Partnerships ($18.97 million) will build on ongoing efforts to enable rigorous and engaging computer science education in schools across the Nation, to prepare the STEM workforce of the future. CSforAll aims to provide high school teachers with the preparation, professional development, and ongoing support that they need to teach rigorous computer science courses and to give preK-8 teachers the instructional materials and preparation they need to integrate computer science and computational thinking into their teaching.

The **Graduate Research Fellowship Program (GRFP)** ($275.28 million) recognizes students with high potential in STEM research and innovation and provides support for them to pursue research across all science and engineering disciplines. GRFP fellows may participate in Graduate Research Opportunities Worldwide (GROW), which provides opportunities to conduct research with international partner countries and organizations, and Graduate Research Internship Program (GRIP), which provides professional development through research internships at federal agencies. In FY 2021, GRFP will continue to align fellowship awards with NSF and Administration research priorities, including IotF research areas of artificial intelligence and quantum information science.

The **Hispanic-Serving Institutions Program (HSI)** ($14.19 million) seeks to enhance the quality of undergraduate STEM education at HSIs and to increase retention and graduation rates of undergraduate students pursuing degrees in STEM fields at HSIs. The HSI Program seeks to build capacity at HSIs that typically do not receive high levels of NSF grant funding.

The **Historically Black Colleges and Universities Undergraduate Program (HBCU-UP)** ($31.22 million) is committed to enhancing the quality of undergraduate STEM education and research at HBCUs to broaden participation in the nation's STEM workforce. HBCU-UP provides awards to develop, implement, and study evidence-based innovative models and approaches for improving the preparation and success of HBCU undergraduate students so that they may pursue STEM graduate programs and/or careers.

The **Improving Undergraduate STEM Education (IUSE)** ($88.21 million) initiative supports the development of the STEM and STEM-capable workforce by investing in the improvement of undergraduate STEM education, with a focus on attracting and retaining students and on degree completion. The initiative funds the development and implementation and the related research and assessment of effectiveness. Directorates across NSF invest in this program to support the development of a workforce that will be able to handle the real-world challenges of a STEM career.

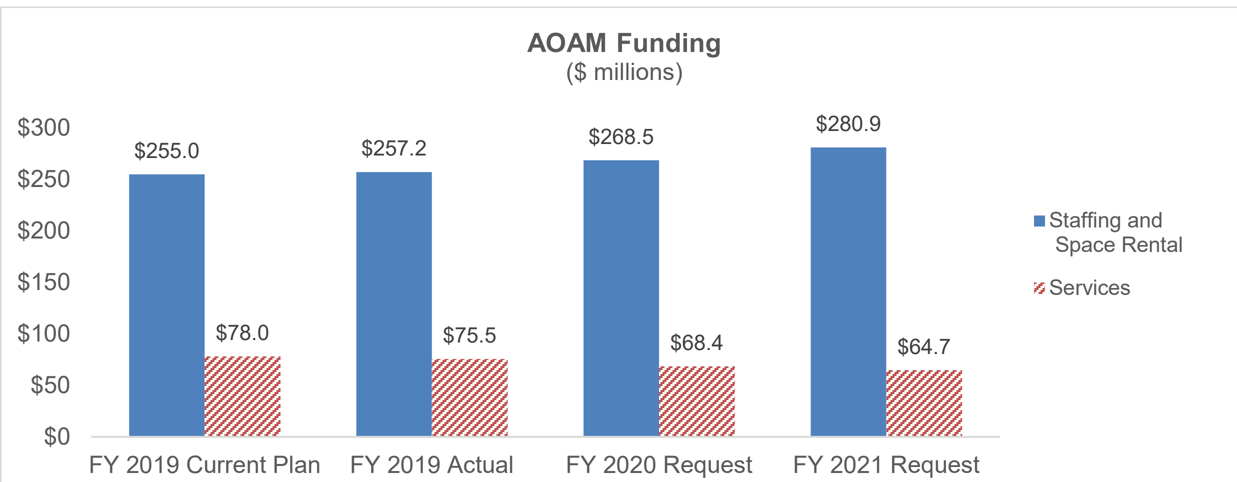
The **Tribal Colleges and Universities Program (TCUP)** ($12.49 million) provides awards to Tribal Colleges and Universities, Alaska Native-serving institutions, and Native Hawaiian-serving institutions to promote high quality STEM education, research, and outreach.

Agency Operations and Award Management

In FY 2021, funding provides a total of $345.64 million, an increase of $12.95 million or 3.9 percent above the FY 2019 Actual for the Agency Operations and Award Management (AOAM) account. NSF continues to operate as a lean agency with AOAM costs representing 4.5 percent of NSF total FY 2021 budget.

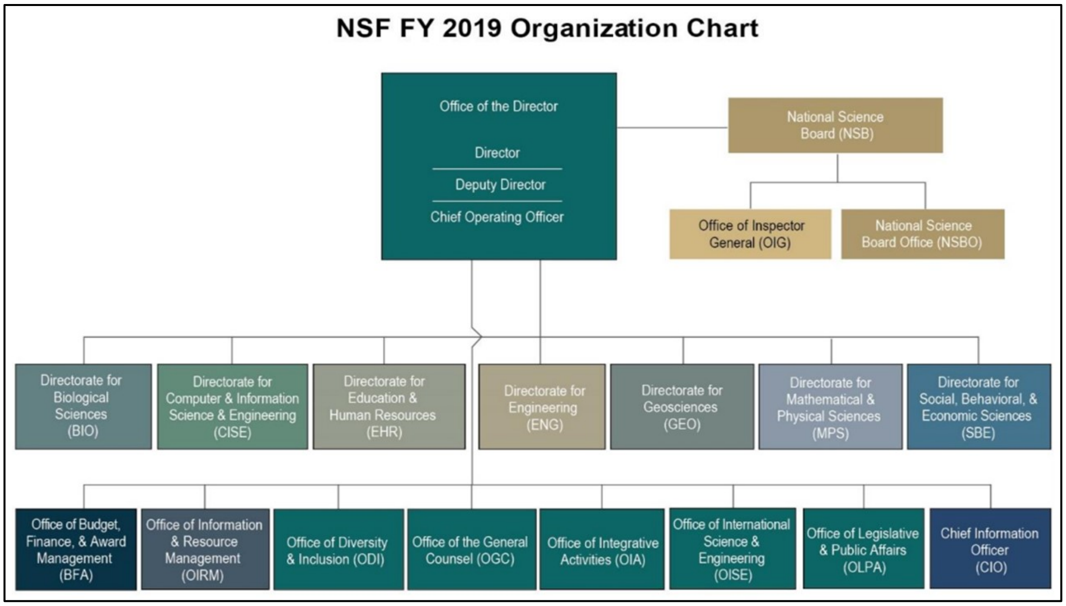
Investments in the AOAM account provide the fundamental framework through which the Foundation's science and engineering research and education programs are administered. AOAM funds the essential services NSF needs to operate, and investments in the AOAM account continue to be an NSF priority. The AOAM account enables NSF to support innovations and workforce development essential to improving agency operations and advancing American leadership in science and technology.

The $7.4 billion in research funding that NSF will support in FY 2021 is made possible by the federal staff that enable the research and steward the taxpayer investment. The AOAM account provides the funding necessary to support NSF the institution, which is largely the cost of NSF personnel and NSF headquarter location in Alexandria, VA. These fixed costs increase year over year and are partially offset by reductions to the mission-support services necessary to operate the agency and support the NSF workforce. In FY 2021, AOAM will also fund NSF's efforts to implement the policy requirements mandated by law, such as the American Innovation and Competitiveness Act (AICA), Digital Accountability and Transparency Act of 2014 (DATA Act), Foundations for Evidence-Based Policymaking Act of 2018 (Evidence Act).



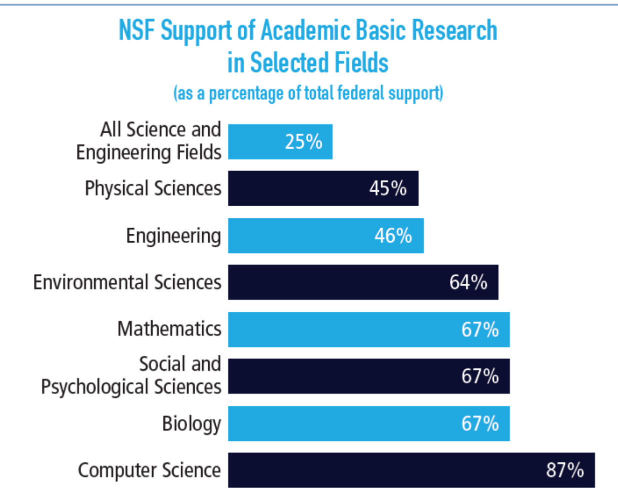
Organization and Role in the Federal Research Enterprise

NSF's comprehensive and flexible support of meritorious projects enables the Foundation to identify and foster both fundamental and transformative discoveries and broader impacts within and among fields of inquiry. NSF has the latitude to support emerging fields, high-risk ideas, interdisciplinary collaborations, and research that pushes—and creates—the very frontiers of knowledge. In these ways, NSF's discoveries inspire the American public—and the world.



NSF's organization represents the major science and engineering fields, including biological sciences; computer and information science and engineering; engineering; geosciences; mathematical and physical sciences; and social, behavioral, and economic sciences. NSF also carries out specific responsibilities for education and human resources, integrative activities, and international science and engineering. The 25-member National Science Board approves the overall policies of the Foundation.

NSF's annual budget represents approximately 25 percent of the total federal budget for basic research conducted at U.S. colleges and universities. In many science and engineering fields, NSF is the primary source of federal academic support.



Note: Biology includes Biological Sciences and Environmental Biology. Biology and Psychological Sciences exclude National Institutes of Health funding from the total amount of federal support.

Source: NSF/National Center for Science and Engineering Statistics, Survey of Federal Funds for Research & Development, FY 2017.

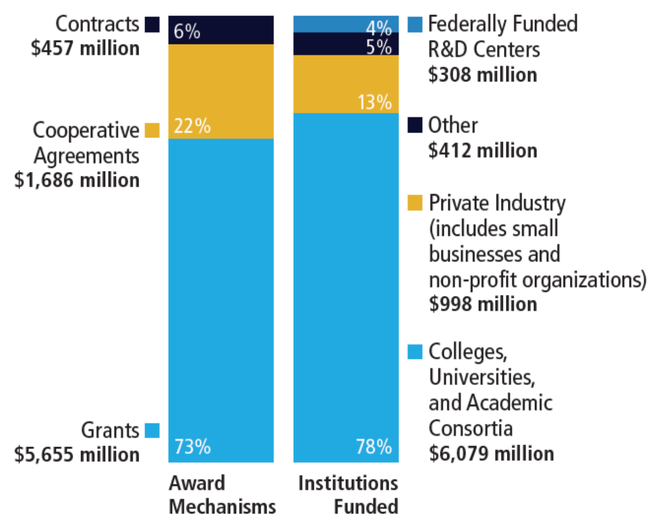
NSF by the Numbers

NSF by the Numbers: In FY 2021, NSF expects to evaluate approximately 43,500 proposals through a competitive merit review process and make approximately 10,700 new competitive awards, 8,100 of which will be new research grants and the remainder of which will be contracts and cooperative agreements. This process involves approximately 192,000 proposal reviews, engaging on the order of 29,000 members of the science and engineering community participating as panelists and proposal reviewers. In a given year, NSF awards reach over 1,800 colleges, universities, and other public and private institutions in 50 states, the District of Columbia, and U.S. territories. In FY 2021, NSF support is expected to reach approximately 299,900 researchers, postdoctoral fellows, trainees, teachers, and students.

The chart on the right shows the distribution of NSF's obligations by institution type and funding mechanism. While the data are based on FY 2019, it is expected that the relative shares in FY 2021 will be similar. As shown on the graph, 95 percent of NSF's FY 2019 projects were funded using grants or cooperative agreements. NSF grants are either standard or continuing awards. That is, the award is made during one fiscal year for the full amount of the award or made over several years in increments. Cooperative agreements are used when the project requires substantial agency involvement during the project performance period (e.g., research centers, major multi-user research facilities). Contracts are used to acquire products, services, and studies (e.g., program evaluations) required primarily for NSF or other government use.

Where It Goes and How It Gets There

FY 2019 Obligations for Research and Education Programs—$7.8 billion



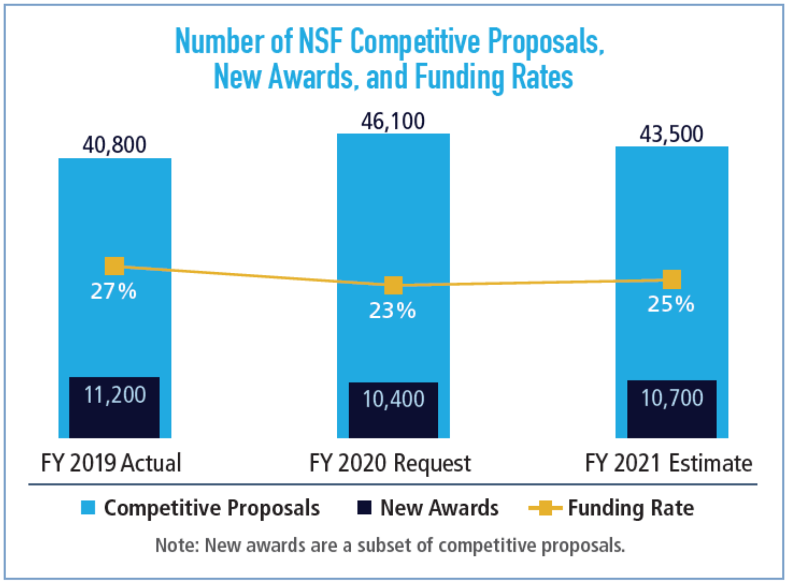
This chart shows the distribution of NSF's obligations by institution type and funding mechanism. While the data shown are based on FY 2019, the relative shares should provide a good indication of the FY 2021 distribution.

Note: NSF Research and Education Programs include R&RA, EHR, and MREFC appropriations. Other institutions funded include federal, state, and local governments; and international organizations. Totals may not add due to rounding.

R&D = Research and Development

Most NSF awards are to academic institutions. As shown in the chart, 78 percent of support for research and education programs ($6,079 million) was to colleges (including two-year and community colleges), universities, and academic consortia. Private industry, including small businesses, accounted for 13 percent ($998 million), and support to Federally Funded Research and Development Centers (FFRDCs) accounted for four percent ($308 million). Other recipients included federal, state, and local governments; nonprofit organizations; and international organizations. A small number of awards fund research in collaboration with other countries, which adds value to the U.S. scientific enterprise and maintains U.S. leadership in the global scientific enterprise.

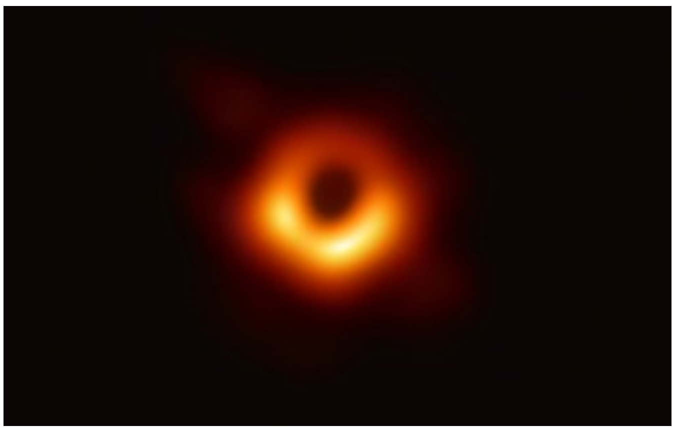
The chart on the left presents a high-level, agency-wide estimate of funding rates, or proposal "success," as a comparison of the number of competitive proposals, new awards, and funding rate between FY 2019, FY 2020, and FY 2021. In FY 2021, NSF expects to make approximately 10.700 new awards, which corresponds to a funding rate of about 25 percent.



Highlights

For 70 years, NSF has invested in fundamental research and education to fulfill its mission of promoting the progress of science and engineering. In doing so, NSF-supported research has connected the discovery and advancement of knowledge with the potential societal, economic, and educational benefits that are critical for continued U.S. prosperity. Below are a few examples of the important advances that NSF funding enables.

Astronomers capture first image of a black hole

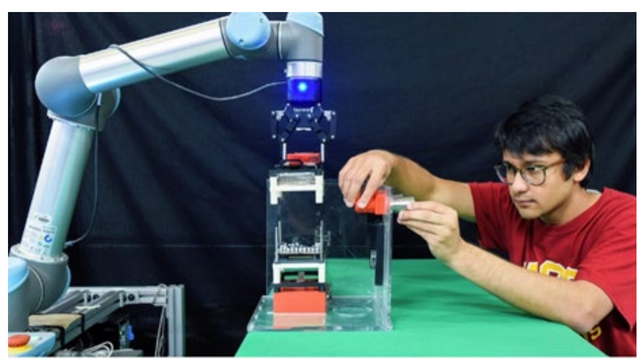


Using the EHT, scientists obtained an image of the black hole at the center of galaxy M87, outlined by emission from hot gas swirling around it under the influence of strong gravity near its event horizon. *Credit: Event Horizon Telescope Collaboration et al.*

The Event Horizon Telescope (EHT) was designed to see the unseeable. Black holes exert such strong gravitational forces that even light can't escape them. It took EHT, a planet-scale array of eight ground-based radio telescopes linked through international collaboration, to gather the first direct visual evidence of a supermassive black hole and its shadow, 55 million light-years from Earth. EHT uses very-long-baseline interferometry (VLBI), which synchronizes telescope facilities around the world to form one huge, Earth-size telescope. Decades of NSF investments in VLBI and radio astronomy technologies led to the creation of EHT and the black-hole image. In 2019, EHT's members received the Breakthrough Prize in Fundamental Physics, an annual recognition of scientific achievements. Their next goals include imaging the supermassive black hole at the center of the Milky Way and capturing video of a black hole.

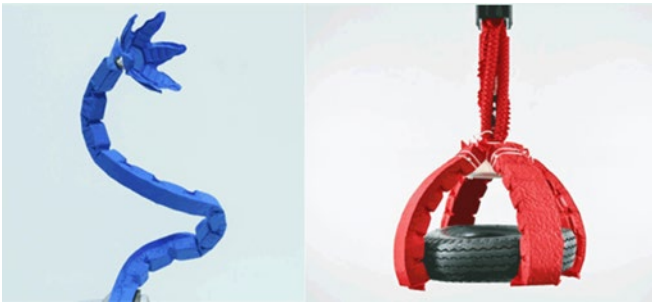
Working with industry to strengthen the STEM workforce

Across the U.S., industries increasingly depend on rapidly changing technology, creating pressure for employers to find workers with STEM skills and knowledge. To empower the workers of today to hold the jobs of tomorrow, a unique public-private partnership will develop online learning platforms and study the effectiveness of courseware to see what connects with learners of different ages and skill levels. Using a $10 million gift from The Boeing Company, NSF funded five separate projects exploring approaches that will allow schools, companies, nonprofits and others to create new learning experiences to build a stronger, more STEM-educated workforce.



The partnership with Boeing will accelerate training in critical skill areas and increase diversity in STEM fields. *Credit: A. Kabir*

Robots with a softer touch



Origami-inspired artificial muscles can lift up to 1,000 times their own weight. *Credit: Shuguang Li, Wyss Institute at Harvard University*

Soft robotics have the potential to revolutionize the way we live, creating machines robust enough to work in healthcare or manufacturing, yet safe to use around people. But for years, their increased dexterity and flexibility came at a cost: reduced strength. NSF-funded researchers found a way around that, though. Using origami as their inspiration, they have created artificial muscles that allow soft robots to lift objects that are up to 1,000 times their own weight—using only air or water pressure. Each artificial muscle consists of an inner "skeleton" surrounded by air or fluid and sealed inside a "skin." The shape and composition of the skeleton determines the muscle's movement. Adaptable, scalable, and presenting comparably little damage if they break, these soft robots could help humans do everything from gently lifting the injured out of hospital beds to assembling cars.

Frontera: Fastest academic supercomputer in the world

Frontera is the most powerful supercomputer on any academic campus and the fifth fastest system in the world. *Credit: TACC*

Scientific challenges increasingly demand more computing power. The U.S. science and engineering community gained a major resource in 2019 when the Texas Advanced Computing Center (TACC) launched Frontera, the most powerful supercomputer on any academic campus and the fifth fastest system in the world. Supported by NSF, Frontera serves as a tool that will enable discoveries by researchers from across the country. Within weeks of coming online, the system had already enabled research in areas ranging from black hole physics to drug design, leveraging data analytics and artificial intelligence capabilities. It has already performed simulations of neutron stars merging and helped train neural networks to predict the characteristics of new drug compounds. Frontera is expected to have a major effect on fields including natural hazards modeling, genomics, astrophysics, and materials sciences.

An entire year trapped in the ice

The German RV Polarstern, which is serving as the base for the MOSAiC expedition, during an Arctic expedition. *Credit: M. Hoppmann*

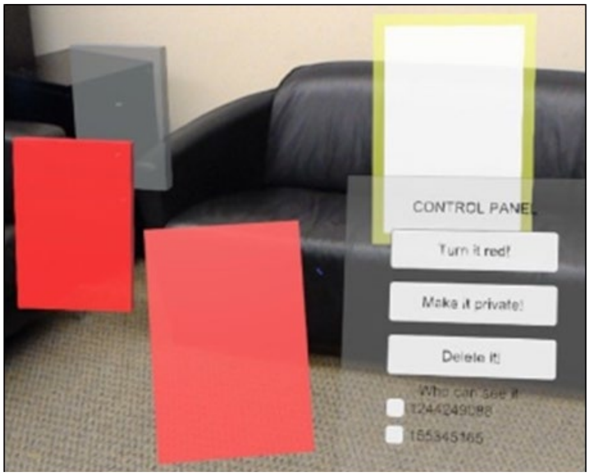
In most cases, having your vessel frozen to an iceberg in the Arctic would be a worst-case scenario. For a group of international researchers who set sail in 2019, it was the launchpad for the largest polar expedition in the world. Hundreds of researchers, including NSF-supported scientists from the U.S., boarded the German research vessel Polarstern for the MOSAiC (Multidisciplinary drifting Observatory for the Study of Arctic Climate) expedition, a year-long operation that required lengthy logistical preparation by NSF staff and their international partners. Researchers worked to set up an observational network monitoring air, land, and sea that stretched over the sea ice as far as 30 miles away from the research vessel. MOSAiC aims to produce breakthroughs in understanding the Arctic climate system.

World's largest outdoor shake table

Earthquakes don't just shake the ground horizontally. They heave it vertically and twist it in ways that can tear buildings apart. Now, thanks to a $16.5 million award from NSF, the world's largest outdoor earthquake simulator, located at the University of California (UC) San Diego, does too. The upgrade will enable this "shake table" to more realistically recreate the ground motions of an earthquake. It will allow engineers to test structures from multi-story buildings to bridge columns and wind turbines to find out how resilient they are to earthquake conditions. The enhanced shake table would teach researchers new lessons even if they just repeated the more than 30 tests conducted since 2004. The engineers working on the upgrade already have a plan for the first structure they'll test with it – a 10-story building made from cross laminated timber.

A graduate student inspects a six-story steel-framed building that is about to be tested on a shake table. *Credit: UC San Diego*

New tools to minimize risks in shared, augmented reality environments

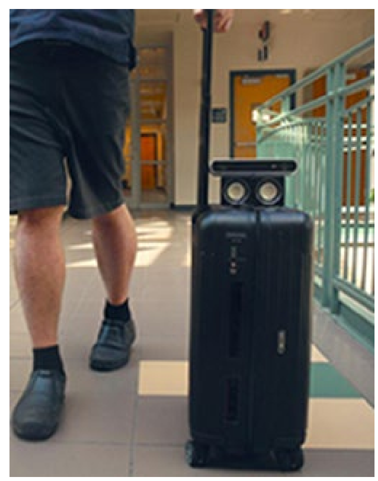


The team tested ShareAR with three case study apps. One of the apps is Doc Edit (above), which lets users create virtual notes or lists they can share or keep private; the semi-transparent gray box in the top left corner represents a "ghost object," or a document that another user wishes to remain private. *Credit: Ruth et al., USENIX Security Symposium*

Augmented reality (AR) has, thus far, largely been deployed in the context of individuals playing popular video games that allow them to use smart phones or other devices to see virtual objects in the physical world around them. But soon this technology may find applications where groups are using it for learning, commerce or industry—which makes it all the more important to figure out how to safeguard AR from hackers and others who would hijack it or breach the privacy of users. NSF-supported researchers are laying the groundwork for a safe AR universe. Their new toolkit, known as ShareAR, lets app developers build in AR features without sacrificing their users' privacy and security. ShareAR is the first of its kind as it takes into account the unique security issues associated with augmented reality, such as the idea that attackers could add malicious or inappropriate items into the virtual environments.

Collision-detecting suitcase

For the visually impaired, unfamiliar environments can prove difficult to navigate. A team of NSF-supported researchers are working to make at least one of those environments safer, with a smart suitcase that warns blind users of impending collisions, along with a wayfinding smartphone app for safe and independent navigation through airport terminals. The rolling suitcase sounds alarms when users are headed for a collision with a pedestrian, and the navigation app provides turn-by-turn audio instructions to users on how to reach a departure gate—or a restroom or a restaurant. The app, known as NavCong, employs airports' Bluetooth beacons, for navigation waypoints.


Researchers have developed a smart suitcase that helps blind travelers navigate crowded airports. *Credit: Carnegie Mellon University*

SUMMARY TABLES

Total NSF Funding:

Major NSF-wide Investments:

STEM Education Investments:

Research Infrastructure:

NATIONAL SCIENCE FOUNDATION
SUMMARY TABLE
FY 2021 BUDGET REQUEST TO CONGRESS
(Dollars in Millions)

NSF by Account	FY 2019 Actual	FY 2020 Enacted[1]	FY 2021 Request	FY 2021 Request change over: FY 2019 Actual Amount	FY 2019 Actual Percent	FY 2020 Enacted Amount	FY 2020 Enacted Percent
BIO	$783.75	-	$704.95	-$78.80	-10.1%	N/A	N/A
CISE	985.12	-	1,062.40	77.28	7.8%	N/A	N/A
ENG	991.15	-	909.78	-81.37	-8.2%	N/A	N/A
Eng Programs	*779.50*	-	*700.53*	*-78.97*	*-10.1%*	*N/A*	*N/A*
SBIR/STTR, including Operations	*211.65*	-	*209.25*	*-2.40*	*-1.1%*	*N/A*	*N/A*
GEO	969.88	-	836.61	-133.27	-13.7%	N/A	N/A
MPS	1,490.61	-	1,448.32	-42.29	-2.8%	N/A	N/A
SBE	271.17	-	246.84	-24.33	-9.0%	N/A	N/A
OISE	49.00	-	44.01	-4.99	-10.2%	N/A	N/A
OPP	488.68	-	419.78	-68.90	-14.1%	N/A	N/A
IA	547.31	-	538.73	-8.58	-1.6%	N/A	N/A
U.S. Arctic Research Commission	1.48	-	1.60	0.13	8.5%	N/A	N/A
Research & Related Activities	**$6,578.14**	**$6,737.20**	**$6,213.02**	**-$365.12**	**-5.6%**	**-$524.18**	**-7.8%**
Education & Human Resources	**$934.53**	**$940.00**	**$930.93**	**-$3.60**	**-0.4%**	**-$9.07**	**-1.0%**
Major Research Equipment & Facilities Construction	**$285.27**	**$243.23**	**$229.75**	**-$55.52**	**-19.5%**	**-$13.48**	**-5.5%**
Agency Operations & Award Management	**$332.69**	**$336.90**	**$345.64**	**$12.95**	**3.9%**	**$8.74**	**2.6%**
Office of Inspector General	**$15.28**	**$16.50**	**$17.85**	**$2.57**	**16.8%**	**$1.35**	**8.2%**
Office of the National Science Board	**$4.32**	**$4.50**	**$4.21**	**-$0.11**	**-2.6%**	**-$0.29**	**-6.4%**
Total, NSF Discretionary Funding	**$8,150.23**	**$8,278.33**	**$7,741.40**	**-$408.83**	**-5.0%**	**-$536.93**	**-6.5%**
Education and Human Resources - H-1B Visa	149.00	234.92	166.26	17.26	11.6%	-68.66	-29.2%
Donations	39.04	65.12	40.00	0.96	2.5%	-25.12	-38.6%
Total, NSF Mandatory Funding	**$188.04**	**$300.03**	**$206.26**	**$18.22**	**9.7%**	**-$93.77**	**-31.3%**
Total, NSF Budgetary Resources	**$8,338.27**	**$8,578.36**	**$7,947.66**	**-$390.61**	**-4.7%**	**-$630.70**	**-7.4%**

Totals exclude reimbursable amounts.

[1] Funding amounts below the account level for the FY 2020 Enacted were not available at the time of printing.

NSF FUNDING PROFILE

The Funding Profile presents a high level, agency-wide estimate of proposal pressure, funding rates (or proposal "success"), and award statistics. These indicators are useful in gauging the relative impact of different funding levels.

Statistics for Competitive Awards: Competitive awards encompass the universe of NSF new activity in a given year. Examples include research grants, cooperative agreements, equipment, fellowships, and conferences.

Statistics for Research Grant Awards: Research Grant Awards are a sub-set of competitive awards. They are limited to research projects and exclude other categories of awards such as those for cooperative agreements, equipment, fellowships, and conferences.

The Number of Proposals is based on several factors, including past actual activity, planned competitions, and research trends within the various disciplinary communities. External factors, such as the state of the national economy and other sources of funding, also play a part. The Number of Awards is also based on several factors, including estimated funding and expected proposal pool. The Funding Rate is the number of awards made during a year as a percentage of total proposals competitively reviewed. This indicates the probability of receiving an award when submitting proposals to NSF. Annualized Award Size shows the annual level of research grant awards provided to awardees by dividing the total dollars of each award by the number of years over which it extends. Average Duration is the length of awards in years.

NSF Funding Profile[1]

	FY 2019 Actual Estimate	FY 2020 (TBD)	FY 2021 Request Estimate
Statistics for Competitive Awards			
Number of Proposals	40,800	-	43,500
Number of Awards	11,200	-	10,700
Funding Rate	27%	-	25%
Statistics for Research Grant Awards			
Number of Research Grant Proposals	33,500	-	34,600
Number of Research Grant Awards	8,500	-	8,100
Funding Rate	25%	-	23%
Median Annualized Award Size	$149,300	-	$220,000
Average Annualized Award Size	$194,400	-	$195,000
Average Duration (years)	3.0	-	3.0

[1] Display excludes NSB, OIG, and staff offices.

NUMBER OF PEOPLE INVOLVED IN NSF ACTIVITIES

NSF estimates that in FY 2021 approximately 299,900 people will be directly involved in NSF programs and activities, receiving salaries, stipends, participant support, and other types of direct involvement. Beyond these figures, NSF programs indirectly impact millions of people, reaching K-12 students and teachers, the general public, and researchers through activities including workshops; informal science activities such as museums, television, videos, and journals; outreach efforts; and dissemination of improved curriculum and teaching methods.

FY 2021 Request
Number of People Involved in NSF Activities

	FY 2019 Actual Estimate	FY 2020 (TBD)	FY 2021 Estimate
Senior Researchers	40,791	-	41,470
Other Professionals	12,134	-	12,110
Postdoctoral Associates	5,320	-	5,050
Graduate Students	41,549	-	39,940
Undergraduate Students	38,226	-	37,030
K-12 Teachers	40,307	-	40,100
K-12 Students	127,332	-	124,200
Total Number of People	**305,659**	**-**	**299,900**

Senior Researchers include scientists, mathematicians, engineers, and educators receiving funding through NSF awards. These include both researchers who are principal or co-principal investigators on research and education projects, and researchers working at NSF-supported centers and facilities.

Other Professionals are individuals who may or may not hold a doctoral degree or its equivalent, are considered professionals but are not reported as senior researchers, postdoctoral associates, or students. Examples are technicians, systems experts, etc.

Postdoctoral Associates are individuals who have received Ph.D., M.D., D.Sc., or equivalent and are not faculty members of the performing institution. These individuals are supported through funds included in research projects, centers, or facilities awards, as well as by postdoctoral fellowships.

Graduate Students include those compensated from NSF grant funds. NSF supports graduate students through NSF's fellowship and traineeship programs as well as research assistantships and funds to assist senior researchers or postdoctoral associates in performing research through awards for research projects, centers, or facilities. NSF provides support for approximately 32 percent of the U.S. science and engineering graduate students receiving federal funds and about five percent of the science and engineering graduate students in the U.S. overall.[1]

Undergraduate Students include students compensated from NSF grant funds who are enrolled in technical colleges or baccalaureate programs. They may be assisting senior researchers or postdoctoral associates in performing research, or participating in NSF programs aimed at undergraduate students, such as Research Experiences for Undergraduates.

[1] Science and Engineering Indicators 2018: Chapter 2 Higher Education in Science and Engineering, Appendix Tables 02-08 and 02-13. Retrieved from www.nsf.gov/statistics/2018/nsb20181/data/appendix?achapter561

K-12 Teachers include teachers at elementary, middle, and secondary schools. These individuals actively participate in intensive professional development experiences in the sciences and mathematics.

K-12 Students are those attending elementary, middle, and secondary schools. They are supported through program components that directly engage students in science and mathematics experiences.

NSF BUDGET REQUESTS AND APPROPRIATIONS BY ACCOUNT: FY 2000 - FY 2021

(Millions of Current Dollars)

Click here for complete history

Fiscal Year	Research & Related Activities (R&RA)		Education & Human Resources (EHR)		Major Research Equipment & Facilities Construction (MREFC)[1]		Agency Operations & Award Management (AOAM)[2]		Office of Inspector General (OIG)		Office of the National Science Board (NSB)		NSF, TOTAL	
	Request	Appropriation	Request	Appropriation	Request	Appropriation	Request	Appropriation	Request	Appropriation	Request	Appropriation	Request	Appropriation
2000	$3,004.00	$2,972.90	$678.00	$690.87	$85.00	$93.50	$149.00	$149.28	$5.45	$5.45	-	-	$3,921.45	$3,912.00
2001	3,540.68	3,356.29	729.01	785.60	138.54	121.33	157.89	161.09	6.28	6.27	-	-	4,572.40	4,430.57
2002	3,326.98	3,612.26	872.41	894.28	96.33	138.80	170.04	171.26	6.76	6.75	-	-	4,472.52	4,823.35
2003	3,783.21	4,069.29	908.08	903.17	126.28	148.54	210.16	189.43	8.06	9.19	-	3.48	5,035.79	5,323.09
2004	4,106.36	4,262.12	938.04	938.98	202.33	154.98	225.70	218.96	8.77	9.94	-	3.88	5,481.20	5,588.86
2005	4,452.31	4,229.98	771.36	841.42	213.27	173.65	294.00	223.45	10.11	10.03	3.95	3.97	5,745.00	5,482.49
2006	4,333.49	4,339.21	737.00	796.69	250.01	190.88	269.00	247.06	11.50	11.35	4.00	3.95	5,605.00	5,589.14
2007	4,665.95	4,654.24	816.22	796.59	240.45	175.61	281.82	248.50	11.86	10.97	3.91	3.97	6,020.21	5,889.87
2008	5,131.69	4,841.73	750.60	765.60	244.74	220.74	285.59	281.79	12.35	11.43	4.03	3.97	6,429.00	6,125.26
2009	*5,593.99*	*5,186.17*	*790.41*	*845.26*	*147.51*	*152.01*	*305.06*	*294.15*	*13.10*	*12.00*	*4.03*	*4.03*	*6,854.10*	*6,493.61*
2009 ARRA	-	*2,500.00*	-	*100.00*	-	*400.00*		-	-	*2.00*		-	-	*3,002.00*
2009 Total	5,593.99	7,686.17	790.41	945.26	147.51	552.01	305.06	294.15	13.10	14.00	4.03	4.03	6,854.10	9,495.61
2010	5,733.24	5,563.92	857.76	872.76	117.29	117.29	318.37	300.00	14.00	14.00	4.34	4.54	7,045.00	6,872.51
2011	6,018.83	5,509.98	892.00	861.03	165.19	117.06	329.19	299.40	14.35	13.97	4.84	4.53	7,424.40	6,805.98
2012	6,253.54	5,689.00	911.20	829.00	224.68	197.06	357.74	299.40	15.00	14.20	4.84	4.44	7,767.00	7,033.10
2013	5,983.28	5,543.72	875.61	833.31	196.17	196.17	299.40	293.60	14.20	13.19	4.44	4.12	7,373.10	6,884.11
2014	6,212.29	5,808.92	880.29	846.50	210.12	200.00	304.29	298.00	14.32	14.20	4.47	4.30	7,625.78	7,171.92
2015	5,807.46	5,933.65	889.75	866.00	200.76	200.76	338.23	325.00	14.43	14.43	4.37	4.37	7,255.00	7,344.21
2016	6,186.30	5,989.68	962.57	878.97	200.31	218.31	354.84	357.00	15.16	15.16	4.37	4.37	7,723.55	7,463.49
2017	6,425.44	6,005.65	952.86	873.05	193.12	214.86	373.02	359.09	15.20	15.20	4.38	4.37	7,964.02	7,472.22
2018[3]	5,361.65	6,334.48	760.55	902.00	182.80	182.80	328.51	328.51	15.01	15.20	4.37	4.37	6,652.89	7,767.36
2019	6,150.68	6,504.51	873.37	922.00	94.65	295.74	333.63	333.03	15.35	15.35	4.32	4.37	7,472.00	8,075.00
2020[4]	5,662.96	6,737.20	823.47	940.00	223.23	243.23	336.89	336.90	15.35	16.50	4.10	4.50	7,066.00	8,278.33
2021	6,213.02	-	930.93	-	229.75	-	345.64	-	17.85	-	4.21	-	7,741.40	-

Appropriations as shown are after supplemental appropriations, transfers, and reprogrammings.

[1] The Major Research Equipment and Facilities Construction (MREFC) account was previously known as Major Research Equipment (MRE) until FY 2002.

[2] The Agency Operations and Award Management (AOAM) account was known as Salaries & Expenses (S&E) until FY 2008.

[3] FY 2018 appropriations include Additional Supplemental Appropriations for Disaster Relief Requirements Act of 2018 (P.L. 115-123), which provided NSF $16.30 million in no-year funding to repair radio observatory facilities damaged by hurricanes that occurred during 2017.

[4] FY 2020 Appropriations are Enacted appropriations.

NATIONAL SCIENCE FOUNDATION
NSF CONVERGENCE ACCELERATOR AND BIG IDEAS FUNDING
FY 2021 BUDGET REQUEST TO CONGRESS
(Dollars in Millions)

NSF Convergence Accelerator and Big Ideas	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
NSF Convergence Accelerator (CA)	**$41.39**	**-**	**$70.00**
Harnessing the Data Revolution for 21st Century Science and Engineering (HDR)	21.45	-	16.50
The Future of Work at the Human-Technology Frontier (FW-HTF)	19.60	-	16.50
New and Emerging CA Research Tracks	0.34	-	35.00
CA Planning and Development	-	-	2.00
Research Ideas	**$179.99**	**-**	**$230.00**
Harnessing the Data Revolution for 21st Century Science and Engineering (HDR)	30.01	-	45.00
The Future of Work at the Human-Technology Frontier (FW-HTF)	29.96	-	45.00
Navigating the New Arctic (NNA)	30.00	-	30.00
The Quantum Leap (QL)	30.02	-	50.00
Understanding the Rules of Life (URoL)	30.00	-	30.00
Windows on the Universe (WoU)	30.00	-	30.00
Enabling Big Ideas	**$102.54**	**-**	**$131.79**
Growing Convergence Research (GCR)	15.80	-	15.20
Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science (NSF INCLUDES)	20.20	-	18.92
Mid-scale Research Infrastructure	60.04	-	97.67
Mid-scale RI Track 1	*60.04*	-	*32.67*
Mid-scale RI Track 2	-	-	*65.00*
NSF 2026[1]	6.51	-	-
Total, NSF Convergence Accelerator and Big Ideas	**$323.92**	**-**	**$431.79**

[1] NSF 2026 funding includes IA support of CAREER and REU Supplement awards.

NATIONAL SCIENCE FOUNDATION
SELECTED CROSSCUTTING PROGRAMS
FY 2021 BUDGET REQUEST TO CONGRESS
(Dollars in Millions)

Selected Cross-Cutting Programs		FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	FY 2021 Request change over FY 2019 Actual Amount	Percent
ADVANCE	Research & Related Activities	16.47	-	-	-16.47	-100.0%
	Education & Human Resources	1.53	-	17.03	15.50	1016.0%
	Total, NSF	**$18.00**	**-**	**$17.03**	**-$0.97**	**-5.4%**
Faculty Early Career Development - CAREER	Research & Related Activities	364.34	-	254.22	-110.12	-30.2%
	Education & Human Resources	-	-	-	-	N/A
	Total, NSF	**$364.34**	**-**	**$254.22**	**-$110.12**	**-30.2%**
Long-Term Ecological Research Sites - LTERs	Research & Related Activities	33.21	-	27.96	-5.25	-15.8%
	Education & Human Resources	-	-	-	-	N/A
	Total, NSF	**$33.21**	**-**	**$27.96**	**-$5.25**	**-15.8%**
National Nanotechnology Coordinated Infrastructure - NNCI	Research & Related Activities	15.25	-	13.71	-1.54	-10.1%
	Education & Human Resources	-	-	-	-	N/A
	Total, NSF	**$15.25**	**-**	**$13.71**	**-$1.54**	**-10.1%**
Research Experiences for Undergraduates - REU - Sites Only	Research & Related Activities	69.57	-	56.03	-13.54	-19.5%
	Education & Human Resources	-	-	-	-	N/A
	Total, NSF	**$69.57**	**-**	**$56.03**	**-$13.54**	**-19.5%**
Research Experiences for Undergraduates - REU - Supplements Only	Research & Related Activities	21.48	-	17.57	-3.91	-18.2%
	Education & Human Resources	-	-	-	-	N/A
	Total, NSF	**$21.48**	**-**	**$17.57**	**-$3.91**	**-18.2%**
Total, Research Experiences for Undergraduates - REU	Research & Related Activities	91.05	-	73.60	-17.45	-19.2%
	Education & Human Resources	-	-	-	-	N/A
	Total, NSF	**$91.05**	**-**	**$73.60**	**-$17.45**	**-19.2%**
Research in Disabilities Education - RDE	Research & Related Activities	1.96	-	-	-1.96	-100.0%
	Education & Human Resources	11.82	-	6.50	-5.32	-45.0%
	Total, NSF	**$13.77**	**-**	**$6.50**	**-$7.27**	**-52.8%**
Research in Undergraduate Institutions - RUI	Research & Related Activities	39.10	-	33.20	-5.90	-15.1%
	Education & Human Resources	-	-	-	-	N/A
	Total, NSF	**$39.10**	**-**	**$33.20**	**-$5.90**	**-15.1%**

NATIONAL SCIENCE FOUNDATION
NSTC CROSSCUTS SUMMARY
FY 2021 BUDGET REQUEST TO CONGRESS
(Dollars in Millions)

National Nanotechnology Initiative (NNI)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	FY 2021 Request change over FY 2019 Actual: Amount	Percent
BIO	$42.50	-	$39.95	-$2.55	-6.0%
CISE	13.50	-	13.08	-0.42	-3.1%
ENG	218.35	-	199.00	-19.35	-8.9%
MPS	243.34	-	199.00	-44.34	-18.2%
SBE	0.40	-	-	-0.40	-100.0%
OISE	0.10	-	-	-0.10	-100.0%
R&RA	**$518.19**	**-**	**$451.03**	**-$67.16**	**-13.0%**
EHR	**$2.53**	**-**	**$2.50**	**-$0.03**	**-1.2%**
NSF Total	**$520.72**	**-**	**$453.53**	**-$67.19**	**-12.9%**

Networking & Information Technology R&D (NITRD)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	FY 2021 Request change over FY 2019 Actual: Amount	Percent
BIO	$77.00	-	$90.00	$13.00	16.9%
CISE	980.32	-	1,062.40	82.08	8.4%
ENG	129.45	-	142.37	12.92	10.0%
GEO	20.00	-	19.00	-1.00	-5.0%
MPS	173.71	-	213.39	39.68	22.8%
SBE	26.56	-	31.67	5.11	19.2%
R&RA	**$1,407.04**	**-**	**$1,558.83**	**$151.79**	**10.8%**
EHR	**$9.90**	**-**	**$9.50**	**-$0.40**	**-4.0%**
NSF Total	**$1,416.94**	**-**	**$1,568.33**	**$151.39**	**10.7%**

U.S. Global Change Research Program (USGCRP)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	FY 2021 Request change over FY 2019 Actual: Amount	Percent
BIO	$90.00	-	$88.25	-$1.75	-1.9%
GEO	120.00	-	106.50	-13.50	-11.3%
SBE	16.50	-	11.73	-4.77	-28.9%
OPP	14.28	-	10.61	-3.67	-25.7%
R&RA	**$240.78**	**-**	**$217.09**	**-$23.69**	**-9.8%**
EHR	**-**	**-**	**-**	**-**	**N/A**
NSF Total	**$240.78**	**-**	**$217.09**	**-$23.69**	**-9.8%**

NATIONAL SCIENCE FOUNDATION
NATIONAL NANOTECHNOLOGY INITIATIVE SUMMARY
FY 2021 BUDGET REQUEST TO CONGRESS
(Dollars in Millions)

	BIO	CISE	ENG	MPS	SBE	OISE	RRA	EHR	Total
Total, FY 2019 Actual	**$42.50**	**$13.50**	**$218.35**	**$243.34**	**$0.40**	**$0.10**	**$518.19**	**$2.53**	**$520.72**
NNI Grand Challenge (GC) and Signature Initiative (NSI) Total	-	1.98	99.35	49.59	-	-	150.92	-	**150.92**
Sustainable Nanomanufacturing	-	-	*30.00*	*10.10*	-	-	*40.10*	-	***40.10***
Nanoelectronics for 2020 and Beyond	-	-	*21.00*	*30.82*	-	-	*51.82*	-	***51.82***
Nanotechnology Knowledge Infrastructure	-	-	*19.00*	*3.67*	-	-	*22.67*	-	***22.67***
Nanotechnology for Sensors and Sensors for Nanotechnology	-	-	*7.00*	*4.59*	-	-	*11.59*	-	***11.59***
Water Sustainability through Nanotechnology	-	-	*12.35*	*0.41*	-	-	*12.76*	-	***12.76***
Nanotechnology-Inspired Grand Challenge for Future Computing	-	*1.98*	*10.00*	-	-	-	*11.98*	-	***11.98***
Environment, Health, and Safety	-	-	9.00	3.81	-	-	12.81	-	**12.81**
Foundational Research	40.00	6.98	52.00	172.39	-	-	271.37	-	**271.37**
Nanotechnology-Enabled Applications, Devices, and Systems	-	2.94	44.00	10.77	-	-	57.71	-	**57.71**
Research Infrastructure and Instrumentation	2.50	1.60	14.00	6.78	0.40	0.10	25.38	2.53	**27.91**
Delta from FY 2019 Actual to FY 2021 Request	**-$2.55**	**-$0.42**	**-$19.35**	**-$44.34**	**-$0.40**	**-$0.10**	**-$67.16**	**-$0.03**	**-$67.19**
NNI Grand Challenge (GC) and Signature Initiative (NSI) Total	-	-0.06	-19.35	-31.09	-	-	-50.50	-	**-50.50**
Sustainable Nanomanufacturing	-	-	-	*-8.10*	-	-	*-8.10*	-	***-8.10***
Nanoelectronics for 2020 and Beyond	-	-	-	*-17.82*	-	-	*-17.82*	-	***-17.82***
Nanotechnology Knowledge Infrastructure	-	-	*-19.00*	*-3.67*	-	-	*-22.67*	-	***-22.67***
Nanotechnology for Sensors and Sensors for Nanotechnology	-	-	-	*-3.09*	-	-	*-3.09*	-	***-3.09***
Water Sustainability through Nanotechnology	-	-	*-0.35*	*0.59*	-	-	*0.24*	-	***0.24***
Nanotechnology-Inspired Grand Challenge for Future Computing	-	*-0.06*	-	*1.00*	-	-	*0.94*	-	***0.94***
Environment, Health, and Safety	-	-	-	-2.29	-	-	-2.29	-	**-2.29**
Foundational Research	-2.40	-0.22	-	-10.31	-	-	-12.93	-	**-12.93**
Nanotechnology-Enabled Applications, Devices, and Systems	-	-0.09	-	-6.87	-	-	-6.96	-	**-6.96**
Research Infrastructure and Instrumentation	-0.15	-0.05	-	6.22	-0.40	-0.10	5.52	-0.03	**5.49**
Total, FY 2021 Request	**$39.95**	**$13.08**	**$199.00**	**$199.00**	**-**	**-**	**$451.03**	**$2.50**	**$453.53**
NNI Grand Challenge (GC) and Signature Initiative (NSI) Total	**-**	**1.92**	**80.00**	**18.50**	**-**	**-**	100.42	-	**100.42**
Sustainable Nanomanufacturing	-	-	*30.00*	*2.00*	-	-	*32.00*	-	***32.00***
Nanoelectronics for 2020 and Beyond	-	-	*21.00*	*13.00*	-	-	*34.00*	-	***34.00***
Nanotechnology Knowledge Infrastructure	-	-	-	-	-	-	-	-	**-**
Nanotechnology for Sensors and Sensors for Nanotechnology	-	-	*7.00*	*1.50*	-	-	*8.50*	-	***8.50***
Water Sustainability through Nanotechnology	-	-	*12.00*	*1.00*	-	-	*13.00*	-	***13.00***
Nanotechnology-Inspired Grand Challenge for Future Computing	-	*1.92*	*10.00*	*1.00*	-	-	*12.92*	-	***12.92***
Environment, Health, and Safety	-	-	9.00	1.52	-	-	10.52	-	**10.52**
Foundational Research	37.60	6.76	52.00	162.08	-	-	258.44	-	**258.44**
Nanotechnology-Enabled Applications, Devices, and Systems	-	2.85	44.00	3.90	-	-	50.75	-	**50.75**
Research Infrastructure and Instrumentation	2.35	1.55	14.00	13.00	-	-	30.90	2.50	**33.40**

NATIONAL SCIENCE FOUNDATION
NETWORKING AND INFORMATION TECHNOLOGY R&D SUMMARY
FY 2021 BUDGET REQUEST TO CONGRESS
(Dollars in Millions)

	BIO	CISE	ENG	GEO	MPS	SBE	RRA	EHR	Total
Total, FY 2019 Actual	**$77.00**	**$980.32**	**$129.45**	**$20.00**	**$173.71**	**$26.56**	**$1,407.04**	**$9.90**	**$1,416.94**
Artificial Intelligence	15.00	135.92	59.23	-	23.52	1.29	234.96	-	234.96
Computing-Enabled Human Interaction,	-	68.53	16.11	-	-	9.99	94.63	-	94.63
Computing-Enabled Networked Physical Systems	1.00	64.36	11.73	-	-	-	77.09	-	77.09
Cyber Security & Privacy	-	99.85	2.17	-	1.70	6.54	110.26	-	110.26
Education and Workforce	6.00	61.23	4.27	-	0.11	-	71.61	9.90	81.51
Enabling-R&D for High-Capability Computing System	-	102.82	1.90	-	74.05	-	178.77	-	178.77
High Capability Computing Infrastructure & Applications	2.50	111.41	9.77	20.00	52.49	-	196.17	-	196.17
Intelligent Robotics and Autonomous Systems	-	30.72	15.17	-	-	-	45.89	-	45.89
Large-Scale Data Management and Analysis	38.00	120.01	7.49	-	21.85	6.90	194.24	-	194.24
Large Scale Networking	-	130.65	0.66	-	-	-	131.31	-	131.31
Software Productivity, Sustainability and Quality	14.50	54.82	0.95	-	-	1.84	72.11	-	72.11
Delta from FY 2019 Actual to FY 2021 Request	**$13.00**	**$82.08**	**$12.92**	**-$1.00**	**$39.68**	**$5.11**	**$151.79**	**-$0.40**	**$151.39**
Artificial Intelligence	1.42	107.36	15.10	-	57.35	8.92	190.15	-	190.15
Computing-Enabled Human Interaction,	-	-0.13	-0.53	-	-	-1.60	-2.26	-	-2.26
Computing-Enabled Networked Physical Systems	-0.06	6.60	-0.74	-	-	-	5.80	-	5.80
Cyber Security & Privacy	-	-0.45	-0.08	-	-0.75	-2.74	-4.02	-	-4.02
Education and Workforce	-0.36	-19.53	-0.08	-	-0.11	-	-20.08	-0.40	-20.48
Enabling-R&D for High-Capability Computing System	-	-8.22	-0.04	-	-7.55	-	-15.81	-	-15.81
High Capability Computing Infrastructure & Applications	-0.15	-8.92	-0.18	-1.00	-15.56	-	-25.81	-	-25.81
Intelligent Robotics and Autonomous Systems	-	11.96	-0.27	-	-	-	11.69	-	11.69
Large-Scale Data Management and Analysis	13.02	16.96	-0.23	-	-10.71	0.56	19.61	-	19.61
Large Scale Networking	-	-17.30	-0.01	-	17.00	-	-0.31	-	-0.31
Software Productivity, Sustainability and Quality	-0.87	-6.25	-0.02	-	-	-0.03	-7.17	-	-7.17
Total, FY 2021 Request	**$90.00**	**$1,062.40**	**$142.37**	**$19.00**	**$213.39**	**$31.67**	**$1,558.83**	**$9.50**	**$1,568.33**
Artificial Intelligence	16.42	243.28	74.33	-	80.87	10.21	425.11	-	425.11
Computing-Enabled Human Interaction,	-	68.40	15.58	-	-	8.39	92.37	-	92.37
Computing-Enabled Networked Physical Systems	0.94	70.96	10.99	-	-	-	82.89	-	82.89
Cyber Security & Privacy	-	99.40	2.09	-	0.95	3.80	106.24	-	106.24
Education and Workforce	5.64	41.70	4.19	-	-	-	51.53	9.50	61.03
Enabling-R&D for High-Capability Computing System	-	94.60	1.86	-	66.50	-	162.96	-	162.96
High Capability Computing Infrastructure & Applications	2.35	102.49	9.59	19.00	36.93	-	170.36	-	170.36
Intelligent Robotics and Autonomous Systems	-	42.68	14.90	-	-	-	57.58	-	57.58
Large-Scale Data Management and Analysis	51.02	136.97	7.26	-	11.14	7.46	213.85	-	213.85
Large Scale Networking	-	113.35	0.65	-	17.00	-	131.00	-	131.00
Software Productivity, Sustainability and Quality	13.63	48.57	0.93	-	-	1.81	64.94	-	64.94

NATIONAL SCIENCE FOUNDATION
U.S. GLOBAL CHANGE RESEARCH PROGRAM
FY 2021 BUDGET REQUEST TO CONGRESS
(Dollars in Millions)

	BIO	GEO	SBE	OPP	RRA	Total
Total, FY 2019 Actual	**$90.00**	**$120.00**	**$16.50**	**$14.28**	**$240.78**	**$240.78**
Communication and Education	-	-	-	-	-	**-**
Integrated Modeling	-	20.00	3.87	3.28	27.15	**$27.15**
Integrated Observations	65.00	20.00	-	5.00	90.00	**$90.00**
Multidisciplinary Earth and Human System Understanding	25.00	75.00	7.26	6.00	113.26	**$113.26**
Science of Adaptation and Science to Inform Adaptation Decisions	-	5.00	5.36	-	10.36	**$10.36**
Delta from FY 2019 Actual to FY 2021 Request	**-$1.75**	**-$13.50**	**-$4.77**	**-$3.67**	**-$23.69**	**-$23.69**
Communication and Education	-	-	-	-	-	**-**
Integrated Modeling	-	-1.00	-0.57	-0.98	-2.55	**-$2.55**
Integrated Observations	-	-4.00	-	-1.50	-5.50	**-$5.50**
Multidisciplinary Earth and Human System Understanding	-1.75	-8.50	-3.75	-1.19	-15.19	**-$15.19**
Science of Adaptation and Science to Inform Adaptation Decisions	-	-	-0.44	-	-0.44	**-$0.44**
Total, FY 2021 Request	**$88.25**	**$106.50**	**$11.73**	**$10.61**	**$217.09**	**$217.09**
Communication and Education	-	-	-	-	-	**-**
Integrated Modeling	-	19.00	3.30	2.30	24.60	**$24.60**
Integrated Observations	65.00	16.00	-	3.50	84.50	**$84.50**
Multidisciplinary Earth and Human System Understanding	23.25	66.50	3.51	4.81	98.07	**$98.07**
Science of Adaptation and Science to Inform Adaptation Decisions	-	5.00	4.92	-	9.92	**$9.92**

NATIONAL SCIENCE FOUNDATION
PROGRAMS TO BROADEN PARTICIPATION
FY 2021 BUDGET REQUEST TO CONGRESS

(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	FY 2021 Request change over FY 2019 Actual	
				Amount	Percent
Total, NSF Broadening Participation Programs	**$1,178.75**	**-**	**$998.42**	**-$180.33**	**-15.3%**

NSF has taken a variety of approaches to broaden participation across its many programs. While broadening participation is included in the NSF review criteria, some program announcements and solicitations go beyond the standard criteria. They range from encouraging language to specific requirements. Investments range from capacity building, research centers, partnerships, and alliances to the use of co-funding or supplements to existing awards in the core research programs.

NSF's broadening participation portfolio can be divided into three categories: (1) Focused, (2) Emphases, and (3) Geographic Diversity. The following sections define each of these categories and provide a list of the programs and activities with their respective funding levels that comprise each.

Focused Programs

Focused Programs have broadening participation as an explicit goal of the program and are included at 100 percent of their funding.

(Dollars in Millions)

	Amount of Funding Captured	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	FY 2021 Request change over FY 2019 Actual Amount	Percent
ADVANCE	100%	$18.00	-	$17.03	-$0.97	-5.4%
Alliances for Graduate Education & the Professoriate (AGEP)	100%	7.99	-	7.13	-0.86	-10.8%
AGEP Graduate Research Supplements (AGEP-GRS)	100%	2.14	-	1.50	-0.64	-30.0%
Broadening Participation in Biology Fellowships	100%	2.50	-	2.50	-	-
Broadening Participation in Engineering (BPE)	100%	2.97	-	6.13	3.16	106.4%
Career-Life Balance (CLB)[1]	100%	0.54	-	-	-0.54	-100.0%
Centers of Research Excellence in Science & Technology (CREST)	100%	24.00	-	21.41	-2.59	-10.8%
Excellence Awards in Science & Engineering (EASE)[2]	100%	5.63	-	3.78	-1.85	-32.8%
Historically Black Colleges & Universities Undergraduate Program (HBCU-UP)	100%	35.01	-	31.22	-3.79	-10.8%
HBCU Excellence in Research (HBCU-EiR)	100%	15.20	-	9.50	-5.70	-37.5%
Improving Undergraduate STEM Education (IUSE): Hispanic Serving Institutions (HSI) program	100%	40.01	-	14.19	-25.82	-64.5%
Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science (NSF INCLUDES)	100%	20.20	-	18.92	-1.28	-6.3%
Louis Stokes Alliances for Minority Participation (LSAMP)	100%	46.01	-	43.53	-2.48	-5.4%
Partnerships for Research & Education in Materials (PREM)	100%	6.55	-	7.00	0.45	6.9%
SBE Postdoctoral Research Fellowships-Broadening Participation	100%	1.33	-	1.41	0.08	6.3%
Science of Broadening Participation	100%	1.40	-	1.42	0.02	1.4%
Tribal Colleges & Universities Program (TCUP)	100%	15.01	-	12.49	-2.52	-16.8%
Subtotal, Focused Programs		**$244.48**	**-**	**$199.16**	**-$45.32**	**-18.5%**

[1] NSF continues to support the Career-Life Balance (CLB) Initiative through supplemental funding to active NSF awards. In general, CLB funding will be reported annually as part of NSF's actual obligations.

[2] The Excellence Awards in Science and Engineering (EASE) program is comprised of both Presidential Awards for Excellence in Science, Math and Engineering Mentoring (PAESMEM) and Presidential Awards for Excellence in Mathematics and Science Teaching (PAEMST).

Emphasis Programs

Emphasis Programs have broadening participation as one of several emphases, but broadening participation is not an explicit goal of the program. These programs are included at a percentage of their funding level. The percentage used equals the 3-year average percentage of the programs' award portfolio that meets one the following criteria where an award:

- Was to a Minority Serving Institution (MSI);
- Had at least 50 percent of its principal investigators from an underrepresented group; or
- Had at least 50 percent of the students or postdocs supported by the grant reporting themselves as members of an underrepresented group on project reports.

(Dollars in Millions)

	Amount of Funding Captured	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	FY 2021 Request change over FY 2019 Actual	
					Amount	Percent
Advancing Informal STEM Learning (AISL)	50%	$31.37	-	$28.00	-$3.37	-10.7%
Computer Science for All (CSforAll)[3]	58%	[11.60]	-	11.00	-0.60	-5.2%
Disability and Rehabilitation Engineering (DARE)	50%	2.61	-	2.21	-0.40	-15.2%
Discovery Research PreK-12 (DRK-12)	64%	56.28	-	57.35	1.07	1.9%
Faculty Early Career Development Program (CAREER)	51%	185.45	-	129.40	-56.05	-30.2%
Graduate Research Fellowship Program (GRFP)	66%	186.38	-	180.31	-6.07	-3.3%
Improving Undergraduate STEM Education (IUSE)	66%	66.98	-	57.95	-9.02	-13.5%
Innovative Technology Experiences for Students and Teachers (ITEST)[4]	71%	24.17	-	27.71	3.54	14.6%
International Research Experiences for Students (IRES)	58%	6.91	-	7.06	0.14	2.1%
NSF Scholarships in STEM (S-STEM)[4]	53%	60.36	-	61.94	1.57	2.6%
Research Experiences for Undergraduates (REU) - Sites and Supplements	64%	58.55	-	47.32	-11.22	-19.2%
Robert Noyce Teacher Scholarship Program (NOYCE)	57%	42.86	-	25.35	-17.51	-40.9%
STEM + Computing (STEM+C) Partnerships[3]	57%	36.70	-	-	-36.70	-100.0%
Subtotal, Emphasis Programs		**$758.60**	**-**	**$635.59**	**-$123.01**	**-16.2%**

[3] In FY 2019, CSforAll was supported as a component of STEM+C. The FY 2019 Actual is shown for comparison purposes only. In FY 2020, funding for STEM+C moves to implement CSforAll as a freestanding program and to expand EHR's computer science education portfolio through existing programs.

[4] Innovative Technology Experiences for Students and Teachers (ITEST) and NSF Scholarships in Science, Technology, Engineering, and Mathematics (S-STEM) are H1B Visa funded programs.

Geographic Diversity Programs

Geographic Diversity Programs, EPSCoR, has geographic diversity as an explicit goal of the program and is included at 100 percent of its funding.

(Dollars in Millions)

	Amount of Funding Captured	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	FY 2021 Request change over FY 2019 Actual	
					Amount	Percent
EPSCoR	100%	$175.67	-	$163.67	-$12.00	-6.8%
Subtotal, Geographic Diversity Program		**$175.67**	**-**	**$163.67**	**-$12.00**	**-6.8%**

NATIONAL SCIENCE FOUNDATION
EDUCATION AND HUMAN RESOURCES FUNDING BY DIVISION AND PROGRAM
FY 2021 BUDGET REQUEST TO CONGRESS
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	FY 2021 Request change over FY 2019 Actual: Amount	Percent
Division of Research on Learning in Formal and Informal Settings (DRL)	**$228.27**	**-**	**$223.53**	**-$4.74**	**-2.1%**
Learning and Learning Environments	**25.70**	**-**	**70.28**	**44.58**	**173.4%**
Computer Science for All (CSforAll)[1]	-	-	9.46	9.46	N/A
EHR Core Research (ECR): STEM Learning	25.70	-	60.82	35.12	136.6%
Broadening Participation and Institutional Capacity	**150.69**	**-**	**145.66**	**-5.03**	**-3.3%**
Advancing Informal STEM Learning (AISL)	62.48	-	55.77	-6.71	-10.7%
Discovery Research PreK-12 (DRK-12)	88.21	-	89.89	1.68	1.9%
STEM Professional Workforce	**51.88**	**-**	**7.59**	**-44.29**	**-85.4%**
National Artificial Intelligence Research Institutes	-	-	7.59	7.59	N/A
STEM + Computing (STEM+C) Partnerships[1]	51.88	-	-	-51.88	-100.0%
Division of Graduate Education (DGE)	**$253.33**	**-**	**$282.03**	**$28.70**	**11.3%**
Learning and Learning Environments	**6.68**	**-**	**-**	**-6.68**	**-100.0%**
Project and Program Evaluation (PPE)[2]	6.68	-	-	-6.68	-100.0%
STEM Professional Workforce	**246.65**	**-**	**282.03**	**35.38**	**14.3%**
EHR Core Research (ECR): STEM Professional Workforce Preparation	16.02	-	30.39	14.37	89.7%
Cybercorps®: Scholarship for Service (SFS)	55.33	-	52.13	-3.20	-5.8%
Graduate Research Fellowship Program (GRFP)	142.26	-	137.64	-4.62	-3.2%
NSF Research Traineeship (NRT)[3]	33.04	-	61.87	28.83	87.3%
Division of Human Resource Development (HRD)	**$188.11**	**-**	**$188.78**	**$0.67**	**0.4%**
Learning and Learning Environments	**59.54**	**-**	**67.87**	**8.33**	**14.0%**
ADVANCE[4]	1.53	-	17.03	15.50	1015.8%
Alliances for Graduate Education and the Professoriate (AGEP)	7.99	-	7.13	-0.86	-10.8%
Historically Black Colleges and Universities Undergraduate Program (HBCU-UP)	35.01	-	31.22	-3.79	-10.8%
Tribal Colleges and Universities Program (TCUP)	15.01	-	12.49	-2.52	-16.8%
Broadening Participation and Institutional Capacity	**98.94**	**-**	**95.72**	**-3.22**	**-3.3%**
EHR Core Research (ECR): Broadening Participation and Institutional Capacity in STEM	12.92	-	28.54	15.62	120.8%
IUSE: Hispanic Serving Institutions (HSI) Program	20.01	-	4.73	-15.28	-76.4%
Big Idea: NSF INCLUDES	20.01	-	18.92	-1.09	-5.4%
Louis Stokes Alliances for Minority Participation (LSAMP)	46.01	-	43.53	-2.48	-5.4%
STEM Professional Workforce	**29.63**	**-**	**25.19**	**-4.44**	**-15.0%**
Centers for Research Excellence in Science and Technology (CREST)	24.00	-	21.41	-2.59	-10.8%
Excellence Awards in Science and Engineering (EASE)	5.63	-	3.78	-1.85	-32.8%
Division of Undergraduate Education (DUE)	**$264.82**	**-**	**$236.59**	**-$28.23**	**-10.7%**
Learning and Learning Environments	**123.12**	**-**	**121.15**	**-1.97**	**-1.6%**
EHR Core Research (ECR): STEM Learning Environments	13.13	-	37.60	24.47	186.3%
Improving Undergraduate STEM Education (IUSE)	89.99	-	74.09	-15.90	-17.7%
IUSE: Hispanic Serving Institutions (HSI) Program	20.00	-	9.46	-10.54	-52.7%
STEM Professional Workforce	**141.70**	**-**	**115.44**	**-26.26**	**-18.5%**
Advanced Technological Education (ATE)	66.51	-	70.97	4.46	6.7%
Robert Noyce Teacher Scholarship Program (Noyce) - Annual	64.50	-	44.47	-20.03	-31.1%
Robert Noyce Teacher Scholarship Program (Noyce) - No Year	10.69	-	-	-10.69	-100.0%
Total, EHR	**$934.53**	**-**	**$930.93**	**-$3.60**	**-0.4%**
Total, Learning and Learning Environments	**$215.04**	**-**	**$259.30**	**$44.26**	**20.6%**
Total, Broadening Participation and Institutional Capacity	**$249.63**	**-**	**$241.38**	**-$8.25**	**-3.3%**
Total, STEM Professional Workforce	**$469.85**	**-**	**$430.25**	**-$39.60**	**-8.4%**

[1] In FY 2019, CSforAll was supported as a component of STEM+C. The FY 2019 Actual is shown for comparison purposes only. In FY 2020, funding for STEM+C will move to implement CSforAll as a freestanding program and to expand EHR's computer science education portfolio through existing programs.

[2] The termination of PPE reflects EHR's return to a decentralized model where evaluation efforts are funded through existing programs. The last year of funding for PPE was FY 2019.

[3] Total FY 2019 Actual funding for NRT is $53.50 million with $20.45 million contributed from the R&RA account. Beginning in FY 2020, all funding for NRT resides in the EHR account. For more information on NRT, see the Major STEM Graduate Education narrative in the NSF-Wide Investments chapter.

[4] Total FY 2019 Actual funding for ADVANCE is $18.0 million with $16.47 million contributed from the R&RA account. Beginning in FY 2020, all funding for ADVANCE resides in the EHR account.

NATIONAL SCIENCE FOUNDATION
CoSTEM INVENTORY AND POSTDOCTORAL FELLOWSHIP PROGRAMS
BY LEVEL OF EDUCATION
FY 2021 BUDGET REQUEST TO CONGRESS
(Dollars in Millions)

		FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	FY 2021 Request change over FY 2019 Actual: Amount	Percent
Minority-Serving Institutions		**$50.02**	**-**	**$43.71**	**-$6.31**	**-12.6%**
UG	Historically Black Colleges and Universities Undergraduate Program (HBCU-UP)	35.01	-	31.22	-3.79	-10.8%
UG	Tribal Colleges and Universities Program (TCUP)	15.01	-	12.49	-2.52	-16.8%
Fellowships and Scholarships		**$583.91**	**-**	**$551.50**	**-$32.41**	**-5.6%**
UG	NSF Scholarships in STEM (S-STEM) (H-1B)	114.76	-	117.75	2.99	2.6%
UG	Robert Noyce Scholarship (Noyce) Program	75.19	-	44.47	-30.72	-40.9%
G	CyberCorps®: Scholarship for Service (SFS)	55.33	-	52.13	-3.20	-5.8%
G	Graduate Research Fellowship Program (GRFP)	284.55	-	275.28	-9.27	-3.3%
G	NSF Research Traineeship (NRT)	54.09	-	61.87	7.78	14.4%
Other Grant Programs		**$731.40**	**-**	**$709.60**	**-$21.80**	**-3.0%**
K-12	Computer Science for All (CSforAll)[1]	[20.00]	-	18.97	-1.03	-5.2%
K-12	Discovery Research PreK-12 (DRK-12)	88.21	-	89.89	1.68	1.9%
K-12	Innovative Technology Experiences for Teachers and Students (ITEST) (H1-B)	34.24	-	39.25	5.01	14.6%
K-12	STEM + Computing (STEM+C) Partnerships[1]	64.38	-	-	-64.38	-100.0%
UG	Advanced Technological Education (ATE)	66.51	-	70.97	4.46	6.7%
UG	Emerging Frontiers in Research and Innovation (EFRI) Research Experience and Mentoring (REM)	1.17	-	0.71	-0.46	-39.3%
UG	Harnessing the Data Revolution (HDR): Data Science Corps (DSC)	7.32	-	6.00	-1.32	-18.0%
UG	IUSE: Hispanic Serving Institutions Program (HSI) Program	40.01	-	14.19	-25.82	-64.5%
UG	Improving Undergraduate STEM Education (IUSE)	101.94	-	88.21	-13.73	-13.5%
UG	International Research Experiences for Students (IRES)	12.00	-	12.25	0.25	2.1%
UG	Louis Stokes Alliances for Minority Participation (LSAMP)	46.01	-	43.53	-2.48	-5.4%
UG	Research Experiences for Undergraduates (REU) - Sites and Supplements	91.05	-	73.60	-17.45	-19.2%
UG	Research Experiences for Teachers (RET) in Engineering and Computer Science	10.85	-	5.44	-5.41	-49.9%
G	Alliances for Graduate Education and the Professoriate (AGEP)	7.99	-	7.13	-0.86	-10.8%
G	Training-based Workforce Development for Advanced Cyberinfrastructure (CyberTraining)	3.64	-	3.64	-0.00	-0.1%
O&I	Advancing Informal STEM Learning (AISL)	62.48	-	55.77	-6.71	-10.7%
O&I	Excellence Awards in Science and Engineering (EASE)	5.63	-	3.78	-1.85	-32.8%
O&I	Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science (NSF INCLUDES)	20.20	-	18.92	-1.28	-6.3%
O&I	EHR Core Research (ECR)[2]	67.77	-	157.35	89.58	132.2%
Subtotal, Above Categories (CoSTEM Inventory		**$1,365.34**	**-**	**$1,304.81**	**-$60.53**	**-4.4%**
G	**NSF Postdoctoral Programs**	**$25.11**	**-**	**$18.86**	**-$6.25**	**-24.9%**
	Astronomy and Astrophysics Postdoctoral Fellowships (AAPF)	2.30	-	2.50	0.20	8.7%
	Geosciences Postdoctoral Fellowships	1.91	-	3.40	1.49	77.6%
	Mathematical Sciences Postdoctoral Research Fellowships (MSPRF)	6.15	-	4.50	-1.65	-26.8%
	Postdoctoral Research Fellowships in Biology (PRFB)	11.65	-	5.64	-6.01	-51.6%
	SPRF-Broadening Participation	1.33	-	1.41	0.08	6.3%
	SPRF-Fundamental Research	1.77	-	1.41	-0.36	-20.4%
K-12 STEM Education Programs (K-12) Subtotal		**$186.83**	**-**	**$148.11**	**-$38.72**	**-20.7%**
Undergraduate STEM Education Programs (UG) Subtotal		**$616.83**	**-**	**$520.83**	**-$96.00**	**-15.6%**
Graduate and Professional STEM Education Programs (G) Subtotal		**$430.71**	**-**	**$418.91**	**-$11.80**	**-2.7%**
Outreach and Informal STEM Education Programs (O&I) Subtotal		**$156.08**	**-**	**$235.82**	**$79.74**	**51.1%**
Total, NSF STEM Education		**$1,390.45**	**-**	**$1,323.67**	**-$66.78**	**-4.8%**

[1] In FY 2019, CSforAll was supported as a component of STEM+C. The FY 2019 Actual is shown for comparison purposes only. In FY 2020, funding for STEM+C moves to implement CSforAll as a freestanding program and to expand EHR's computer science education portfolio through existing programs.

[2] ECR was not included in previous years, but recent evaluations by EHR determined that ECR does meet the CoSTEM inclusion criteria. Beginning with the FY 2021 Budget Request to Congress ECR is included.

NATIONAL SCIENCE FOUNDATION
RESEARCH INFRASTRUCTURE (RI) FUNDING, BY ACCOUNT AND ACTIVITY
FY 2021 BUDGET REQUEST TO CONGRESS
(Dollars in Millions)

	FY 2019 Actual	**FY 2019 Actual RI Funding**	FY 2020 (TBD)	**FY 2020 (TBD) RI Funding**	FY 2021 Request	**FY 2021 Request RI Funding**	**FY 2021 Request RI change over FY 2019 Actual RI**	
							Amount	**Percent**
BIO	$783.75	**$139.26**	-	-	$704.95	**$125.11**	-$14.15	-10.2%
CISE	985.12	**172.23**	-	-	1,062.40	**150.60**	-21.63	-12.6%
ENG	991.15	**23.49**	-	-	909.78	**21.97**	-1.52	-6.5%
GEO	969.88	**422.44**	-	-	836.61	**356.06**	-66.38	-15.7%
MPS	1,490.61	**430.34**	-	-	1,448.32	**337.16**	-93.18	-21.7%
SBE	271.17	**62.68**	-	-	246.84	**59.39**	-3.29	-5.2%
OISE	49.00	**0.10**	-	-	44.01	**-**	-0.10	-100.0%
OPP	488.68	**363.45**	-	-	419.78	**317.74**	-45.71	-12.6%
IA	547.31	**138.14**	-	-	538.73	**97.60**	-40.54	-29.3%
U.S. Arctic Research Commission	1.48	**-**	-	-	1.60	**-**	-	N/A
Research & Related Activities	$6,578.14	**$1,752.12**	-	-	$6,213.02	**$1,465.63**	-$286.49	-16.4%
Education & Human Resources	$934.53	**-**	-	-	$930.93	**-**	-	N/A
Major Research Equipment & Facilities Construction	$285.27	**$284.95**	-	-	$229.75	**$228.75**	-$56.20	-19.7%
Agency Operations & Award Management	$332.69	**-**	-	-	$345.64	**-**	-	N/A
Office of Inspector General	$15.28	**-**	-	-	$17.85	**-**	-	N/A
Office of the National Science Board	$4.32	**-**	-	-	$4.21	**-**	-	N/A
Total	**$8,150.23**	**$2,037.07**	**-**	**-**	**$7,741.40**	**$1,694.38**	**-$342.69**	**-16.8%**

NATIONAL SCIENCE FOUNDATION
RESEARCH INFRASTRUCTURE SUMMARY
FY 2021 BUDGET REQUEST TO CONGRESS
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	FY 2021 Request change over FY 2019 Actual Amount	Percent
Operations and Maintenance of Major Facilities[1]	**$1,024.38**	**-**	**$867.42**	**-$156.96**	**-15.3%**
Major Research Facilities Construction Investments	**$286.95**	**-**	**$163.75**	**-$123.20**	**-42.9%**
Construction, Acquisition, and Commissioning (MREFC)[2]	284.95	-	163.75	-121.20	-42.5%
Design Stage Activities[3]	2.00	-	-	-2.00	-100.0%
Mid-scale Research Infrastructure[4]	**$94.46**	**-**	**$116.73**	**$22.27**	**23.6%**
MREFC Mid-scale Research Infrastructure[2]	-	-	65.00	65.00	N/A
NSF-wide Mid-scale Research Infrastructure (R&RA)	60.04	-	32.67	-27.37	-45.6%
Directorate Midscale Research Infrastructure Programs	34.43	-	19.06	-15.37	-44.6%
Major Research Instrumentation (MRI)	**$75.11**	**-**	**$61.70**	**-$13.41**	**-17.9%**
Polar Logistical and Infrastructure Support[5]	**$138.57**	**-**	**$118.36**	**-$20.21**	**-14.6%**
CISE Networking and Computational Resources Infrastructure and Services (NCRIS)[6]	**$124.91**	**-**	**$111.04**	**-$13.87**	**-11.1%**
Research Resources[7]	**$210.89**	**-**	**$173.10**	**-$37.79**	**-17.9%**
BIO	63.98	-	58.76	-5.22	-8.2%
CISE	44.71	-	39.00	-5.71	-12.8%
GEO	63.11	-	48.22	-14.89	-23.6%
MPS	22.32	-	15.10	-7.22	-32.4%
SBE	8.82	-	7.98	-0.84	-9.5%
OPP	7.95	-	4.04	-3.91	-49.2%
Other Research Infrastructure	**$83.53**	**-**	**$83.60**	**$0.07**	**0.1%**
Subtotal, Research Infrastructure Support	**$2,038.81**	**-**	**$1,695.70**	**-$343.11**	**-16.8%**
Research Infrastructure Stewardship Offset	-1.74	-	-1.32	0.42	-24.1%
RESEARCH INFRASTRUCTURE TOTAL	**$2,037.07**	**-**	**$1,694.38**	**-$342.69**	**-16.8%**

[1] For facility level detail on operations and maintenance, see the Major Multi-User Research Facilities table in the Facilities chapter.

[2] Construction, Acquisition, and Commissioning are for implementation support provided through the MREFC account. MREFC funding is included for Daniel K. Inouye Solar Telescope (DKIST, $19.59 million); Regional Class Research Vessels (RCRV, $108.12 million); and National Ecological Observatory Network (NEON, $70,000) in FY 2019; and Antarctic Infrastructure Modernization for Science (AIMS, $103.70 million in FY 2019 and $90.0 million in FY 2021); Vera C. Rubin Observatory ($53.48 million in FY 2019 and $40.75 million in FY 2021); the High Luminosity-Large Hadron Collider Upgrade (HL-LHC) ($33.0 million in FY 2021), and Mid-scale Research Infrastructure ($65.0 million in FY 2021, shown on the MREFC Mid-scale RI line below).

[3] Design Stage Activities include support for potential next generation multi-user facilities funded through R&RA. This line reflects FY 2019 funding of $2.0 million for the potential Leadership Class Computing Facility.

[4] NSF-wide Mid-scale Research Infrastructure is provided through both the R&RA account (if the total project cost is less than $20.0 million) and the MREFC account (if the total project cost is greater than $20.0 million). For more information, please refer to the Mid-scale Research Infrastructure narrative in the NSF-wide Investments chapter.

[5] Polar Logistical and Infrastructure Support includes funding for Arctic Logistics; U.S. Antarctic Logistical Support Activities (USALS); and Polar Environment, Health, and Safety (PEHS).

[6] Funding for Networking and Computational Resources Infrastructure and Services excludes support for the potential Leadership Class Computing Facility in FY 2019 ($2.0 million), which is captured under Design Stage Activities above.

[7] Funding for Research Resources includes support for the operation and maintenance of minor facilities, infrastructure and instrumentation, field stations, museum collections, etc.

NSF AUTHORIZATIONS

NATIONAL SCIENCE FOUNDATION CURRENT AUTHORIZATIONS

(Dollars in Millions)

LEGISLATION	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Authorization Levels FY 2019	FY 2020	FY 2021
National Science Foundation Act of 1950, P.L. 81-507[1]						
Scholarships and Graduate Fellowships				*within limits of funds made available for this purpose*		
General Authority				*within the limits of available appropriations*		
Administering Provisions				*to make such expenditures as may be necessary*		
International Cooperation and Coordination with Foreign Policy				*within the limit of appropriated funds*		
Contract Arrangements				*utilize appropriations available*		
American Innovation and Competitiveness Act P.L. 114-329 (Does not authorize appropriations)				*(Does not authorize appropriations)*		
The American Innovation and Competitiveness Act authorizes NSF's research and education programs. The law also promotes NSF's commitment to diversity in STEM fields, and incentivizes NSF programs which encourage private-sector involvement, while re-affirming NSF's continued commitment to entrepreneurship and commercialization.						
SBIR and STTR reauthorized through 2022 at current levels under the National Defense Authorization Act of Fiscal Year 2017, P.L. 114-328						
Small Business Innovation Research (SBIR) Program[2]	**$181.87**	**-**	**$179.06**	*3.2% of research funds in 2019, 2020, and 2021*		
Small Business Technology Transfer (STTR) Program[2]	**$24.78**	**-**	**$25.19**	*0.45% of research funds in 2019, 2020, and 2021*		
The Research Excellence and Advancements for Dyslexia Act (READ Act), P.L. 114-124[3]	**$11.07**	*	*	*$5.00*	*$5.00*	*$5.00*
The National Science Foundation shall support multi-directorate, merit-reviewed, and competitively awarded research on the science of specific learning disability, including dyslexia, such as research on the early identification of children and students with dyslexia, professional development for teachers and administrators of students with dyslexia, curricula and educational tools needed for children with dyslexia, and implementation and scaling of successful models of dyslexia intervention.[4]						

NATIONAL SCIENCE FOUNDATION CURRENT AUTHORIZATIONS

(Dollars in Millions)

LEGISLATION	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Authorization Levels FY 2019	FY 2020	FY 2021
Promoting Women in Entrepreneurship Act, P.L. 115-6 (Does not authorize appropriations) *Amends the Science and Engineering Equal Opportunities Act to authorize the National Science Foundation to encourage its entrepreneurial programs to recruit and support women to extend their focus beyond the laboratory and into the commercial world.*				*(Does not authorize appropriations)*		
National Defense Authorization Act for Fiscal Year 2018, P.L. 115-91 (Does not authorize appropriations) *Amends the Cyber Scholarship-for-Service program established under section 302 of the Cybersecurity Enhancement Act of 2014 (15 U.S.C. 7442) to implement a pilot program at community colleges to provide scholarships to eligible students who are pursuing associate degrees or specialized program certifications in the field of cybersecurity; and have bachelor's degrees; or are veterans of the Armed Forces.* *It also amends the National Science Foundation Authorization Act of 2002 (42 U.S.C. 1862n-1(i)) to define the term 'mathematics and science teacher 'and the term 'science, technology, engineering, or mathematics professional'.*				*(Does not authorize appropriations)*		
Women in Aerospace Education Act, P.L. 115-303 (Does not authorize appropriations) *Amends the National Science Foundation Authorization Act of 2002 to permit certain grants awarded by the National Science Foundation (NSF) to be used to provide internships that include research experiences at national laboratories and National Aeronautics and Space Administration (NASA) centers. NSF Master Teaching Fellows and undergraduate freshman and sophomore students studying to become mathematics and science teachers under the Robert Noyce Teacher Scholarship Program are eligible for the internships.*				*(Does not authorize appropriations)*		

NATIONAL SCIENCE FOUNDATION CURRENT AUTHORIZATIONS

(Dollars in Millions)

LEGISLATION	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Authorization Levels FY 2019	FY 2020	FY 2021
National Earthquake Hazards Reduction Program Reauthorization Act of 2018, P.L. 115-307 *Amends the Earthquake Hazards Reduction Act of 1977 to expand activities under the National Earthquake Hazards Reduction Program to include: (1) gathering information on community resilience (i.e., the ability of a community to prepare for, recover from, and adapt to earthquakes); (2) publishing a systematic set of maps of active faults and folds, liquefaction susceptibility, susceptibility for earthquake-induced landslides, and other seismically induced hazards; and (3) continuing the development of the Advanced National Seismic System, including earthquake early warning capabilities.* *With respect to earthquake hazard reduction activities, the bill revises or expands the duties of: (1) the Interagency Coordinating Committee on Earthquake Hazards Reduction, (2) the National Institute of Standards and Technology (NIST), (3) the Federal Emergency Management Agency (FEMA), (4) the U.S. Geological Survey (USGS), and (5) the National Science Foundation.* [5]	**$46.96**	**-**	**$50.61**		*$54.00*	*$54.00*
National Quantum Initiative Act, P.L. 115-368 *Authorizes the National Science Foundation to carry out a basic research and education program on quantum information science and engineering, and award grants for the establishment of at least 2 but not more than 5 Multidisciplinary Centers for Quantum Research and Education up to $10 million each for each of fiscal years 2019 through 2023.*				*(Does not authorize appropriations)*		

[1] Organic legislation establishing NSF.

[2] SBIR and STTR are reauthorized through September 30, 2022.

[3] Actual amounts will be reported after awards are completed.

[4] The $5.0 million shall include not less than $2.50 million for research on the science of dyslexia, for each of fiscal years 2017 through 2021. FY 2019 Actuals funding includes $7.99 million for dyslexia research.

[5] Authorizes $54.0 million for the National Earthquake Hazards Reduction Program at NSF for each of fiscal years FY 2019 through FY 2023.

NATIONAL SCIENCE FOUNDATION (NSF)
COMPUTER SCIENCE EDUCATION RESEARCH CONGRESSIONAL REPORT
IN COMPLIANCE WITH PUBLIC LAW 114-329:
AMERICAN INNOVATION AND COMPETITIVENESS ACT, SEC. 310 (E)

Summary

The American Innovation and Competitiveness Act, 2017, Public Law 114-329, requires the National Science Foundation (NSF) to undertake specific activities regarding computer science education research (Sec. 310):

"(b) GRANT PROGRAM.-

(1) IN GENERAL. — The Director of the Foundation shall award grants to eligible entities to research computer science education and computational thinking.

(2) RESEARCH. — The research described in paragraph (1) may include the development or adaptation, piloting or full implementation, and testing of —

A. models of preservice preparation for teachers who will teach computer science and computational thinking;
B. scalable and sustainable models of professional development and ongoing support for the teachers described in subparagraph (A);
C. tools and models for teaching and learning aimed at supporting student success and inclusion in computing within and across diverse populations, particularly poor, rural, and tribal populations and other populations that have been historically underrepresented in computer science and STEM fields; and
D. high-quality learning opportunities for teaching computer science and, especially in poor, rural, or tribal schools at the elementary school and middle school levels, for integrating computational thinking into STEM teaching and learning.

(c) COLLABORATIONS. — In carrying out the grants established in subsection (b), eligible entities may collaborate and partner with local or remote schools to support the integration of computing and computational thinking within pre-kindergarten through grade 12 STEM curricula and instruction.

(d) METRICS. — The Director of the Foundation shall develop metrics to measure the success of the grant program funded under this section in achieving program goals.

(e) REPORT. — The Director of the Foundation shall report, in the annual budget submission to Congress, on the success of the program as measured by the metrics in subsection (d).

(f) DEFINITION OF ELIGIBLE ENTITY. — In this section, the term "eligible entity" means an institution of higher education or a non-profit research organization."

Background

NSF launched the Computer Science for All: Researcher Practitioner Partnerships (CSforAll: RPP) program in 2017 with solicitation NSF 17-525.[1] In 2018, NSF issued an updated solicitation, NSF 18-537.[2]

[1] www.nsf.gov/pubs/2017/nsf17525/nsf17525.htm
[2] www.nsf.gov/pubs/2018/nsf18537/nsf18537.htm

The CSforAll: RPP synopsis, as articulated in the latest solicitation, is as follows:

> "This program aims to provide all U.S. students the opportunity to participate in computer science (CS) and computational thinking (CT) education in their schools at the preK-12 levels. With this solicitation, the National Science Foundation (NSF) focuses on researcher-practitioner partnerships (RPPs) that foster the research and development needed to bring CS and CT to all schools. Specifically, this solicitation aims to provide high school teachers with the preparation, professional development (PD) and ongoing support that they need to teach rigorous computer science courses; preK-8 teachers with the instructional materials and preparation they need to integrate CS and CT into their teaching; and schools and districts the resources needed to define and evaluate multi-grade pathways in CS and CT."

The revised solicitation added the focus on researcher-practitioner partnerships that are supporting schools and districts in defining and evaluating multi-grade pathways in CS and CT. Clear pathways for coursework and other experiences in CS and CT - from elementary to middle school, middle to high school, and high school into the first years of college - are important for educators to support systemic implementation of CS and CT in schools.

Metrics

The program team developed and reported short-, mid-, and longer-term metrics for success as follows:

- Short-term metrics will focus on ensuring that the program is making awards in the four areas outlined in the law and that the awards address the goal of broadening participation in computer science. One indicator of broadening participation is the diversity of the populations supported educationally in the awards.
- Mid-term metrics will include the extent to which funded projects are achieving goals as measured by the progress reported in NSF's required annual and final project reports.
- Longer-term (beyond five years) metrics will include an evaluation of the outcomes of the program, which are based on the program aims as described in the program solicitation and the requirements of Public Law 114-329. Program staff are working with the Evaluation and Monitoring group within NSF's Directorate for Education and Human Resources and Evaluation and Assessment Capability within NSF's Office of Integrative Activities to develop (1) a set of specific longer-term metrics and (2) a program evaluation plan for measuring the collective success of the CSforAll: RPP projects using these longer-term metrics.

Report on the Success of the Program as Measured by the Short-Term Metrics

Between the submission of the last annual report and December 2019, 31 new awards were made by the program in FY 2019 pursuant to NSF 18-537. Below is a summary of the FY 2019 CSforAll: RPP projects [Note: some awards address more than one of the goals described in (b)(2)A-D, so the number of awards sums to more than 31]:

- 9 awards address subsection (b)(2)A and (b)(2)B;
- 20 awards address subsection (b)(2)C; and
- 9 awards address multi-grade pathways to CT and CS.

Finally, all new awards served at least one underrepresented or underserved group, as outlined in the table below (Note: some awards serve more than one underrepresented group, so the number of awards in the table sum to more than 31).

Underrepresented or Underserved Group Served by Backbone Organizations

Category	Groups Served
Rural	8
Low Socio-Economic Status	11
Disabilities	4
Pacific Islanders	4
Women/Girls	11
English Language Learners	4
African-Americans	11
Native Americans	7
Latino/a	15

NATIONAL SCIENCE FOUNDATION (NSF)
ESTABLISHED PROGRAM TO STIMULATE COMPETITIVE RESEARCH (EPSCOR)
CONGRESSIONAL REPORT IN COMPLIANCE WITH PUBLIC LAW 114-329: AMERICAN INNOVATION AND COMPETITIVENESS ACT, SEC. 103 (D) (1-3)
FISCAL YEAR 2019

This report summarizes fiscal year (FY) 2019 NSF funding to institutions and entities in EPSCoR jurisdictions, as required by the American Innovation and Competitiveness Act Sec. 103(d)(1-3). Specifically, the report itemizes

(1) a description of the program strategy and objectives;
(2) a description of the awards made in the previous fiscal year including
  (A) the total amount made available, by state, under EPSCoR;
  (B) the total amount of agency funding made available to all institutions and entities within each EPSCoR state;
  (C) the efforts and accomplishments to more fully integrate the EPSCoR states in major agency activities and initiatives;
  (D) the percentage of EPSCoR reviewers from EPSCoR states;
  (E) the number of programs or large collaborator awards involving a partnership of organizations and institutions from EPSCoR and non-EPSCoR states; and
(3) an analysis of the gains in academic research quality and competitiveness, and in science and technology human resource development, achieved by the program over the last 5 years.

Introduction

EPSCoR utilizes three investment strategies in pursuit of its goal to strengthen research capacity and competitiveness in eligible jurisdictions. These investment strategies are: (1) Research Infrastructure Improvement (RII) awards that support physical, human, and cyberinfrastructure development; (2) Co-Funding in partnership with NSF directorates and offices that support individual investigators and groups within EPSCoR jurisdictions; and (3) Outreach activities and workshops that bring EPSCoR jurisdiction investigators together with program staff from across the Foundation to explore opportunities in emerging areas of science and engineering aligned with NSF strategic priorities and with jurisdictional science and technology goals.

EPSCoR Strategies and Objectives (Sec. 103(d)(1)).c

EPSCoR's strategies and objectives in FY 2019 remain the same as those described in the FY 2018 report. Specifically, the mission of EPSCoR is "to enhance research competitiveness of targeted jurisdictions (states, territories, commonwealths) by strengthening STEM capacity and capability." Thus, EPSCoR's goals are:

- To catalyze the development of research capabilities and the creation of new knowledge that expands jurisdictions' contributions to scientific discovery, innovation, learning, and knowledge-based prosperity.
- To establish sustainable Science, Technology, Engineering and Math (STEM) education, training, and professional development pathways that advance jurisdiction-identified research areas, NSF focus areas, and workforce development.
- To broaden direct participation of diverse individuals, institutions, and organizations in the project's science and engineering research and education initiatives.
- To effect sustainable engagement of project participants and partners, the jurisdiction, the national research community, and the general public through data-sharing, communication, outreach, and dissemination.

- To impact research, education, and economic development beyond the project at academic, government, and private sector levels.

NSF Funding Made Available, by jurisdiction, under EPSCoR (Sec. 103(d)(2)(A)).

In FY 2019, NSF EPSCoR invested a total of $175.67 million in support of its programmatic activities. Of this, $144.94 million (82.5 percent) was directed to RII, $30.61 million (17.4 percent) to co-funding, and $120,000 (0.1 percent) to outreach activities and workshops. The table below details the investments from EPSCoR resources and EPSCoR investments in co-funding actions.

FY 2019 EPSCoR Funding by Jurisdiction

(Dollars in Millions)

EPSCoR Jurisdiction	RII Program	Outreach & Workshops	EPSCoR Co-funding	EPSCoR Total
AK	$11.29	-	$0.96	$12.25
AL	3.77	0.10	2.63	6.50
AR	-	-	1.37	1.37
DE	7.52	-	1.46	8.98
GU	-	-	0.43	0.43
HI	3.00	-	0.30	3.30
IA	-	-	1.65	1.65
ID	13.39	-	0.51	13.90
KS	1.96	-	1.69	3.65
KY	3.82	-	1.27	5.09
LA	6.04	-	1.98	8.02
ME	7.88	-	0.41	8.29
MS	3.97	-	1.82	5.79
MT	8.30	-	0.78	9.08
ND	-	-	0.76	0.76
NE	8.75	-	1.28	10.03
NH	6.41	-	1.52	7.93
NM	8.20	-	0.84	9.04
NV	0.80	-	1.15	1.95
OK	1.00	-	1.56	2.56
PR	5.72	-	0.62	6.34
RI	9.06	-	1.12	10.18
SC	9.05	-	1.40	10.45
SD	9.83	-	0.09	9.92
VI	-	-	0.30	0.30
VT	-	-	0.54	0.54
WV	6.00	-	0.35	6.35
WY	4.96	-	1.27	6.23
Admin	4.22	0.02	0.55	4.79
Total	**$144.94**	**$0.12**	**$30.61**	**$175.67**

Total NSF Funding Made Available in all EPSCoR Jurisdictions (Sec. 103 (d)(2)(B)).

In FY 2019, NSF invested a total of $915.70 million in support of EPSCoR jurisdictions. The table below details NSF investments in EPSCoR jurisdictions including research support funding, education and human resources, and major research equipment.

FY 2019 NSF Funding
Made Available to All EPSCoR Jurisdictions
(Dollars in Millions)

EPSCoR Jurisdiction	NSF Funding
AK	$62.20
AL	58.99
AR	19.72
DE	41.14
GU	1.21
HI	54.18
IA	45.64
ID	30.77
KS	37.96
KY	32.03
LA	39.21
ME	25.01
MS	24.51
MT	31.49
ND	8.67
NE	41.76
NH	41.95
NM	45.76
NV	25.95
OK	31.12
PR	19.36
RI	56.49
SC	67.59
SD	20.29
VI	2.92
VT	6.12
WV	15.13
WY	28.53
Total	**$915.70**

Integration of EPSCoR Jurisdictions in Major Activities and Initiatives of the Foundation (Sec. 103 (d)(2)(C)).

All EPSCoR programmatic activities target integration and assimilation of EPSCoR jurisdictions into the research and education programs of the Foundation's disciplinary directorates. RII awards promote the coordination and integration of recipient jurisdictions into major NSF programmatic activities. Additionally, EPSCoR consults and engages NSF disciplinary program officers (POs) in merit review processes and post-award evaluations, such as site visits and reverse site visits (RSVs). Site visits and RSVs are intended to provide additional project oversight by allowing jurisdictions to report on the progress of their RII projects in relation to their stated goals and the programmatic terms and conditions. Disciplinary POs assist in the identification of reviewers, serve as site visit and RSV observers, and provide knowledge about the ongoing activities within the directorate that could be leveraged to sustain RII efforts after the performance period of the EPSCoR award.

National, regional, and jurisdictional meetings of the EPSCoR community facilitate grantee interactions with NSF leadership to learn about the Foundation's strategic priorities and funding opportunities. Participation by EPSCoR researchers and educators in the merit review process across all disciplinary domains of the Foundation, in Committees of Visitors (COV) activities, in external advisory (Federal Advisory Committee Act) committees, and in disciplinary workshops that shape new activities is also vital to this integration.

Outreach to EPSCoR jurisdictions by NSF staff promotes integration of the EPSCoR community into mainstream NSF programs, as does co-funding of awards with the disciplinary programs of the Foundation. There is also an effort to promote in-reach, whereby EPSCoR facilitates opportunities for researchers and educators from EPSCoR jurisdictions to meet with NSF staff at the Foundation's headquarters. In these meetings, the EPSCoR participants are provided with information on NSF strategic priorities and funding opportunities.

In FY 2019, EPSCoR staff promoted engagement of the EPSCoR community in NSF and other national activities. Examples are:

- Convened a regional outreach meeting, "All About NSF Research Center Programs," in Mobile, AL. The event provided extensive information about the various NSF Center programs and was intended to help pave the way for EPSCoR researchers to take the next steps in leveraging their current funding and research to create a culture of sustainability and move onto the next big project. Over 80 participants attended, representing 17 jurisdictions.
- Hosted its annual principal investigator meeting, a two-day event with opportunities for the EPSCoR community and NSF program officers to interact and share best practices in strategic planning, diversity, communication, evaluation, and other areas of importance to EPSCoR jurisdictions and NSF.
- Supported planning for the 26th NSF EPSCoR National Conference, in Columbia, SC, in October 2019. The theme of the conference was *Science and Partnerships across Disciplinary Boundaries* and ~400 faculty, staff, students and postdoctoral scholars from all EPSCoR jurisdictions and RII Tracks as well as interested stakeholders attended.
- Encouraged EPSCoR-supported faculty to participate in NSF committee and review panels across NSF (e.g., COVs, site visits, and merit review panels).
- Continued the RII Track-2: Focused EPSCoR Collaborations (RII Track-2 FEC) solicitation. RII Track-2 FEC builds interjurisdictional collaborative teams of EPSCoR investigators in scientific focus areas consistent with NSF priorities. In addition, these awards have a particular focus on the development of early career/junior faculty. In FY 2019, proposals were invited on the topic of "Harnessing big data to solve problems of national importance," aligned with the NSF Big Idea of Harnessing the Data Revolution, and ten awards were made.
- Continued the RII Track-4, EPSCoR Research Fellows solicitation, which provides opportunities for early career researchers to further develop their individual research potential through extended collaborative visits to the Nation's premier private, governmental, or academic research centers. Proposals in all areas of science and engineering supported by NSF were invited and awards for the FY 2019 competition were made with next year funding.
- Convened two meetings with the EPSCoR Interagency Coordinating Committee (EICC) to share relevant program information and identify opportunities for coordination.

EPSCoR Reviewers (Sec. 103(d)(2)(D)).

Demographics of all reviewers who evaluated EPSCoR proposals or the program in FY 2019 are as follows: of the 114 reviewers, 19 percent were underrepresented minorities, 46 percent were female, 18 percent were from EPSCoR jurisdictions.

EPSCoR Collaborations and Partnerships (Sec. 103(d)(2)(E)).

All RII awards involve collaborations among scientists and engineers in EPSCoR jurisdictions. Additionally, RII awards require institutional collaborations, which are defined as collaborations between researchers at a RII awardee or sub-awardee and those at institutions not receiving any RII funds.

In FY 2019, there were 519 institutional collaborations within EPSCoR jurisdictions; 557 institutional collaborations between EPSCoR jurisdictions and other EPSCoR and non-EPSCoR jurisdictions; and 220 collaborations between institutions in EPSCoR jurisdictions and in foreign countries. These collaborative efforts highlight the vast network of institutional involvement among EPSCoR jurisdictions and their partners in RII projects.

Among the 185 awards co-funded by EPSCoR in FY 2019, 77 involved collaborative research between multiple institutions. Of those 77 collaborative awards, 54 were collaborations between investigators from institutions in EPSCoR and non-EPSCoR jurisdictions.

An analysis of the gains in academic research quality and competitiveness, and in science and technology human resource development, achieved by the program over the last 5 fiscal years (Sec. 103(d)(3)).

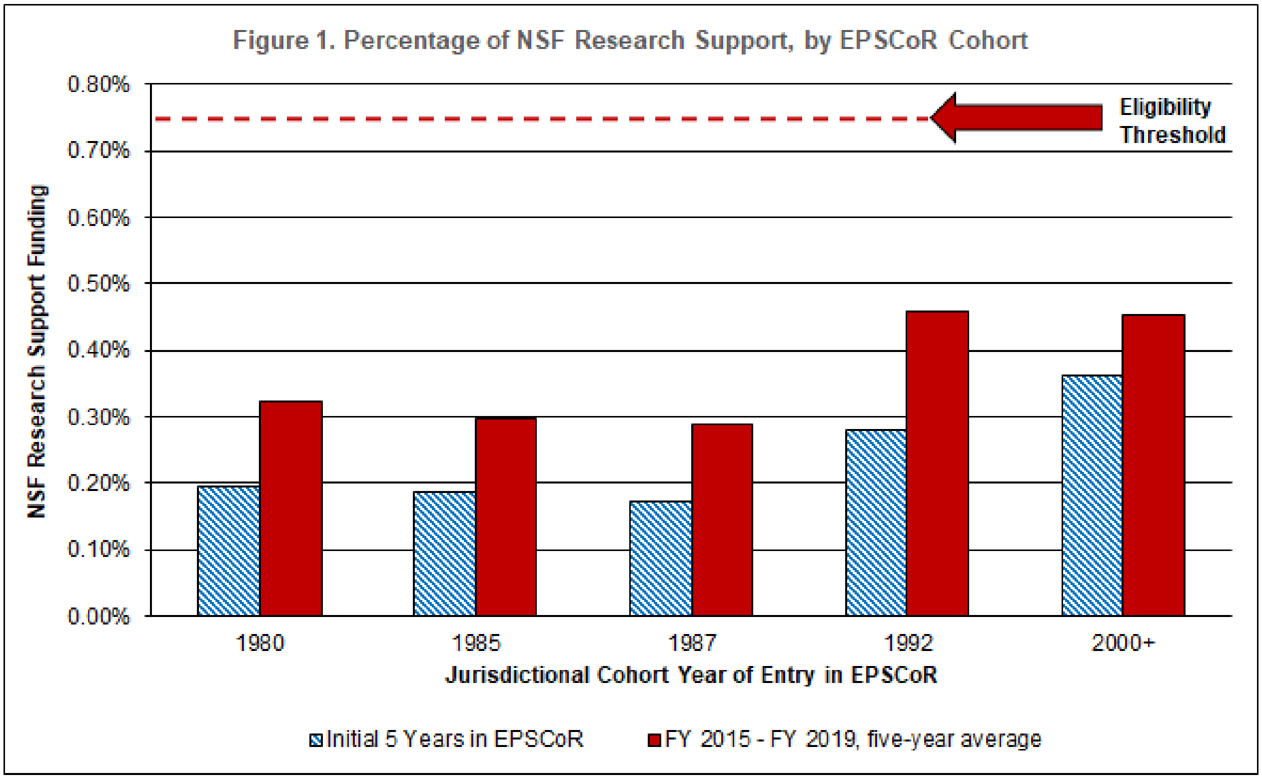
Eligibility to participate in NSF EPSCoR programmatic activities is based upon the jurisdictions' demonstrated ability to obtain NSF research funds. Currently, a jurisdiction is eligible to participate in EPSCoR programs if its level of NSF research support is equal to or less than 0.75 percent of the total NSF research and related activities budget over the most recent three-year period.

Given EPSCoR's aim to stimulate research that is fully competitive in NSF's disciplinary and multidisciplinary research programs, increases in the ability to capture NSF research funds serve as a proxy for gains in research competitiveness. As in FY 2018, former EPSCoR jurisdictions Missouri, Tennessee, and Utah exceeded the 0.75 percent threshold and continued to be ineligible to compete in new FY 2019 RII competitions. In FY 2019, both Iowa and New Mexico, which had both been ineligible in FY 2018, fell back below the 0.75 percent eligibility threshold.

Figure 1 (below) shows the average amount of NSF research funds by cohort for the initial five years (hatched bars) and the most recent five years (solid bars) of their participation in the NSF EPSCoR Program. A cohort is defined as the group of states or jurisdictions that entered the EPSCoR program within a given fiscal year. For example, the 1980 cohort consists of the initial five states that qualified for EPSCoR: Arkansas, Maine, Montana, South Carolina, and West Virginia. For this summary, the 2000+ cohort consists of jurisdictions that entered EPSCoR in FY 2000 or later and are still EPSCoR-eligible for RII competitions: Alaska, Delaware, Guam, Hawaii, New Hampshire, Rhode Island, and the U.S. Virgin Islands. Former EPSCoR jurisdictions Missouri, Tennessee, and Utah are excluded because they were no longer EPSCoR-eligible in FY 2019.

Each cohort shows an increase in competitiveness over the periods of participation. For example, the 1980 cohort shows a 66 percent increase in NSF research funding over the past 39 years of EPSCoR activity. The 1985 cohort (Alabama, Kentucky, Nevada, North Dakota, Oklahoma, Puerto Rico, Vermont, and Wyoming) demonstrates a 59 percent increase during its 34 years of participation in EPSCoR. The 1987 cohort (Idaho, Louisiana, Mississippi, and South Dakota) shows a 69 percent increase over the past 32 years, while the 1992 cohort (Kansas and Nebraska) has a 64 percent increase in competitiveness over its 27 years of EPSCoR involvement. Currently eligible jurisdictions participating in EPSCoR since FY 2000 entered into the program at a higher level of NSF research funding than the previous cohorts. For the 2000+ cohort, there has been a small, yet demonstrable 25 percent increase in research funding.

Figure 1. Percentage of NSF Research Support Funding by EPSCoR Cohort



Percentage of NSF Research Support Funding, by Jurisdiction and EPSCoR Cohort

	Initial 5 Years in EPSCoR*	Most Recent 5 Year Period (FY 2015-2019)**
1980 Cohort	0.19%	0.32%
Arkansas	0.10%	0.24%
Maine	0.27%	0.28%
Montana	0.13%	0.34%
South Carolina	0.41%	0.61%
West Virginia	0.07%	0.15%
1985 Cohort	0.19%	0.30%
Alabama	0.33%	0.66%
Kentucky	0.22%	0.38%
Nevada	0.14%	0.25%
North Dakota	0.06%	0.16%
Oklahoma	0.30%	0.43%
Puerto Rico	0.15%	0.17%
Vermont	0.10%	0.12%
Wyoming	0.20%	0.20%
1987 Cohort	0.17%	0.29%
Idaho	0.08%	0.27%
Louisiana	0.36%	0.46%
Mississippi	0.16%	0.28%
South Dakota	0.09%	0.15%
1992 Cohort	0.28%	0.46%
Kansas	0.34%	0.48%
Nebraska	0.22%	0.44%
2000+ Cohort	0.36%	0.45%
Alaska	0.55%	0.57%
Delaware	0.41%	0.42%
Guam	0.02%	0.01%
Hawaii	0.56%	0.61%
Iowa	-	0.74%
New Hampshire	0.44%	0.46%
New Mexico	0.58%	0.63%
Rhode Island	0.70%	0.61%
Virgin Islands	-	0.03%

*Percentages based on eligibility guidelines at the time of entry into the EPSCoR program.
**Percentages based on new eligibility guidelines.

The following table demonstrates the quantifiable outputs of NSF EPSCoR's RII Track-1 program over the last five fiscal years. This information elucidates the gains in academic research quality over time, as defined by publications, leveraged grants, and patents. For publications, primary support is defined as research that is directly funded by EPSCoR and partial support is defined as use of equipment or facilities funded by EPSCoR. The number and valuation of grants awarded encompass all federal, private industry, and private foundation awards across the U.S. in a given fiscal year for all EPSCoR jurisdictions.

Aggregate of EPSCoR Outputs (n=27*)

	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	Total
Primary Support Publications	581	409	293	404	274	**1,961**
Partial Support Publications	1,026	927	692	640	458	**3,743**
Grants Awarded	563	675	455	505	451	**2,649**
Value of Grants Awarded (Dollars in Millions)	$181.80	$379.10	$492.10	$269.13	$214.40	**$1,536.53**
Patents Awarded	13	14	17	8	17	**69**
Patents pending	44	34	29	15	44	**166**

* The maximum number of jurisdictions with active RII Track-1 awards in FY 2019. Outputs are not comparable from year-to-year due to the influx of new and expiring awards over the time period.

The table below indicates EPSCoR's ongoing support of human resource development over the last five fiscal years in the RII Track-1 program. The number of faculty and students involved in RII Track-1 projects has remained fairly constant over time, signifying a strong commitment by NSF and the jurisdictions in strengthening jurisdictional human capital in science and engineering research and education.

EPSCoR Human Resource Development

	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	Total
Faculty Supported	1,602	1,552	1,183	1,126	1,062	**N/A***
Post-Docs Supported	231	200	156	179	165	**N/A***
Graduate Students Supported	1,361	1,332	1,056	1,128	992	**N/A***
Undergraduates Supported	1,965	1,861	1,220	1,187	1,168	**N/A***
New Faculty Hired	89	84	54	27	40	**294**
Graduate Degrees Conferred	245	258	254	262	202	**1,221**
Undergraduate Degrees Conferred	408	404	634	357	297	**2,100**

* The number of faculty and students supported are not summed because many of them remain tied to their respective projects for the duration of the award and would, therefore, be double-counted over time.

In FY 2019, EPSCoR undertook a re-examination of its eligibility methodology[1] to ensure that it is simple, transparent, fair, and stable. NSF is implementing changes that incorporate stakeholder feedback and are supported by robust data analyses. The new eligibility table utilizing the improved methodology will be published in February 2020 and will apply to the FY 2021 EPSCoR competitions. The FY 2020 eligibility will be the same as FY 2019.

NSF EPSCoR is continuing to refine and implement a cohesive Research Competitiveness evaluation framework for the program. This evaluation, once completed in 2020, will address the legislative objective of increasing the research competitiveness of jurisdictions receiving EPSCoR funding by (1) developing a flexible framework to explore, define, and measure research competitiveness in relation to each unique jurisdictional context, and (2) using evidence of jurisdictional progress toward research competitiveness over time for strategic program improvement. The evaluation builds on the findings and recommendations from the EPSCoR retrospective evaluation completed by the Science and Technology Policy Institute in 2012. The contract for this new, forward looking evaluation has been underway since 2017. Key activities to date include identification, merging, and cleaning of data sets, descriptive and correlational analyses, refinement of the logic model for the research competitiveness framework, and development of a data dashboard tool to visualize outputs. The study report is expected to be finalized in April 2020.

[1] Description of redefined EPSCoR eligibility methodology is available at www.nsf.gov/od/oia/programs/epscor/Eligibility_Tables/EPSCoR_Eligibility_Methodology.pdf

RESEARCH AND RELATED ACTIVITIES (R&RA)

$6,213,020,000
-$365,110,000 / -5.6%

The FY 2021 Budget Request for the Research and Related Activities account is $6,213.02 million. Funding within the R&RA Appropriation invests in early-stage research as well as development of a future-focused science and engineering workforce that can support the private sector and accelerate progress in basic science and engineering research.

NSF is the only federal agency dedicated to funding basic research across all areas of non-biomedical science and engineering. In FY 2020, NSF will continue its longstanding commitment to investing in learning and discovery that will promote the innovations that will be the foundation for the Nation's future prosperity.

R&RA Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 Enacted	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Biological Sciences	$783.75	-	$704.95	-$78.80	-10.1%
Computer & Information Science and Engineering	985.12	-	1,062.40	77.28	7.8%
Engineering	991.12	-	909.78	-81.34	-8.2%
Geosciences	969.89	-	836.61	-133.28	-13.7%
Mathematical & Physical Sciences	1,490.61	-	1,448.32	-42.29	-2.8%
Social, Behavioral & Economic Sciences	271.17	-	246.84	-24.33	-9.0%
Office of International Science and Engineering	49.00	-	44.01	-4.99	-10.2%
Office of Polar Programs	488.68	-	419.78	-68.90	-14.1%
Integrative Activities	547.31	-	538.73	-8.58	-1.6%
U.S. Arctic Research Commission	1.48	-	1.60	0.12	8.1%
Total, R&RA	**$6,578.13**	**$6,737.20**	**$6,213.02**	**-$365.11**	**-5.6%**

Appropriations Language

For necessary expenses in carrying out the National Science Foundation Act of 1950 (42 U.S.C. 1861 et seq.), and Public Law 86–209 (42 U.S.C. 1880 et seq.); services as authorized by section 3109 of title 5, United States Code; maintenance and operation of aircraft and purchase of flight services for research support; acquisition of aircraft; and authorized travel; ~~$6,737,200,000,~~$6,213,020,000, to remain available until September 30, ~~2021,~~2022, of which not to exceed $544,000,000 shall remain available until expended for polar research and operations support, and for reimbursement to other Federal agencies for operational and science support and logistical and other related activities for the United States Antarctic program: *Provided*, That receipts for scientific support services and materials furnished by the National Research Centers and other National Science Foundation supported research facilities may be credited to this appropriation.

Research and Related Activities
FY 2021 Summary Statement
(Dollars in Millions)

	Enacted/ Request	Unobligated Balance Available Start of Year	Unobligated Balance Available End of Year	Adjustments to Prior Year Accounts	Transfers	Obligations Actual/ Estimates
FY 2019 Appropriation	$6,520.00	$28.87	-$16.21	$60.97	-$15.49	$6,578.14
FY 2020 Enacted	6,737.20	16.21				6,753.41
FY 2021 Request	6,213.02					6,213.02
$ Change from FY 2020 Enacted						-$540.39
% Change from FY 2020 Enacted						-8.0%

Totals exclude reimbursable amounts.

Explanation of Carryover

Within the Research and Related Activities (R&RA) account, $18.60 million (including $2.39 million in reimbursable funds) was carried over into FY 2020.

Directorate for Engineering STTR Phase I and II
- Amount: $4.04 million
- Purpose: Funds will be used on STTR Phase I or Phase II awards.
- Obligation: Anticipated FY 2020 Quarter 2

Directorate for Engineering SBIR Phase I and II
- Amount: $3.77 million
- Purpose: Funds will be used on SBIR Phase I or Phase II awards.
- Obligation: Anticipated FY 2020 Quarter 2

Integrative Activities for STC Program
- Amount: $95,895
- Purpose: These carryover funds will be used for an STC professional development workshop for students involved in the STCs.
- Obligation: Anticipated FY 2020 Quarter 2

Integrative Activities for Convergence Accelerator
- Amount: $2.65 million
- Purpose: These funds will be used to fund initial Convergence Accelerator Phase 2 awards. The Convergence Accelerator teams are working on the technical tracks—AI & Future Jobs and National Talent Ecosystem—which are based on the Future of Work at the Human-Technology Frontier (FW-HTF) Big Idea. The Phase 2 awards will be determined based on a proposal submission and a Pitch Competition in March 2020. This plan meets the current organizational goals to fund use-inspired convergence research with multi-disciplinary and multi-institutional teams, including industry and other participants.
- Obligation: Anticipated FY 2020 Quarter 3

Integrative Activities for Program Planning and Policy Development
- Amount: $2.65 million
- Purpose: These funds will be used for contracts in Quarters 1-3 of FY 2020: to implement the Committee of Visitors dashboard, automate the productions of the Merit Review Digest, develop the web infrastructure for the online Merit Review Summary, and to analyze administrative data on NSF's merit review process.
- Obligation: Anticipated FY 2020 Quarter 3

Office of Polar Programs

- Amount: $1.90 million
- Purpose: Unobligated balance carried forward for future projects.
- Obligation: Funds were obligated during FY 2020 Quarter 1

National Coordination Office for Networking and Information Technology Research and Development

- Amount: $202,499
- Purpose: Operational funds are needed to continue government procurements and operations (credit card purchases, government travel, mailroom operations, etc.).
- Obligation: Anticipated FY 2020 Quarter 2

National Nanotechnology Coordination Office

- Amount: $33,366
- Purpose: Funding for the National Nanotechnology Coordination Office (NNCO) for the required Quadrennial Review of the National Nanotechnology Initiative, rent for NNCO's new location, and other NNCO operational expenses.
- Obligation: Anticipated FY 2020 Quarter 2

The remaining R&RA carryover of $870,000 consists of funds from throughout the Foundation for projects that were not funded in FY 2019.

DIRECTORATE FOR BIOLOGICAL SCIENCES (BIO) **$704,950,000**
-$78,790,000 / -10.1%

BIO Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Molecular and Cellular Biosciences (MCB)	$144.70	-	$130.89	-$13.81	-9.5%
Integrative Organismal Systems (IOS)	194.38	-	175.84	-18.54	-9.5%
Environmental Biology (DEB)	153.60	-	150.26	-3.34	-2.2%
Biological Infrastructure (DBI)	180.79	-	158.07	-22.72	-12.6%
Emerging Frontiers (EF)	110.27	-	89.89	-20.38	-18.5%
Total	**$783.74**	**-**	**$704.95**	**-$78.79**	**-10.1%**

About BIO

BIO supports fundamental research and infrastructure that promotes a unified understanding of life in all forms, from the biological molecules that are the machinery of living cells to the populations of organisms and species that underpin the functioning of the Nation's ecosystems. In the past decade biology has been transformed by new tools to describe and manipulate genomes, new means of sensing processes at multiple biological scales simultaneously, and new computational and artificial intelligence (AI) approaches in bioinformatics and modeling to unveil the regulation of complex living systems. BIO seeks to capitalize on these advances to vastly improve our ability to understand life's deepest mysteries, and to enable new capabilities to modify organisms and ecosystems for societal benefit and economic prosperity.

BIO investments in genomics, in cellular, organismal and developmental biology, and in bioinformatics spur further development of capabilities in synthetic biology and enhance biotechnology beyond the current state-of-the-art. The accelerating power of this advanced biotechnology promises to sustain U.S. economic growth and innovation across multiple sectors including agriculture, biomanufacturing, pharmaceuticals, and other bioproducts. In this way, BIO programs directly support the Administration's priorities in and the bioeconomy industries of the future. BIO investments in ecology, evolution and biodiversity, including support for the National Ecological Observatory Network (NEON), promote the development of dynamic, eco-forecasting models to predict environmental change at regional and continental scales. These investments support the Administration's priority to advance Earth System Predictability, and address gaps in national security concerning the environmental spread and evolution of biothreats and engineered organisms.

Biological questions often drive convergence research in critical areas of science and technology and stimulate applications that enhance economic and societal well-being. Pursuits in the biological sciences to quantify living systems at all scales has propelled the frontiers of research in statistics and mathematical and computer sciences to consider larger and more complex data sets that benefit from machine learning. Foundational research on microbes and their interactions with plants leverages these advances in data analytics using AI and advanced computing to fuel a revolution in agriculture. Similarly, collaborations between the biological and physical sciences have contributed to advances such as biological computing, taking advantage of the extraordinary information density in genetic polymers, and the development of neuro-technologies that are powering advances in neuroscience and cognition. Quantum biology—the application of quantum theory to biological systems—provides new insights into the power of photosynthesis for energy production as well as a fundamental understanding of vision, olfaction, magnetoreception, and other sensing systems. This research will enable bioinspired designs based on quantum energy production and sensing systems that will enhance American security.

As the lead directorate for the URoL Big Idea, BIO provides the stewardship support for URoL, an NSF-wide, convergence research funding opportunity addressing scientific and societal needs pertinent to the Administration's priorities in the bioeconomy. URoL is focused on elucidating the rules that govern the emergence of complex organismal traits and behaviors, such as robustness and adaptability, using a highly interdisciplinary approach that engages all the major disciplines represented across NSF's directorates and offices. URoL frames the essential challenges and opportunities associated with genotype to phenotype (structure to function) relationships. Through stewardship of URoL, BIO enables research that leads to a predictive understanding of biological systems at all scales. This knowledge is what drives advances in understanding the human body and improving health, enabling sustainable and efficient food production, and harnessing biological systems to enable bio-based manufacturing and new forms of energy production.

BIO also invests in Biology Integration Institutes (BII) to enable the discovery of underlying principles operating across all hierarchical levels of life, from biomolecules to organisms to ecosystems. Unlike URoL, BII provides institute-scale funding to address the critical need for integration within biology itself, both integration of approaches across scales that will enable biology to become a predictive science, and also cultural integration across the traditional sub-disciplines of biology that will propel significant advances in the life sciences. BII will provide support for research and training to promote this integrative biology through highly collaborative, team-science endeavors, which foster diversity and inclusion in science. This complements BIO's other investments in workforce development, including postdoctoral fellowships and research experiences for undergraduates.

BIO promotes other opportunities for convergence research and training through active participation and foundational investments in several Big Ideas beyond URoL. BIO participates in QL—contributing to more efficient and robust quantum technologies for solar energy harvesting, communication, and navigation as well as cutting edge DNA-based quantum computing. BIO will support basic research in this area primarily through established research programs in MCB and research resource programs in DBI. BIO is making strategic investments in HDR—from contributing to the mapping and understanding of the properties, structure, and functions of tens of thousands of molecules in cells, to collecting and analyzing data from leading facilities such as NEON, which provides data on environmental and land use change for the entire United States. BIO investments include CyVerse, Protein Data Bank, iDigBio, and Advancing Digitization of Biodiversity Collections. BIO participates in the NNA Big Idea through investments in environmental research and observational infrastructure in the Arctic, through the Long-Term Ecological Research program (LTER) and NEON. For more information about the Big Ideas, please see the narratives in the NSF-Wide Investments chapter.

BIO provides 67 percent of the federal funding for basic research at academic institutions in the life sciences.

Major Investments

BIO Major Investments

(Dollars in Millions)

Area of Investment[1,2]	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Advanced Manufacturing	$4.50	-	$7.16	$2.66	59.1%
Artificial Intelligence	12.53	-	38.09	25.56	204.0%
Bioeconomy	90.00	-	96.00	6.00	6.7%
BRAIN	24.96	-	17.20	-7.76	-31.1%
IUSE	2.68	-	1.81	-0.87	-32.5%
NSF I-Corps™	1.00	-	1.00	-	-
Quantum Information Science	1.05	-	3.12	2.07	197.1%
NSF's Big Ideas					
UROL Stewardship	*30.00*	-	*30.00*	-	-

[1] Major investments may have funding overlap and thus should not be summed.

[2] This table reflects support for selected areas of BIO's investments. In other directorate narratives, the selected areas of investment displayed may differ and thus should not be summed across narratives.

- Advanced Manufacturing: BIO will support Advanced Manufacturing in collaboration with ENG, by supporting basic research, infrastructure, and standards in synthetic biology. BIO will also support the development of new tools and new platform organisms to advance biotechnology that will enable new biomanufacturing capabilities. BIO will continue support for an Industry-Academia-NSF partnership (the Engineering Biology Research Consortium) that provides leadership and training to a network of practitioners that will sustain and grow the U.S. bioeconomy.
- AI: BIO, together with other NSF directorates and offices, will increase support for artificial intelligence. BIO's AI investments occur primarily in DBI through the Advances in Biological Informatics program, and center-scale investments that advance computational capacity in bioinformatics. AI methods such as machine learning, natural language processing, computer vision, and genetic algorithms are increasingly applied in biological research to solve problems such as genome sequence alignment, prediction of protein structure, reconstructing evolutionary relationships, predicting species range distributions, and extracting quantitative information from multi-media data sources.
- Bioeconomy: BIO will increase investments in support of the bioeconomy through research funding programs in synthetic biology, genomics, bioinformatics, and biotechnology, and training fellowships that help build the U.S. workforce in this area.
- BRAIN: BIO will continue to support the BRAIN Initiative through the Collaborative Research in Computational Neuroscience program and the Next Generation Networks for Neuroscience (NeuroNex) program which involves a partnership of NSF and funding agencies in Germany, United Kingdom, and Canada.
- IUSE: BIO will continue to support activities related to undergraduate biology education through Research Collaboration Networks—Undergraduate Biology Education. For more information regarding IUSE, see the NSF-Wide Investments chapter.
- I-Corps™: BIO will continue support for I-Corps™ nodes and teams that test the feasibility of commercial prototypes developed from NSF/BIO supported research. For more information on NSF I-Corps™, see the NSF-Wide Investments chapter.

- Quantum Information Science (QIS): BIO will continue to support QIS through investments in fundamental research in biophysics that seek to understand quantum phenomena within living systems and can inform applications in quantum information science.
- URoL: BIO will provide stewardship support for NSF URoL Big Idea initiative. URoL emphasizes multi-disciplinary, team science approaches to achieving a predictive understanding of how complex traits of an organism emerge from the interaction of its genetic makeup with the environment. Science outcomes from URoL advance biological theory that explains the complexity, diversity, and adaptability of living systems, inform applications in human health and agriculture, and expand the bioeconomy.

BIO Funding for Centers Programs and Facilities

BIO Funding for Centers Programs
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual	
				Amount	Percent
Total	**$13.75**	**-**	**$9.15**	**-$4.60**	**-33.5%**
Centers for Analysis and Synthesis (DBI)	0.05	-	-	-0.05	-100.0%
STC: Bio/computation Evolution in Action	3.70	-	-	-3.70	-100.0%
STC: Biology with X-ray Lasers (BioXFEL) (DBI)	5.00	-	4.15	-0.85	-17.0%
STC: Center for Cellular Construction (CCC) (DBI)	5.00	-	5.00	-	-

For additional information on NSF's centers programs, please see the NSF-Wide Investments chapter.

BIO Funding for Major Multi-User Facilities
(Dollars in Millions)

	FY 2019 Actual[1]	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual	
				Amount	Percent
Total	**$70.40**	**-**	**$65.00**	**-$5.40**	**-7.7%**
National Ecological Observatory Network (DBI)	70.40	-	65.00	-$5.40	-7.7%

[1] Includes $8.93 million for continuity of operations into FY 2020.

For information on continuity of operations funding, see the opening narrative of the Facilities chapter. For detailed information on individual facilities, please see the Facilities chapters.

Funding Profile

BIO Funding Profile

	FY 2019 Actual Estimate	FY 2020 (TBD)	FY 2021 Estimate
Statistics for Competitive Awards:			
Number of Proposals	3,113	-	3,200
Number of New Awards	1,049	-	900
Funding Rate	34%	N/A	28%
Statistics for Research Grants:			
Number of Research Grant Proposals	2,458	-	2,500
Number of Research Grants	811	-	700
Funding Rate	33%	N/A	28%
Median Annualized Award Size	$215,000	-	$220,000
Average Annualized Award Size	$262,945	-	$270,000
Average Award Duration, in years	3.4	-	3.4

BIO supports investment in core research and education as well as research infrastructure. In FY 2021, BIO will invest $9.15 million in research centers, accounting for 1.3 percent of the BIO budget. This total is down from FY 2019 Actual as two centers sunset and another is phasing down as planned. BIO's FY 2021 Request funds two Science and Technology Centers. O&M funding for BIO-supported facilities is 9.2 percent of BIO's FY 2021 Request.

Performance and Management

External Program Evaluations and Studies

- DBI funded an award to the National Academies of Science, Engineering and Medicine to produce a report entitled, "Biological Collections: Their Past, Present, and Future Contributions and Options for Sustaining Them."[1] This will inform how the division chooses to proceed at the end of the 10-year campaign on digitizing and maintaining collections through the Advancing Digitization of Biodiversity Collections and Collections in Support of Biological Research programs.
- In 2019, IOS received a consensus study report from the National Academies of Sciences, Engineering and Medicine entitled "Science Breakthroughs to Advance Food and Agricultural Research by 2030". This consensus study was co-funded by NSF, USDA/NIFA, DOE and the Supporters of Agricultural Research Foundation. The recommendations from this report will inform future investments in the plant sciences to produce the cross-disciplinary basic research to enable more efficient, resilient and sustainable agricultural systems crucial to the bioeconomy.

Workshops and Reports

- BIO supported the following workshops that have and continue to inform the planning of the directorate's research programs.
    - A workshop entitled "Workshop: Biology, Information, Communication and Coding Theory"[2] was funded in 2019 and will be held in January of 2020, to help inform future activities associated with the NSF Big Idea URoL.

[1] Biological Collections: Their Past, Present and Future Contributions and Options for Sustaining Them (Award 1827445); www.nsf.gov/awardsearch/showAward?AWD_ID=1827445&HistoricalAwards=false

[2] Workshop: Biology, Information, Communication and Coding Theory (Award 1945773); www.nsf.gov/awardsearch/showAward?AWD_ID=1945773&HistoricalAwards=false

  - A workshop entitled "Trans-US Government expert meeting to examine synthetic biology roadmap"[3] was held in October 2019. The workshop, which included attendees across academia, industry, and US government agencies, was convened to examine use cases in the field of synthetic biology and the most pressing basic research, technology, infrastructure, and workforce needs to advance the field. The results of the workshop helped inform the development of the work plan for the Interagency Synthetic Biology Working group as well as agency priorities in this area. A new Dear Colleague Letter in the area of plant synthetic biology, to be released in FY 2020 and supported by BIO and ENG at NSF, is one early outcome of this activity.
  - A series of virtual and in-person workshops entitled "Reintegrating Biology Jumpstarts" were funded in 2019 and held throughout fall 2019 to engage the broader biological community in identifying: the exciting new research questions that could be addressed by combining approaches and perspectives from different sub-disciplines of biology; the key challenges and scientific gaps that must be addressed to answer these questions; and the physical infrastructure and workforce training needed. These workshops will inform research and training activities supported by Biology Integration Institutes.
- MCB supported multiple workshops that have and continue to inform the planning of the division's research programs.
  - A Workshop series entitled "Finding your inner modeler: how computational biology can advance your research and how to get started" was initiated in FY 2017. The series of workshops were developed to promote the use of computational modeling by cell biologists. The third workshop in this series was funded in FY 2019. These workshops contribute to the continued enhancement of the quantitative/predictive portfolio of awards in MCB.[4]
  - A travel grant was awarded in 2019, titled "BIOROBOOST", that provides travel support for US-based researchers attending workshops to develop standards in synthetic biology , to support US leaders in the development of experimental, data, and computational standards in the area of synthetic biology to work with European experts in the field to ensure common standards are developed to enable rapid development and commercialization of the field.
- IOS supported multiple workshops and meetings to inform the planning of the division's research programs for FY 2021.
  - A workshop in FY 2018 "Breakthroughs 2030: A Strategy for Food and Agricultural Research" led to a National Academies of Sciences, Engineering and Medicine (NASEM) Breakthroughs 2030 report that helped guide the FY 2019 solicitation for plant genomics research in IOS.[5] The workshop report on functional genomics is scheduled to be released in FY 2020.
  - In FY 2019, IOS commissioned a workshop from the NASEM on future directions in Functional Genomics. That workshop will be held February 10-12, 2020 at the NASEM in Washington, D.C. The workshop report is expected mid-year and will inform future investments in all IOS programs and NSF's URoL Big Idea.
  - In spring of 2019, IOS held the first community visioning workshop for the organismal functional genomics community who discussed new areas of opportunity for non-traditional research organisms in functional genomics research. These discussions informed the recent addition of a track for research into complex multigenic traits to the Enabling Discovery Through Genomic Tools (EDGE) solicitation.
  - In late FY 2019, IOS held a community visioning workshop with the plant genomics research community. The plant genomics community discussed new areas for high impact plant sciences research. These discussions informed the creation of opportunities for synthetic plant biology

[3] Trans-US Government expert meeting to examine synthetic biology roadmap (Award 1938199); www.nsf.gov/awardsearch/showAward?AWD_ID=1938199&HistoricalAwards=false
[4] Stone, D. Haswell E. and Sztul, E., 2017. Finding your inner modeler: An NSF-sponsored workshop to introduce cell biologists to modeling/computational approaches. *Cellular Logistics*; 7: e1382669. https://doi.org/10.1080/21592799.2017.1382669
[5] http://nas-sites.org/dels/studies/agricultural-science-breakthroughs/

research forthcoming in FY 2020. he "Interagency Strategic Plan for Microbiome Research FY 2018-2022"[6] released in April 2018 continues to guide IOS investment into microbiomes, including microbial interactions with the environment, with animals and plants, and important ecosystem services such as soil stability, fertility, and sustainability.
  - In March 2019, IOS received the workshop report from the "Rules of Life in the Context of Future Mathematical Sciences" workshop. This workshop brought together mathematicians and biologists to identify emerging research challenges in mathematical biology central to URoL. Increasing computational capacity in our communities is an important IOS goal and the opportunities and challenges identified in this report will focus IOS investments in mathematical biology and computation.
- DEB supported multiple workshops to inform the planning of the division's research programs for FY 2021.
  - A 2019 workshop "Ecosystem Responses to Hurricanes Synthesis" provided valuable information on the broader implications of major catastrophic disturbances and the types of research that are likely to provide conceptual breakthroughs and a better understanding of the consequences of individual hurricanes.
  - Three virtual and two in-person international workshops in 2018 and 2019 discussed new procedures for enhancing the taxonomy and classification of uncultured microorganisms and improving the systematics of microbes.
  - "Workshop to stimulate research on microbial eukaryotic diversity" supported two workshops to identify priorities and coordinate research on the phylogenetics of microbial eukaryotes that will provide valuable information on investments for DEB on these poorly known organisms.
  - A 2020 workshop titled "Developing a vision for the future of systematics at the Society of Systematic Biologists conference" will discuss the challenges and opportunities in systematic biology and develop priorities for future biodiversity research.
  - Two workshops on "Genomics of Diseases in Wildlife" supported hands-on training on computationally extensive ("big data") predictive analyses of animal pathogen outbreaks while also developing an inclusive and diverse research community including academic, governmental and private stakeholders.

Committees of Visitors (COVs)

- The DEB COV convened June 12-14, 2019, and reviewed division operations and the programmatic portfolio for the four-year period spanning FY 2015 – FY 2018. DEB is evaluating all the COV recommendations and working to include them in future planning activities.
- In 2020, a COV will review programs in DBI.
- There are no scheduled BIO COVs in 2021.

The Performance and Management chapter provides details regarding the periodic reviews of programs and portfolios of programs by external COVs and directorate Advisory Committees. Please see this chapter for additional information.

[6] https://science.energy.gov/~/media/ber/pdf/workshop%20reports/Interagency_Microbiome_Strategic_Plan_FY2018-2022.pdf

People Involved in BIO Activities

Number of People Involved in BIO Activities

	FY 2019 Actual Estimate	FY 2020 (TBD)	FY 2021 Estimate
Senior Researchers	3,690	-	3,300
Other Professionals	1,338	-	1,200
Postdoctoral Associates	1,360	-	1,200
Graduate Students	2,716	-	2,400
Undergraduate Students	4,398	-	4,000
K-12 Teachers	-	-	-
K-12 Students	-	-	-
Total Number of People	**13,502**	**-**	**12,100**

DIVISION OF MOLECULAR AND CELLULAR BIOSCIENCES (MCB) **$130,890,000**
-$13,810,000 / -9.5%

MCB Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
Total	**$144.70**	**-**	**$130.89**	**-$13.81**	**-9.5%**
Research	**141.91**	**-**	**128.35**	**-13.56**	**-9.6%**
Education	**1.79**	**-**	**1.54**	**-0.25**	**-14.0%**
Infrastructure	**1.00**	**-**	**1.00**	**-**	**-**
Center for High Energy X-ray Sciences	1.00	-	1.00	-	-

About MCB

MCB supports fundamental interdisciplinary research to uncover the basic principles that describe information content in cells and how: (a) it guides expression of cellular characteristics and is maintained and transmitted to the next generation, (b) material and energy are taken up, transformed, and flow through biological systems, and (c) biological molecules, which assemble into complex structures and compartments with varied functions, contribute to the processes required for life. Due to its interdisciplinary nature, MCB research contributes to NSF's Big Ideas, URoL and QL.

Additionally, MCB supports convergence research at the molecular and cellular scales. This basic research at the interface of biological, mathematical, physical, and computer sciences and engineering provides the basis for a quantitative, predictive, theory driven understanding of molecular and cellular functions of biological systems across the tree of life. MCB supported research continues to leverage the latest advances across science and engineering, including single molecule imaging, artificial intelligence, and synthetic biology, and advances a clear mechanistic understanding of biological processes such as deoxyribonucleic acid (DNA) maintenance and repair, clustered regularly interspaced short palindromic repeats (CRISPR), and CRISPR-associated (Cas) genome editing. Advances in basic research enable the development of design rules for engineering molecules and cells, which contributes directly to biological innovations that advance the U.S. bioeconomy, medicine, agriculture, environmental sustainability, and biomanufacturing.

In general, about 67 percent of the MCB portfolio is available to support new research grants, and 33 percent is available for continuing grants.

DIVISION OF INTEGRATIVE ORGANISMAL SYSTEMS (IOS) **$175,840,000**
-$18,540,000 / -9.5%

IOS Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
Total	**$194.38**	**-**	**$175.84**	**-$18.54**	**-9.5%**
Research	**186.83**	**-**	**167.66**	**-19.17**	**-10.3%**
Education	**4.73**	**-**	**2.94**	**-1.79**	**-37.8%**
Infrastructure	**2.82**	**-**	**5.24**	**2.42**	**85.8%**
Research Resources	2.82	-	5.24	2.42	85.8%

About IOS

IOS focuses on the organism and the key link between single biological molecules and complex populations. IOS programs support research and education aimed at integrating knowledge across different levels of biological organization, with the goal of understanding the processes that build and maintain organisms. More specifically, IOS activities focus on mechanistic analyses of how biological systems interact and function – spanning the nervous system, growth and development, behavior, and biochemical, biophysical, and physiological processes – and how these are integrated and result in stability of organisms living in dynamic environments. Such analysis is fundamental to understanding the principles that produce the vast diversity of life on Earth and the mechanisms that allow for biological adaptation to change.

IOS encourages interdisciplinary science and the development of new approaches through the Enabling Discovery through GEnomic (EDGE) Tools program. Investments in research, including tools for high-throughput analysis of agriculturally-important plants, and support for the NSF-Simons Research Centers for Mathematics of Complex Biological Systems, are maintained as priorities. IOS will continue to leverage its activities across the spectrum of NSF basic science in conjunction with agricultural research supported by the U.S. Department of Agriculture's National Institutes of Food and Agriculture. Funding research centered around plant biotic interactions, is an example of this partnership.

Results of IOS-supported research are fully consistent with the NSF Big URoL Idea. IOS's contribution provides information to enable multi-scale biological integration to reveal emergent properties of organisms—spanning the gamut of biological diversity including microbes, plants, and animals. IOS science is highly relevant to societal needs for future food security and sustainability, understanding the healthy brain, and providing new knowledge on how organisms respond to environmental and social stressors.

In general, about 62 percent of the IOS portfolio is available for new research grants, and 38 is available for continuing grants.

DIVISION OF ENVIRONMENTAL BIOLOGY (DEB) — $150,260,000
-$3,340,000 / -2.2%

DEB Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$153.60**	**-**	**$150.26**	**-$3.34**	**-2.2%**
Research	**151.09**	**-**	**148.32**	**-2.77**	**-1.8%**
Education	**2.51**	**-**	**1.94**	**-0.57**	**-22.7%**

About DEB

DEB supports fundamental research on Earth's biodiversity and the ecological and evolutionary processes that explain the origin and maintenance of genetic variation in nature, including its history and patterns of speciation and extinction. DEB supported research also advances understanding of the functional importance of our natural biodiversity heritage to ecological and ecosystem processes occurring over short- and long-temporal and spatial scales. The discoveries from this research can inform strategies to develop, use, and sustain biological resources, including natural, agricultural, and other managed ecosystems, and to forecast changes in species populations and ecosystems over time.

In addition to disciplinary programs in ecology, evolution and biodiversity, DEB provides support for long term ecological research (LTER), and for research addressing continental-scale questions in macrosystem biology. DEB programs encourage the use of data samples and other resources provided by the National Ecological Observatory Network (NEON) and other NSF infrastructure investments. DEB funded research provides the data, knowledge, and capability to advance models that can predict the spread of infectious diseases and of invasive species, and their impacts on wild, managed, and agricultural systems. Eco-forecasting models developed from biodiversity and ecological research are also used to predict environmental drivers of conflict, enhance our ability to strategically prepare for environmental threats, and field defense and mitigation capabilities that are resilient and adaptive.

In general, 80 percent of the DEB portfolio is available for new research grants, and 20 percent is available for continuing grants.

DIVISION OF BIOLOGICAL INFRASTRUCTURE (DBI)

$158,070,000
-$22,720,000 / -12.6%

DBI Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$180.79**	**-**	**$158.07**	**-$22.72**	**-12.6%**
Research	**23.19**	**-**	**20.92**	**-2.27**	**-9.8%**
Centers Funding (total)	13.75	-	9.15	-4.60	-33.5%
Centers for Analysis and Synthesis	0.05	-	-	-0.05	-100.0%
STC: Bio/computation Evolution in Action CONsortium (BEACON)[1]	3.70	-	-	-3.70	-100.0%
STC: Biology with X-ray Lasers (BioXFEL)	5.00	-	4.15	-0.85	-17.0%
STC: Center for Cellular Construction (CCC)	5.00	-	5.00	-	-
Education	**28.54**	**-**	**18.28**	**-10.26**	**-35.9%**
Infrastructure	**129.06**	**-**	**118.87**	**-10.19**	**-7.9%**
NEON[2]	70.40	-	65.00	-5.40	-7.7%
NNCI	0.35	-	0.35	-	-
Research Resources	58.31	-	53.52	-4.79	-8.2%

For information on continuity of operations funding, see the opening narrative of the Facilities chapter.

[1]STC BEACON will sunset as planned in FY 2020.

[2]FY 2019 Actual includes $8.93 million for continuity of operations into FY 2020.

About DBI

DBI empowers biological discovery by supporting the development and enhancement of biological research resources, human capital, and facilities. DBI supports the development of, or improvements to, research infrastructure, including cyberinfrastructure; instrumentation; and improvements to biological research collections, living stock collections, and field stations and marine labs. In addition, DBI supports the development of human capital through undergraduate research experiences by participating in the NSF-wide IUSE and Research Experiences for Undergraduate Sites program. DBI also offers a multi-track postdoctoral research fellowships program with special emphasis on emerging areas of the biological sciences. Support for facilities, such as NEON, create opportunities to address targeted but deep biological questions that have major societal impact, particularly with respect to ecological forecasting. NEON is enabling the study of the biosphere and its response to environmental change at a continental scale. Additional infrastructure support will focus on developing capacity of the biological sciences research community through funding cyberinfrastructure and other tools necessary to address the NSF URoL Big Idea.

In general, about 27 percent of the DBI portfolio is available for new research grants. The remaining 73 percent supports research grants made in prior years and the research infrastructure needed by the biological sciences community.

DIVISION OF EMERGING FRONTIERS (EF) **$89,890,000**
-$20,380,000 / -18.5%

EF Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$110.27**	**-**	**$89.89**	**-$20.38**	**-18.5%**
Research	**103.34**	**-**	**89.89**	**-13.45**	**-13.0%**
Education	**0.56**	**-**	**-**	**-0.56**	**-100.0%**
Infrastructure	**6.37**	**-**	**-**	**-6.37**	**-100.0%**
NEON	3.53	-	-	-3.53	-100.0%
Research Resources	2.84	-	-	-2.84	-100.0%

About EF

EF serves as an incubator for innovation and integration within the biological sciences. It supports research that transcends scientific disciplines and advances conceptual foundations across all levels of biological organization. Innovative research and infrastructure activities in BIO typically begin development in EF and then move to other BIO divisions to become part of the disciplinary knowledge base. For example, support for design and early construction of NEON originated within EF but moved to DBI once NEON operations were initiated. EF also facilitates the development and implementation of new forms of merit review and mechanisms to support transformative research and stimulate creativity.

EF also provides the support for BIO participation in national initiatives, NSF priority areas, and other interdisciplinary, cross-division, and cross-directorate programs. Hence, EF is the steward for investments in NSF's URoL Big Idea. In addition, EF will support innovative research and training that integrates across scales of biology, contributes to a re-unification of biology, and supports U.S. global competitiveness in the bioeconomy.

In general, 61 percent of the EF portfolio is available for new research grants, and 39 percent is available for continuing grants.

DIRECTORATE FOR COMPUTER AND INFORMATION SCIENCE AND ENGINEERING (CISE) $1,062,400,000 +$77,280,000 / 7.8%

CISE Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Office of Advanced Cyberinfrastructure (OAC)	$221.84	-	$232.72	$10.88	4.9%
Computing and Communication Foundations (CCF)	193.55	-	202.96	9.41	4.9%
Computer and Network Systems (CNS)	229.42	-	240.42	11.00	4.8%
Information and Intelligent Systems (IIS)	208.37	-	240.05	31.68	15.2%
Information Technology Research (ITR)	131.93	-	146.25	14.32	10.9%
Total	**$985.12**	**-**	**$1,062.40**	**$77.28**	**7.8%**

About CISE

Advances in information technology (IT) over the past two decades have proven to be key drivers of the American economy. Essentially all practical applications of today's IT are based on ideas and concepts that emerged from investments in fundamental computing research, many of them funded by CISE.[1] Fundamental ideas and concepts advanced through computing research have enabled innovative products and applications that now permeate many aspects of daily life, including personal communication, energy, transportation, health care, advanced manufacturing, national and homeland security, disaster preparedness and response, education and workforce development, public and private organizational effectiveness and efficiency, and discovery and innovation at the frontiers of all areas of scientific and engineering research.

CISE's mission is to promote the progress of computer and information science and engineering research and education, and advance the development and use of CI across the science and engineering research enterprise; to promote understanding of the principles and uses of advanced computer, communication, and information systems in advancing science and engineering and in service to society; and to contribute to universal, transparent, and affordable participation in a knowledge-based society. CISE supports ambitious, long-term research and research infrastructure projects within and across the many subfields of computing, as well as advanced research CI for all areas of science and engineering; contributes to the education and training of computing professionals; and more broadly, informs the preparation of an American workforce with computing and computational competencies essential for success in an increasingly competitive global and digital market. CISE investments foster and support research and teaching environments that reflect American values. CISE executes its mission through its Divisions of Computing and Communication Foundations, Computer and Network Systems, Information and Intelligent Systems, and Information and Technology Research, and through the Office of Advanced Cyberinfrastructure, which has a Foundation-wide role supporting advanced research CI for all areas of science and engineering—and in close partnership with other NSF units, federal agencies, the private sector, and international funders.

In FY 2021, CISE will continue to play a leadership role in advancing the Nation's priorities, including the Administration's Industries of the Future (IotF) initiative, through seminal investments in Artificial Intelligence (AI), Quantum Information Science (QIS), Advanced Wireless (beyond fifth-generation, or "5G," wireless networks), Advanced Manufacturing, and Biotechnologies (including synthetic biology) that will drive the future bioeconomy. CISE will also continue to invest in strategic computing as well as microelectronics and semiconductor research. Investments in these areas are critically important for national security, economic competitiveness, and the broad advancement of all fields of science and

[1] www.nap.edu/catalog.php?record_id=13427

engineering. Advances in these areas will provide opportunities for major scientific breakthroughs and will positively transform American lives and industry for years to come. For example, investments in next-generation manufacturing technologies enabled by AI and machine learning (ML) will help keep jobs in America, ensure products are made in America, and strengthen our national manufacturing industrial base. Development of powerful quantum computers will help solve extreme-scale optimization and ML problems that are unsolvable today, maintaining American leadership in future advanced computing systems.

CISE's FY 2021 Budget Request is also shaped by the directorate's continued support for NSF's Big Ideas, including co-leadership of HDR, FW-HTF, and QL, and participation in NNA and URoL. Advances in AI and ML are essential to both HDR and FW-HTF, and will help to achieve the full potential of QL. Further, as part of HDR, and in partnership with the other research directorates and offices, CISE will invest funds in its ITR division to support convergent activities that transcend the traditional disciplinary boundaries of individual NSF units. CISE's FY 2021 Budget Request comprises support for other ongoing NSF-wide priorities as well, including IUSE; NSF I-Corps™; and SaTC.

CISE, through OAC, will provide NSF's co-leadership of the recently updated, whole-of-nation National Strategic Computing Initiative (NSCI).[2] As part of its support for NSCI, CISE investments will (i) advance future computing paradigms, devices, architectures, and platforms; and (ii) further the development and deployment of advanced computing systems and services, including maximizing the benefits of these systems and services through the deep integration of emerging computing paradigms with current science and engineering research drivers. Key foci will include sustainable and interoperable software that will exploit emerging highly multicore, heterogeneous, and energy-efficient architectures; data maintenance and curation; next-generation security capabilities; and workforce training and re-skilling. These investments will enable shared resources and improved capabilities across a range of disciplines, a broad set of users within a large number of academic institutions, and a diversity of science and engineering advances.

In addition, CISE will continue to provide leadership for the federal government's Networking and Information Technology Research and Development (NITRD) program. The NITRD Subcommittee of the National Science and Technology Council (NSTC), which coordinates investments in networking and information technology research and development across more than 20 federal departments, agencies, and offices, is co-chaired by the NSF assistant director for CISE. All research, education, and research infrastructure projects supported by CISE contribute to NSF's NITRD portfolio. CISE will also continue to co-chair the NSTC Machine Learning and Artificial Intelligence Subcommittee.

Finally, CISE will build, strengthen, and expand strategic, multisector partnerships, including those with other NSF units, other federal agencies, private industry and foundations, and international funders, as an increasingly important means to maximize the scientific, economic, and societal impacts of the directorate's investments. These external partnerships leverage resources, inform use-inspired research, accelerate the transition of research innovations to practice, and enhance workforce development.

CISE provides about 87 percent of the federal funding for fundamental computer science research at U.S. academic institutions.

[2] www.whitehouse.gov/wp-content/uploads/2019/11/National-Strategic-Computing-Initiative-Update-2019.pdf

Major Investments

CISE Major Investments
(Dollars in Millions)

Area of Investment[1,2]	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Advanced Manufacturing	$41.27	-	$39.41	-$1.86	-4.5%
Advanced Wireless Research	79.30	-	75.70	-3.60	-4.5%
Artificial Intelligence	297.00	-	525.44	228.44	76.9%
Bioeconomy	7.66	-	4.75	-2.91	-38.0%
IUSE	2.74	-	2.00	-0.74	-27.0%
Microelectronics and Semiconductors	17.20	-	16.43	-0.77	-4.5%
NSF I-Corps™	11.70	-	13.11	1.41	12.1%
Quantum Information Science	12.10	-	14.60	2.50	20.7%
SaTC	70.22	-	65.00	-5.22	-7.4%
NSF's Big Ideas					
HDR Stewardship	*30.00*	-	*45.00*	*15.00*	*50.0%*

[1] Major investments may have funding overlap and thus should not be summed.

[2] This table reflects this directorate's support for selected areas of investment. In other directorate narratives, areas of investment displayed in this table may differ and thus should not be summed across narratives.

- Advanced Manufacturing: CISE will invest in research that integrates ubiquitous sensors, computational tools, and highly connected cyber-physical systems in smart processing and "cyber-manufacturing" systems. This investment will enable new functionalities that will increase the efficiency and sustainability of the production of the next generation of products and services.
- Advanced Wireless Research (Beyond 5G): CISE will continue to invest in research in advanced wireless networks, building on its track record of enabling early stage successes in 5G through ground-breaking millimeter-wave research. CISE investments will enable further exploration of additional spectrum bands, efficient spectrum sharing, spectrum monitoring, and development of novel applications that leverage advanced wireless communication networks. CISE investments in city-scale research testing platforms through the Platforms for Advanced Wireless Research program will speed up the lab-to-market translation of innovative research outcomes in academic and government labs to successful commercial products and services.
- AI: CISE, together with other NSF directorates and offices, other federal agencies, and the private sector, will increase support for AI research and development. A key focal point will be support for a set of National AI Research Institutes. These center-scale projects will advance foundational research; leverage use-inspired research; build the next-generation of talent; mobilize multidisciplinary groups of scientists, engineers, and educators; and serve as a nexus point for multisector collaborative efforts. The National AI Research Institutes will fill a critical gap in America's AI research and education portfolio by accelerating AI innovations, training AI researchers and innovators, and transitioning outcomes across a range of sectors. CISE investments in AI align with the *National Artificial Intelligence Research and Development Strategic Plan: 2019 Update*.[3]
- Bioeconomy: CISE, together with other NSF directorates/offices, will invest in fundamental research in synthetic biology, biotechnology, bioinformatics, and computational biology, as well as the

[3] www.nitrd.gov/pubs/National-AI-RD-Strategy-2019.pdf

infrastructure and education that will advance the foundational knowledge needed to understand and harness biological processes for societal benefit (e.g., economy, food, health, national security).

- IUSE: Given the increasing centrality of computing and information to innovation across a wide range of disciplines, undergraduate computer science (CS) programs are being called upon to prepare larger and more diverse student populations for careers in both CS and non-CS fields. This preparation includes providing the understandings and competencies needed to learn how to use computation collaboratively across different, challenging contexts and problems. Through IUSE: Computing in Undergraduate Education, CISE, together with EHR, will continue to support efforts to re-envision the role of computing in interdisciplinary collaboration within America's institutions of higher education.
- Microelectronics and Semiconductors: CISE, together with ENG and MPS, will support research to address fundamental science and engineering questions about the concepts, materials, devices, circuits, and platforms necessary to sustain progress in microelectronics and semiconductor technologies. Such progress is critical for emerging technologies such as AI and quantum computing, and will in turn contribute to advances across all sectors of the economy, including energy, transportation, health care, and advanced manufacturing. Investments in microelectronics and semiconductor research will enable whole-of-government access to trusted and assured systems for future storage and computing paradigms.
- NSF I-Corps™: CISE, in partnership with the other directorates, will continue to support the I-Corps™ program, which is establishing a National Innovation Network that connects NSF-funded science and engineering research with the technological, entrepreneurial, and business communities, linking scientific discovery with technology development, societal needs, and economic growth.
- QIS: CISE will continue to advance quantum computing, quantum communication, and other quantum-based approaches for processing, communicating, and using information. CISE investments will specifically support novel quantum algorithms, programming languages, architectures, and circuits; simulation of quantum algorithms and systems; and designing, programming, optimizing, and testing quantum computers and systems, including through cloud-based services. A particular focus of CISE's investments in QIS will be to continue growing capacity within academic computer and information science departments, including cross-disciplinary and multi-department collaborations, to support advances in quantum computing and/or communication over the long term.
- SaTC: CISE will continue to lead SaTC in partnership with EHR, ENG, MPS, and SBE, investing in current and emerging areas of importance for security and privacy. These areas include the application of AI to security, security and resilience of AI systems, security implications of quantum computation and communication, and critical infrastructure security. These investments will also nurture the next generation of American cybersecurity and privacy researchers and practitioners.
- HDR Stewardship: CISE, as the steward for HDR, will support fundamental research in data science and engineering; development of a cohesive, federated approach to the research data infrastructure; and development of a 21st-century data-capable workforce. Increased investment in HDR stewardship funds in FY 2021 will allow NSF to fund critical new methods and advances in artificial intelligence (AI), notably in deep learning and ML.

CISE Funding for Centers Programs

CISE Funding for Centers Programs
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$8.70**	**-**	**$4.15**	**-$4.55**	**-52.3%**
STC: Center for the Science of Information (CCF)[1]	3.70	-	-	-3.70	-100.0%
STC: Center for Brains, Minds and Machines: The Science and the Technology of Intelligence (CCF, IIS, ITR)	5.00	-	4.15	-0.85	-17.0%

[1] The Center for the Science of Information is sunsetting as planned.

For additional information on NSF's centers programs, please see the NSF-Wide Investments chapter.

Funding Profile

CISE Funding Profile

	FY 2019 Actual Estimate	FY 2020 (TBD)	FY 2021 Estimate
Statistics for Competitive Awards:			
Number of Proposals	8,616	-	9,500
Number of New Awards	2,009	-	2,200
Funding Rate	23%	N/A	23%
Statistics for Research Grants:			
Number of Research Grant Proposals	8,240	-	9,100
Number of Research Grants	1,696	-	1,900
Funding Rate	21%	N/A	21%
Median Annualized Award Size	$166,559	-	$175,000
Average Annualized Award Size	$211,653	-	$220,000
Average Award Duration, in years	3.0	-	3.0

In FY 2021, the number of research grant proposals is expected to increase as compared to the FY 2019 Actual Estimate, and correspondingly the number of research grant awards is anticipated to increase to 1,900. The funding rate for research grants is expected to be 21 percent in FY 2021, the same as in FY 2019. Average annualized award size and average award duration are expected to increase slightly between the FY 2019 Actual Estimate and FY 2021 Estimate.

Program Monitoring and Evaluation

External Program Evaluations and Studies

- In FY 2012, the Science and Technology Policy Institute (STPI) conducted a program evaluation feasibility study for SaTC. This feasibility study provided methods for examining baseline portfolio investments and identifying metrics to measure progress toward program goals. The study was part of a broader effort to develop a plan for a future impact assessment. STPI identified baseline evaluation metrics in FY 2013-FY 2015 and completed the evaluation feasibility study in FY 2016. CISE, together with the NSF Evaluation and Assessment Capability, funded a program evaluation of SaTC, and the results of that program evaluation are anticipated in FY 2020.

- Evaluation is a key part of all of CISE's education programs. K-12 computer science education projects managed by CISE include rigorous research and evaluation plans designed to guide project progress and measure project impacts. CISE has also funded a third-party evaluation across individual teacher professional development projects at the high school level. The evaluators for these activities meet regularly, discuss evaluation issues, and contribute statistics to a common dataset in order to track program-level progress. CISE expects to continue these evaluation activities in FY 2021.
- CISE is co-leading NSF's FY 2020-FY 2021 Agency Priority Goal (APG) to expand public and private partnerships agency-wide in order to enhance the impact of NSF's investments and contribute to American economic competitiveness and security. This APG builds on a prior APG on the same topic, which allowed NSF to develop an inventory of its public and private partnerships, along with a toolkit for aiding in partnership development. The new APG will focus on an agency-wide strategy for public and private partnerships, including identifying potential areas for partnership as well as prospective partners. Outputs of this APG will help in the evaluation of the impacts of NSF's partnerships across its portfolio of research, education, and research infrastructure investments.
- In FY 2020, CISE launched an impact analysis and evaluation of programs in which the directorate partners with the private sector to jointly support research at colleges and universities across the U.S. This study will identify the critical success factors and key performance indicators in both quantitative and qualitative form, to assess these in the context of specific partnership programs over the last five years, and to convey the outcomes in communications materials. The impact analysis and program evaluation are expected to conclude in FY 2021.

<u>Workshops and Reports</u>

- CISE has funded several studies led by the Computer Science and Telecommunications Board (CSTB) within the National Academies of Sciences, Engineering, and Medicine that resonate with the directorate's FY 2021 investments:
  - In FY 2017, CISE funded CSTB to update the so-called "tire-tracks" diagram[4] from the 2012 report, *Continuing Innovation in Information Technology*,[5] depicting the interconnections across research areas with the creation and evolution of billion-dollar IT industry sectors.[6]
  - *Information Technology and the U.S. Workforce: Where Are We and Where Do We Go from Here?*[7] a 2017 report on the interactions between technological, economic, and societal trends, notably how significant advances in IT and automation have profoundly impacted the way work is conducted, and identified open questions and promising research pathways.[8]
  - *Assessing and Responding to the Growth of Computer Science Undergraduate Enrollments*,[9] a 2018 report recommending responses to growing undergraduate computer science enrollments.
  - *Data Science for Undergraduates: Opportunities and Options*,[10] a 2018 report offering a vision for the emerging discipline of data science at the undergraduate level along with considerations and approaches for academic institutions and others to help guide the ongoing transformation of the field.
  - *Quantum Computing: Progress and Prospects*,[11] a 2019 report assessing the current progress and possible future pathways toward developing a general-purpose quantum computer as well as its potential implications.

[4] www.nap.edu/resource/23393/innovation-brochure-2017-forweb.pdf
[5] www.nap.edu/catalog.php?record_id=13427
[6] www.nsf.gov/awardsearch/showAward?AWD_ID=1748756&HistoricalAwards=false
[7] www.nap.edu/catalog/24649/information-technology-and-the-us-workforce-where-are-we-and
[8] www.nap.edu/catalog/24649/information-technology-and-the-us-workforce-where-are-we-and
[9] www.nap.edu/catalog/24926/assessing-and-responding-to-the-growth-of-computer-science-undergraduate-enrollments
[10] www.nap.edu/catalog/25104/data-science-for-undergraduates-opportunities-and-options
[11] www.nap.edu/catalog/25196/quantum-computing-progress-and-prospects

- The Computing Community Consortium has led several community visioning efforts that resonate with the directorate's FY 2021 investments:
  - *Computing Visions 2025.*[12] Two workshops were held under this activity: *Interacting with Computers All Around Us* (May 2014), and *The New Making Renaissance: Programmable Matter and Things* (June 2014).
  - *Intelligent Infrastructure*,[13] jointly with the Electrical and Computer Engineering Department Heads Association, presented a national research agenda for intelligent infrastructure, or the deep embedding of sensing, computation, and communication capabilities into traditional physical infrastructure such as roads, bridges, railways, and buildings, for enhancing efficiency, resiliency, and safety.
  - *Next Steps in Quantum Computing: Computer Science's Role*,[14] brought together researchers from quantum computing, computer architecture, electronic design automation, compiler construction, and classical programming languages to articulate the central role that various CISE subfields play to close the gap between the problems for which a quantum computer might be useful and what we can currently build, program, and run.
  - *Thermodynamic Computing*,[15] discussed the re-emergence of thermodynamics in a new role as an algorithmic technique in areas such as ML, annealing, quantum systems, and neuromorphic systems, with recent theoretical developments in non-equilibrium thermodynamics leading to computing systems that self-organize in response to external input.
  - *The Frontiers of Fairness in Machine Learning*,[16] convened a group of about 50 experts drawn from academia, industry, and government, to assess the state of understanding of the fundamentals of the nascent science of fairness in machine learning, and to identify the unanswered questions that seem the most pressing.
  - *Algorithmic and Economic Perspectives on Fairness*,[17] brought together computer science researchers with backgrounds in algorithmic decision making, machine learning, and data science with policy makers, legal experts, economists, and business leaders to discuss methods to ensure economic fairness in a data-driven world.
  - *Identifying Research Challenges in Post Quantum Cryptography Migration and Cryptographic Agility*,[18] identified academic research challenges in post quantum cryptography migration and cryptographic agility, identifying aspects of the complex and global migration to new public-key cryptography standards that could benefit from a more rigorous study and analysis.
  - *A 20-Year Community Roadmap for Artificial Intelligence Research in the US*,[19] developed a roadmap for AI research over the next 20 years, including research priorities, challenges, and recommendations.
- CISE-funded community workshops also resonate with the directorate's FY 2021 investments. For example, a May 2019 workshop on *Future Directions for Parallel and Distributed Computing*[20] brought together researchers from academia, industry, and government to discuss how the next generation of parallel and distributed computing systems will be domain-specific, and ways to combine a heterogeneous mix of computational patterns, algorithms, and hardware to achieve a set of goals that go beyond the aims of traditional systems to meet society's needs for more scalable, energy-efficient, reliable, verifiable, and secure computing systems. The outputs of this workshop align with CISE's co-leadership of the recently updated NSCI.

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[12] https://cra.org/ccc/visioning/computing-visions-2025/
[13] https://cra.org/ccc/wp-content/uploads/sites/2/2017/03/A-National-Research-Agenda-for-Intelligent-Infrastructure.pdf
[14] https://cra.org/ccc/events/quantum-computing/
[15] https://cra.org/ccc/events/thermodynamic-computing/
[16] https://cra.org/ccc/events/fair-representations-fair-interactive-learning/
[17] https://cra.org/ccc/events/economics-and-fairness//
[18] https://cra.org/ccc/events/identifying-research-challenges-in-pqc-migration-and-cryptographic-agility/
[19] https://cra.org/ccc/wp-content/uploads/sites/2/2019/08/Community-Roadmap-for-AI-Research.pdf
[20] www.sigarch.org/nsf-workshop-report-on-future-directions-for-parallel-and-distributed-computing/

Committees of Visitors (COVs)[21]

- In early FY 2018, OAC convened a COV to examine and assess the quality of the merit review process across OAC. The report from that COV was accepted by the Advisory Committee for Cyberinfrastructure (ACCI) at its Spring 2018 meeting.
- In early FY 2020, CISE convened a COV to conduct a similar review of the FY 2014-FY 2018 programmatics within its CCF, CNS, and IIS divisions. The report from that COV was accepted by the CISE Advisory Committee at its Fall 2019 meeting.

The Performance and Management chapter provides details regarding the periodic reviews of programs and portfolios of programs by external COVs and directorate Advisory Committees. Please refer to this chapter for additional information.

People Involved in CISE Activities

Number of People Involved in CISE Activities

	FY 2019 Actual Estimate	FY 2020 (TBD)	FY 2021 Estimate
Senior Researchers	7,936	-	8,600
Other Professionals	1,229	-	1,400
Postdoctoral Associates	471	-	500
Graduate Students	6,495	-	6,700
Undergraduate Students	3,242	-	3,900
K-12 Teachers	-	-	-
K-12 Students	-	-	-
Total Number of People	**19,373**	**-**	**21,100**

[21] www.nsf.gov/od/oia/activities/cov/covs.jsp#cise

OFFICE OF ADVANCED CYBERINFRASTRUCTURE (OAC) **$232,720,000**
+$10,880,000 / 4.9%

OAC Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$221.84**	**-**	**$232.72**	**$10.88**	**4.9%**
Research	**87.17**	**-**	**116.42**	**29.25**	**33.6%**
Education	**7.76**	**-**	**5.26**	**-2.50**	**-32.2%**
Infrastructure	**126.91**	**-**	**111.04**	**-15.87**	**-12.5%**
Networking and Computational Resources Infrastructure and Services	126.91	-	111.04	-15.87	-12.5%

About OAC

OAC supports the conceptualization, design, and implementation of the advanced research cyberinfrastructure (CI) ecosystem that is critical to advances in all areas of science and engineering research and education in the 21st century, including the Industries of the Future such as AI, QIS, and advanced wireless. In this way, OAC serves to sustain U.S. economic competitiveness and national security. Given its role across all of science and engineering, OAC works in partnership with all NSF directorates and offices as well as other CISE divisions, to provide support to academic institutions, and encourages a rich and vibrant ecosystem that blends translational computer and computational research and research-specific CI with innovations from the private sector. Specifically, OAC investments include acquisition, integration, coordination, and operations associated with shared data, secure networking, advanced computation, scientific software and data services, and the design and development of computational and data-enabled science and engineering tools. OAC also nurtures the computational and data skills and expertise needed for next-generation science and engineering research. Collectively, OAC enables more than 8,000 faculty and researchers to address complex and multidisciplinary discovery, prediction, and innovation challenges by providing access to CI resources and services, along with secure connectivity to major national and international facilities and scientific instruments. OAC promotes innovative, robust, secure, and interoperable CI, as well as sharing and collaboration among academic research infrastructure groups, other federal agencies and international research funders, and the private sector.

OAC will continue to provide NSF's co-leadership of the recently updated NSCI. This activity will support research advances in new, advanced computing architectures, systems, and services to address 21st-century scientific and technological challenges and opportunities; develop and broaden the Nation's computational infrastructure ecosystem; and forge and expand partnerships for the future of computing.

In general, about 34 percent of the OAC portfolio is available to support new grants. The remaining 66 percent supports grants made in prior years.

DIVISION OF COMPUTING AND COMMUNICATION FOUNDATIONS (CCF) — $202,960,000 +$9,410,000 / 4.9%

CCF Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$193.55**	**-**	**$202.96**	**$9.41**	**4.9%**
Research	**182.11**	**-**	**193.80**	**11.69**	**6.4%**
Centers Funding (total)	6.70	-	2.49	-4.21	-62.8%
STC: Center for the Science of Information[1]	3.70	-	-	-3.70	-100.0%
STC: Center for Brains, Minds and Machines: The Science and the Technology of Intelligence	3.00	-	2.49	-0.51	-17.0%
Education	**9.84**	**-**	**7.60**	**-2.24**	**-22.8%**
Infrastructure	**1.60**	**-**	**1.56**	**-0.04**	**-2.5%**
National Nanotechnology Coordinated Infrastructure (NNCI)	0.60	-	0.56	-0.04	-6.7%
Research Resources	1.00	-	1.00	-	-

[1] The Center for the Science of Information is sunsetting as planned.

About CCF

CCF supports research and educational activities involving the theoretical foundations of computing, communication, and information. CCF's investments enable advances in the design and analysis of algorithms, computational complexity, and mathematical modeling of systems, with attention to the fairness, correctness, and verification of AI systems. CCF also invests in foundational research on the theoretical underpinnings of information acquisition, transmission, and processing in communication and information networks, such as sensor, advanced wireless, multimedia, and biological networks. In addition, CCF provides support for advancing the design, validation, verification and evaluation of computing hardware and software through new theories, programming languages, testing approaches, and formal methods for improving system performance, correctness, usability, reliability, and scalability. CCF investments also explore the potential impact of emerging technologies, including quantum devices and systems, neuromorphic architectures, biocomputing, synthetic biology, and nanotechnology, on the various facets of computation, communication, and information that are of relevance to the IotF, notably advanced manufacturing and biotechnologies.

In general, about 69 percent of the CCF portfolio is available to support new grants. The remaining 31 percent supports grants made in prior years.

DIVISION OF COMPUTER AND NETWORK SYSTEMS (CNS) **$240,420,000**
+$11,000,000 / 4.8%

CNS Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$229.42**	**-**	**$240.42**	**$11.00**	**4.8%**
Research	**185.72**	**-**	**207.77**	**22.05**	**11.9%**
Education	**18.64**	**-**	**10.65**	**-7.99**	**-42.9%**
Infrastructure	**25.06**	**-**	**22.00**	**-3.06**	**-12.2%**
Research Resources	25.06	-	22.00	-3.06	-12.2%

About CNS

CNS supports research and education activities that advance understanding of the fundamental properties of computer systems and networks. CNS investments produce new insights into the dynamics of complex hardware and software systems and explore new architectures for future-generation computing and communication infrastructures and services, thereby lowering barriers to innovation and enhancing economic competitiveness. These investments enable future AI, quantum computing and communication, and advanced wireless systems. CNS-enabled systems include, but are not limited to, cyber-physical, embedded, distributed, centralized, virtualized, cloud, wireless, and mobile systems. CNS also supports research and education activities in cybersecurity, including post-quantum cryptography, to ensure that society's ubiquitous computing and communication infrastructures deliver the quality of service they are designed to achieve without disruption, while enabling and preserving privacy, security, and trust. CNS also plays a leadership role in coordinating CISE investments in systems research infrastructure and in the development of the computing workforce of the future.

In general, about 70 percent of the CNS portfolio is available to support new grants. The remaining 30 percent supports grants made in prior years.

DIVISION OF INFORMATION AND INTELLIGENT SYSTEMS (IIS) — $240,050,000 / +$31,680,000 / 15.2%

IIS Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual: Amount	Change over FY 2019 Actual: Percent
Total	**$208.37**	**-**	**$240.05**	**$31.68**	**15.2%**
Research	**194.24**	**-**	**230.45**	**36.21**	**18.6%**
Centers Funding (total)	1.00	-	0.83	-0.17	-17.0%
STC: Center for Brains, Minds and Machines: The Science and the Technology of Intelligence	1.00	-	0.83	-0.17	-17.0%
Education	**11.94**	**-**	**7.60**	**-4.34**	**-36.3%**
Infrastructure	**2.19**	**-**	**2.00**	**-0.19**	**-8.7%**
Research Resources	2.19	-	2.00	-0.19	-8.7%

About IIS

IIS supports research that studies the interrelated roles of people, computers, and information. Specifically, IIS supports research and education in AI, data science, and human-computer interaction. Research in AI includes machine learning, knowledge representation, computer vision, and natural language processing. Research in data science includes data management, data collection, data analytics, and data integration. Research in human-computer interaction includes work on computer system usability, new kinds of user interfaces, and computer systems to augment human capabilities. Research supported by IIS addresses fundamental questions about machine intelligence, helps us understand how data can improve our lives, and lays the foundation for innovations in a myriad of sectors including energy, transportation, healthcare, manufacturing, and defense.

In general, about 77 percent of the IIS portfolio is available to support new grants. The remaining 23 percent supports grants made in prior years.

DIVISION OF INFORMATION TECHNOLOGY RESEARCH (ITR) $146,250,000 +$14,320,000 / 10.9%

ITR Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
Total	**$131.93**	**-**	**$146.25**	**$14.32**	**10.9%**
Research	**114.00**	**-**	**132.25**	**18.25**	**16.0%**
Centers Funding (total)	1.00	-	0.83	-0.17	-17.0%
STC: Center for Brains, Minds and Machines: The Science and the Technology of Intelligence	1.00	-	0.83	-0.17	-17.0%
Education	**1.47**	**-**	**-**	**-1.47**	**-100.0%**
Infrastructure	**16.46**	**-**	**14.00**	**-2.46**	**-14.9%**
Research Resources	16.46	-	14.00	-2.46	-14.9%

About ITR

ITR provides support for transformative explorations in computer and information science and engineering research, infrastructure, and education, which are foundational for the IotF. These investments support emerging and urgent high-priority areas that cut across traditional disciplinary boundaries and promise to accelerate discovery at the frontiers of the field. This includes support for fundamental research on AI, QIS, particularly quantum computation and communication, and advanced wireless; innovative partnerships and collaborations between academia and industry; as well as the development of world-class research infrastructure. This is done in partnership with all of the CISE divisions as well as through cross-NSF and interagency activities.

ITR, in partnership with all of the NSF directorates and research offices, will advance the HDR Big Idea by investing funds to support convergent activities that transcend the traditional disciplinary boundaries of individual NSF directorates and offices. These activities will enable pursuit of fundamental research in data science and engineering; the development of a cohesive, federated, national-scale approach to research data infrastructure; and the development of a 21st-century data-capable workforce. While budget management and reporting for this investment will be the responsibility of CISE, the convergent activities will be overseen and managed collaboratively by the multi-directorate/office HDR leadership team.

In general, about 44 percent of the ITR portfolio is available to support new grants. The remaining 56 percent supports grants made in prior years.

APPENDIX A – ADVANCED COMPUTING SYSTEMS AND SERVICES PORTFOLIO

Advanced Computing Systems and Services Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
Leadership Class Computing	$55.07	-	$12.00
Advanced/Innovative Computing	27.38	-	37.00
Coordination and Support Services	11.81	-	29.00
Total	**$94.26**	**-**	**$78.00**

Advanced Computing Systems and Services Overview

For nearly four decades, NSF has been a recognized leader in enabling the innovative use and broad availability of a cohesive, powerful, and advanced computing ecosystem to accelerate fundamental science and engineering. NSF aims to sustain America's leadership in the research, development, and broad deployment of existing as well as new advanced computing technologies, services, and skills, in part through co-leadership of the recently updated NSCI.[22] Within the broad goals set for the updated NSCI, key NSF foci include fundamental research to support future generations of an advanced computing ecosystem and research CI including software and data services and CI expertise to promote cohesive platforms and interoperability for large-scale data analytics as well as modeling and simulation applications across all of science and engineering.[23] These foci include an emphasis on a holistic approach to America's computational infrastructure for science and engineering research, spanning both human and technical dimensions, including forging and expanding partnerships that ensure American leadership in science, technology, and innovation.

The overall NSF advanced computing strategy and program portfolio receives guidance and input from the ACCI; Assistant Directors (AD) Council, which includes ADs and office heads from the NSF research and education directorates and offices; Cyberinfrastructure Strategy Group, which includes division directors or deputy division directors from the NSF research and education directorates and offices; cross-directorate working group for strategic computing; and directly from the research community through principal investigators' meetings, workshops, and sessions at professional conferences.[24] In 2013, OAC supported a National Academies of Sciences, Engineering, and Medicine study to further inform the implementation of its advanced computing strategy in the 2017 to 2020 timeframe. The final report, *Future Directions for NSF Advanced Computing Infrastructure to Support U.S. Science and Engineering in 2017-2020*, was published in 2016.[25] In 2017, OAC launched an effort to refresh the vision, strategy, and investment approaches for CI, including advanced computing, to support the evolving needs of the science and engineering community,[26] and also funded a study seeking to identify and catalog best practices for collaborations between academic or federally-funded High-Performance Computing (HPC) centers and industry.[27] In 2018, NSF funded a workshop focused on "Future Cyberinfrastructure: Rethinking NSF's Computational Ecosystem for 21st-Century Science and Engineering."[28] In 2019, NSF funded a follow-on conference, the *National Cyberinfrastructure Coordination Service Conference*, which examined the configuration of services intrinsic to a national CI; the report is currently under development. Additionally, international

[22] www.whitehouse.gov/wp-content/uploads/2019/11/National-Strategic-Computing-Initiative-Update-2019.pdf
[23] www.nsf.gov/cise/nsci/
[24] See, for example, https://sc18.supercomputing.org/presentation/?id=bof154&sess=sess417
[25] www.nap.edu/catalog/21886/future-directions-for-nsf-advanced-computing-infrastructure-to-support-us-science-6
[26] www.nsf.gov/cise/oac/ci2030/
[27] www.ncsa.illinois.edu/assets/pdf/industry/Industry_Report_2017.pdf
[28] https://uiowa.edu/nsfcyberinfrastructure/article/workshop-report

activities to accelerate investments in leadership-class computing, particularly in Europe and Asia, are providing additional urgency and importance for this investment strategy to ensure the U.S. maintains its global leadership role in science and engineering.

Technological advances come rapidly, along with changes in the capabilities and services offered by commercial interests (e.g., cloud services). In addition, the requirements of the science and engineering research communities are heterogeneous and also rapidly evolving. As outlined in the forward-looking computational ecosystem blueprint released in FY 2019,[29] NSF currently invests in three broad and complementary advanced computing areas that enable it to meet these continually evolving needs in an agile yet predictable way. These investments complement each other as well as discipline-specific investments by NSF's directorates, mission-specific investments by other agencies, and cumulatively extensive, but individually smaller, investments by academic institutions at the regional and campus levels. Specifically, these areas are:

- **Leadership-Class Computing** which aims to provide unique services and resources to advance the largest and most computationally-intensive science and engineering research frontiers not otherwise possible;
- **Advanced/Innovative Computing Systems and Services** which aims to provide a technically diverse and potentially future-looking advanced computing portfolio, reflecting the growing and changing use of computation and data in both the research and education processes, and capable of supporting hundreds to thousands of investigators conducting cutting-edge science and engineering research; and
- **Coordination and Support Services** which aims to coordinate the provisioning, allocation, and operations of NSF's advanced computing resources, providing advanced assistance to the user community, supporting aggregation and federation capabilities, enabling the translation of CI research advances, and broadening participation.

Leadership-Class Computing

Description

Leadership-class computing systems have represented a key component of NSF's computational portfolio for decades. NSF's current leadership-class computing system is Frontera, which is deployed at the Texas Advanced Computing Center (TACC) at the University of Texas at Austin (UT Austin). Frontera is one of the most powerful supercomputers in the world and is the most powerful supercomputer ever deployed on a U.S. academic campus. The system began accepting early science and engineering research users in May 2019 and became fully operational in October 2019. Frontera is expected to allow researchers to tackle much larger and more complex science and engineering applications than ever before, within and across disciplines as diverse as biology, astronomy, engineering, materials science, and the geosciences.

Blue Waters, the NSF-funded leadership-class computing resource deployed at the National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign (UIUC), became operational in FY 2013. Although Blue Waters was originally anticipated to complete its operational cycle in December 2019, the National Geospatial-Intelligence Agency has provided funding to NSF to maintain the system into FY 2021 to support automated, large-scale generation of digital elevation models. The continued operations of Blue Waters will produce geospatial products that will contribute significantly to the advancement of Earth science and provide critical benefits to Federal agencies needing to access unclassified geospatial data.[30]

Current Status

The acquisition of Frontera was the result of a year-long competition from FY 2017 to FY 2018. At its July

[29] www.nsf.gov/cise/oac/vision/blueprint-2019/nsf-aci-blueprint-v10-508.pdf
[30] www.congress.gov/116/crpt/hrpt101/CRPT-116hrpt101.pdf (pg. 97)

2018 meeting, the NSB authorized the Director at her discretion to make an award to TACC for the acquisition of the Frontera system in an amount not to exceed $60.0 million over a period of five years. The resolution also authorized, pending appropriate approval associated with NSF's MREFC policies, an additional amount not to exceed $8.0 million to be made available to TACC in the form of supplemental funding to advance the design of a Phase 2 leadership-class computing facility (LCCF).

At its May 2019 meeting, the NSB authorized the Director at her discretion to make an award to TACC for the O&M of Frontera in an amount not to exceed $60.0 million over a period of five years. It offers the highest scale, throughput, and data analysis capabilities ever deployed on a U.S. university campus. Through its primary central processing unit subsystem, Frontera offers more than five times greater capacity than Blue Waters. In addition, Frontera's graphics processing unit (GPU) accelerates discoveries in important research areas such as deep learning and molecular dynamics.

In July 2019, TACC started the design and planning process for a follow-on Phase 2 LCCF, which will enable a 10 times performance improvement over the existing Frontera system. The Phase 2 LCCF will be managed and overseen by the NSF MREFC process. This project is therefore subject to MREFC policies regarding entry and approval into the required design stages as laid out in the NSF Major Facilities Guide.[31] The Frontera system is providing science and engineering evaluation to inform the design of the future facility.

Science and Engineering Research and Education Activities Enabled by Leadership-Class Computing

Leadership-class computing systems enable investigators across the Nation to conduct innovative research that is not otherwise possible due to demanding computing requirements. In FY 2019, NSF issued a Dear Colleague Letter[32] inviting supplemental funding requests to active NSF research awards for time on the Frontera and Blue Waters systems to enable scientific and engineering research that would not otherwise be possible without access to a leadership-class computing resource; this effort resulted in 48 awards to research teams across the country. Research topics supported through these awards include: a very large-scale simulation of the entire stellar universe to understand the first billion years of cosmic evolution; a never-before-done simulation of mammalian brain activity at varied behavioral time scales to better understand how the human brain works; a comprehensive climate model study to understand the role of atmospheric rivers in shaping recorded hydroclimates in the southwest region of North America; detailed calculations of seismic energy propagation to enable better earthquake prediction and its effects on buildings and other civil infrastructure; a massive computation effort to produce openly distributed, very high-resolution digital surface models covering a substantial portion of the Earth's land mass; simulations of the largest and most aggressive types of tornadoes common in the U.S. to enable better severe weather predictions; development of a new framework for cosmological simulations of galaxy formation, combining machine learning with cosmological codes; and the integration of deep learning methods with biophysics models in the application of understanding how brain cancer develops and progresses.

In FY 2020, NSF issued a Dear Colleague Letter[33] describing a new innovative pilot mechanism for the Nation's researchers to request access to Frontera. The pilot mechanism is expected to promote novel leadership-class applications, ensure appropriate prioritization of cutting-edge science and engineering, and enable maximal utilization of the computing resource. New awards for access to Frontera through this mechanism are anticipated to begin in April 2020.

Education and outreach activities supported by the program consist of projects targeting students at pre-college, undergraduate, graduate, and post-graduate levels; workshops, conferences, summer schools, and

[31] www.nsf.gov/pubs/2019/nsf19068/nsf19068.pdf
[32] www.nsf.gov/pubs/2019/nsf19030/nsf19030.jsp
[33] www.nsf.gov/pubs/2020/nsf20018/nsf20018.jsp

seminars; and industry partnership activities. To date, NSF-funded leadership-class computing activities have enabled more than 200 education, outreach, and training projects at over 160 institutions, including institutions in the Established Program to Stimulate Competitive Research jurisdictions.

Management and Oversight

The Frontera and Blue Waters projects are overseen by OAC's program directors and BFA's Division of Grants and Agreements staff, who receive strategic advice from the AD Council. Advice from the NSF Office of General Counsel is also sought, as necessary. Planning for the Phase 2 system is coordinated through the Large Facilities Office, as well as the Division of Acquisition and Cooperative Support, and will be reviewed in accordance with NSF's major facilities policies and procedures.

The NSB receives updates on any major changes in risk assessments, which are reviewed annually by an external panel. Risks monitored during the operational phase of a project include system security, performance, reliability, usability, project management, and other factors that could reduce the overall scientific impact.

Advanced/Innovative Computing Systems and Services

Description

NSF funds the acquisition and operation of nationally available Advanced/Innovative Computing Systems and Services that, in aggregate, are forward-looking and technically diverse, and reflect changing and growing use of data-intensive computation in both the research and education processes. At the same time, they are intended to enable discoveries at a computational scale beyond the reach of an individual or regional academic institution.

Deployed systems currently serve as a cohesive set of allocable resources within the eXtreme Digital (XD) integrated services infrastructure, which is described in the following section. Awards are generally made as two parts: an acquisition and deployment award, which may be the result of a competitive or a renewal proposal; and a separate award for operations and maintenance following deployment. When an award is made, the awardee institution issues sub-awards to vendors and/or other organizations for acquisitions and services as necessary. Expenditures are contingent on successful completion of deployment milestones.

Current Status

Four resources (Wrangler, Comet, Bridges, and Jetstream) commenced operations in FY 2015 and FY 2016. In FY 2018, the period of operation for these four systems was extended, as noted below, allowing for increased return on investment and ensuring continuity of operations for the research community. Stampede 2, the largest of the currently active HPC resources within this portfolio, commenced operation in FY 2017.

Deployed in FY 2015 at TACC, Wrangler is the most powerful data analysis system allocated in XD and provides flexible support for a wide range of scientific domains and will remain operational through December 2020.

Comet also came online in FY 2015 at the University of California, San Diego (UCSD). It supports research interests and priorities requiring large, high-throughput workloads, as well as massive amounts of computation but at moderate scale. Comet was augmented with GPUs in FY 2018 and is planned to remain operational through March 2021.

Bridges came online in FY 2016 at the Pittsburgh Supercomputing Center on the campus of Carnegie Mellon University (CMU). Bridges provides an innovative HPC and data analytics system integrating advanced memory technologies to empower new communities. It brings desktop convenience to HPC, potentially enabling new communities to access advanced computing resources. Bridges was augmented with GPU nodes in FY 2018 and will remain operational through November 2020.

Jetstream also came online in FY 2016 at Indiana University. Jetstream is a cloud-based platform that incorporates the elements of commercial cloud computing resources with important scientific applications. Jetstream's system operation was augmented in FY 2017 to provide additional focused staff expertise to accelerate effective researcher utilizations of the programmable CI/virtual machine-enabled architecture. The system will continue operations through November 2020.

In FY 2016, NSF awarded *Stampede 2: The Next Generation of Petascale Computing for Science and Engineering* to TACC following a rigorous merit review, enabling the acquisition and deployment of Stampede 2 as a successor resource to the highly successful Stampede system. Stampede operated from 2013 through 2017 and was considered the "backbone" for the XD environment, annually supporting more than 5,000 researchers and more than 1,000 computationally-intensive projects across the Nation. Stampede 2 similarly serves as the primary national resource for thousands of academic researchers, complements other national advanced computing systems and services, and provides capabilities beyond the reach of individual campuses and regional resources. Stampede 2 was fully deployed as a production resource by the end of 2018 and is expected to continue operations through November 2022.

As noted above, Wrangler, Comet, Bridges, and Jetstream are all scheduled to ramp down operations during the FY 2020 to FY 2021 timeframe. During this period, Stampede 2 will continue full operations and the new leadership-class computing system, Frontera, will ramp up to full operations, ensuring continued support for the science and engineering research community. Moving forward, NSF envisions that investments in advanced/innovative computing systems and services will foster an integrated CI ecosystem that addresses the growing scale and diversity of the science and engineering community, the changing nature of science and engineering research requirements, and the rapidly evolving technology and services landscape, with the overarching goal of supporting the full range of computational- and data-intensive research across all science and engineering domains. To further this goal, NSF issued a solicitation for advanced computing systems and services in FY 2019 with anticipated awards spanning FY 2019 to FY 2024.[34] This solicitation calls for investments in two categories:

- Category I, Capacity Systems: production computational resources maximizing the capacity provided to support the broad range of computation and data analytics needs in science and engineering research.
- Category II, Innovative Prototypes/Testbeds: innovative forward-looking capabilities deploying novel technologies, architectures, usage modes, etc., and exploring new target applications, methods, and paradigms for science and engineering discoveries.

The solicitation allowed for two competitions spanning FY 2019 and FY 2020. In the first competition, three awards were made: two in Category I, to the Pittsburgh Supercomputing Center at CMU and to the San Diego Supercomputer Center at UCSD; and one in Category II to the State University of New York at Stony Brook. The second competition is currently underway.

<u>Science and Engineering Research and Education Activities Enabled by Advanced/Innovative Computing Systems and Services</u>

The ecosystem of advanced/innovative computing systems and services is enabling new, world-leading, and transformative advances across the breadth of science and engineering research, in the integration of research and education, and in broadening participation in science and engineering by underrepresented groups. It is enabling new collaborations across public and private sectors to advance American security and economic competitiveness. These advances are made possible by providing researchers and educators with access to world-leading computational systems and services beyond what is typically available on most campuses. Providing access includes providing the necessary expertise, interfaces, consulting support, and training necessary to facilitate use of the systems and services. This activity is central to America

[34] www.nsf.gov/pubs/2019/nsf19534/nsf19534.htm

achieving the full potential of complementary investments by NSF, other federal agencies, and academic institutions in computing infrastructure.

<u>Management and Oversight</u>
OAC's program directors provide direct oversight during both the acquisition, and O&M awards. Formal reporting consists of quarterly and annual reports, which are reviewed by the program directors.

Awards for advanced/innovative computing system and services are managed under cooperative agreements that include the management structures, milestones, spending authorization levels, and review schedules. Each awardee is responsible for the satisfactory completion of milestones prior to NSF authorization of spending. Progress is assessed with the aid of annual external reviews. In addition, each project is required to have a project management plan.

Any activity of this nature, and at this scale, comes with a certain element of risk. The review process, conducted prior to award, analyzes the risks as presented in the proposal and identifies any additional risks that should be considered. During the award process, risks are identified and analyzed, and a mitigation plan is created and followed. One of the activities of the periodic NSF external reviews, conducted by an external panel of experts, is to revisit and reassess the risk situation and make recommendations as deemed necessary. In the case of projects that involve an acquisition, project risks are generally substantially reduced subsequent to deployment. Thus, the pacing of the acquisitions and deployments for such projects provides balance in the overall risk portfolio for the program.

Milestone-driven reviews occur during the acquisition award, typically with an external review prior to deployment. Annual reviews, conducted by an external panel of expert reviewers and managed by OAC program directors, are performed during the operational phase of each project.

Coordination and Support Services

<u>Description</u>
NSF's investments in coordination and support services, as exemplified by the XD integrated services infrastructure, add value to the NSF advanced/innovative computing systems and services by coordinating allocations and access to the systems and services, providing advanced assistance to the user community, and broadening participation. The XD program's shared services model for coherently and efficiently providing researchers with both access and expertise to diverse, dynamic, and distributed resources is a cornerstone of the American advanced computing ecosystem. Enabling the connection between individual campuses and national resources is an essential aspect of the advanced computing ecosystem.

XD enables and supports leading-edge scientific discovery and promotes science and technology education. The program encourages innovation in the design and implementation of an effective, efficient, increasingly virtualized approach to the provision of high-end digital services, while ensuring that the infrastructure continues to deliver high-quality access for the many researchers and educators who use it in their work.

XD shared services consist of several interrelated parts: allocation of resources to computational and data research projects; advanced user assistance; training, education, and outreach; architecture and operation of an integrated digital services infrastructure; metrics services; and overall coordination. These elements are designed and implemented in a way that is clearly tied to the requirements of the science and engineering research community, using a flexible methodology that permits the architecture to evolve in response to changing community needs and that presents individual users with a common environment regardless of where the resources or researchers are located.

Current Status

Two awards are currently active within the XD program: XD Metrics Service (XMS) and the eXtreme Science and Engineering Discovery Environment (XSEDE). The XMS award was made in FY 2015 to The State University of New York at Buffalo. This award provides metrics services allowing measurement of key operational data for both resources and services. All other services are provided by XSEDE. The XSEDE award to UIUC was renewed in September 2016, continuing the prior XSEDE award for another five-year period. The award will conclude at the end of August 2021, and in anticipation of that date, NSF has initiated engagements with the community about the structure and composition of future coordination efforts.

Within the current XSEDE project, there are 18 partners engaged via subawards to the University of Tennessee at Knoxville (National Institute for Computational Sciences), CMU and University of Pittsburgh (Pittsburgh Supercomputing Center), UT Austin (TACC), UCSD (San Diego Supercomputing Center), University of Chicago, Indiana University, Purdue University, Shodor Education Foundation, Ohio Supercomputer Center, Southeastern Universities Research Association, Cornell University, National Center for Atmospheric Research, Georgia Institute of Technology, Oklahoma State University, University of Georgia, Oklahoma University, University of Southern California, and University of Arkansas.

The mid-project external site review of the XMS project took place in June 2018 and continued operations were authorized based on the successful outcome of that review. XSEDE has annual external reviews at NSF. The first external review of the renewed XSEDE project took place in June 2017; subsequent external milestone reviews have taken place in January and June, with the most recent review having occurred in June 2019. On the basis of these successful reviews, funds were authorized for continued operations. NSF has outlined its plans for national CI coordination services moving forward in a blueprint document released in Q1 of FY 2020.[35]

Science and Engineering Research and Education Activities Enabled by Coordination and Support Services

Coordination and support services, as exemplified by XD, enable transformative advances in science and engineering research, in the integration of research and education, and in broadening the participation of underrepresented groups in science and engineering. These advances are accomplished by providing researchers and educators with coherent and highly usable access to extreme-scale digital resources beyond those typically available on most campuses, together with the interfaces, consulting, advanced user support, and training necessary to facilitate their use.

XD coordinates access to advanced/innovative computing systems and services and enables researchers to efficiently manipulate, analyze, visualize, and share extremely large amounts of distributed digital information from simulations, sensors, and experiments.

The XSEDE project delivers tools and services that not only link users to national facilities, but also enable scientific collaborations of geographically distributed teams. In doing so, it facilitates dynamic access to digital resources and experimental testbeds within and across university campuses, as well as government laboratories. XSEDE includes outreach and training critical to reducing barriers to the use of advanced digital systems by the research and education communities, thereby promoting enhanced productivity.

The XMS project develops analysis tools and collects operational data from XSEDE services and the advanced computing/innovative systems and services. The immediate users of these methods and tools are the providers of NSF-supported advanced computing systems and services. However, both tools and data are publicly available and used by other projects such as Blue Waters, Frontera, and individual universities.

[35] www.nsf.gov/cise/oac/vision/blueprint-2019/nsf-aci-blueprint-services.pdf

Management and Oversight

OAC's program directors oversee the XD projects. XSEDE has an external advisory board, a user board, and a service provider forum to ensure that all stakeholders can provide project input. OAC oversight of the XSEDE project includes participation in weekly teleconferences with senior XSEDE personnel and in quarterly project-wide staff meetings. Formal reporting consists of quarterly and annual reports, which are reviewed by the program directors.

Each XD award is managed under a cooperative agreement that includes requirements for a specific management structure, milestones, reporting of spending levels over time, and a review schedule. Each awardee is responsible for the satisfactory completion of milestones prior to NSF authorization of spending. In addition, each project is required to have a detailed management plan in place.

While XD is operational in nature, the virtual organizations of the XSEDE project and the services of all XD projects are innovative and thus bear inherent risks. The projects maintain risk registers that are reviewed periodically by external panels and by the cognizant program directors.

Annual reviews for XSEDE and mid-project reviews for XMS are conducted by external panels of expert reviewers and managed by OAC program directors.

DIRECTORATE FOR ENGINEERING (ENG)

$909,780,000
-$81,370,000 / -8.2%

ENG Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Chemical, Bioengineering, Environmental and Transport Systems (CBET)	$190.47	-	$160.29	-$30.18	-15.8%
Civil, Mechanical, and Manufacturing Innovation (CMMI)	237.91	-	200.54	-37.37	-15.7%
Electrical, Communications, and Cyber Systems (ECCS)	118.03	-	103.74	-14.29	-12.1%
Engineering Education and Centers (EEC)	102.76	-	89.49	-13.27	-12.9%
Industrial Innovation and Partnerships (IIP)	268.67	-	257.90	-10.77	-4.0%
Emerging Frontiers and Multidisciplinary Activities (EFMA)	73.30	-	97.82	24.52	33.4%
Total	**$991.15**	**-**	**$909.78**	**-$81.37**	**-8.2%**

About ENG

In FY 2021, ENG will spur engineering breakthroughs to help ensure America's security, prosperity, health, and technological leadership in the future. ENG will invest in groundbreaking fundamental engineering research including key Administration and NSF-wide research priorities. Substantial directorate investments in NSF's Big Ideas will emphasize convergence research approaches to help address grand challenges and societal impact. In addition, to advance U.S. global competitiveness, strategic ENG support will strengthen the engineering workforce and accelerate innovation created by deep-technology small businesses and industry.

ENG funding in FY 2021 will help protect Americans. ENG investments will drive advances in secure quantum communications systems and quantum computing as part of the QL Big Idea. ENG will continue its long-term support of engineering research to improve resilience to hurricanes, earthquakes, and other disasters, including the Natural Hazards Engineering Research Infrastructure (NHERI). Other ENG-funded research will investigate methods and technologies for securing the electric grid, detecting biological threats, and disrupting illicit supply networks.

Additional ENG FY 2021 investments in NSF's Big Ideas will help to build future prosperity. ENG will steward the FW-HTF Big Idea and make essential contributions to research on soft robotics, advanced manufacturing, and artificial intelligence. ENG collaboration in the HDR Big Idea will intersect with support for advanced materials, smart and autonomous systems, and disruptive technologies for energy-efficient computing and spectrum-efficient wireless communications. ENG's NNA Big Idea investments will also help ensure sustainable and reliable infrastructure systems in the Arctic through, for example, sensor systems to understand soil dynamics, complex models of food-energy-water systems, and resilient structure designs.

ENG support will help to advance health technologies and systems. ENG will invest in fundamental research to observe nanoscale cellular processes and changes, engineering biology to reverse disease and produce therapies, and synthetic biology to contribute to the URoL Big Idea. The directorate also will support neuro-technologies and imaging relevant to brain research. ENG investments will continue advances in prosthetic and assistive technologies for veterans, senior citizens, and people with disabilities.

While fundamental engineering research fuels U.S. technological innovation and competitiveness, ENG support for workforce development and innovation speeds and strengthens the translation of discoveries. The directorate will invest in research on education, broadening participation, and inclusion in engineering, as well as in student experiences with industry. ENG will maintain its commitment to talented faculty by continuing investments in the CAREER program. ENG investments in academic partnerships with industry, entrepreneurial training through NSF Innovation Corps (I-Corps™), and startups through the Small Business Innovation Research (SBIR)/Small Business Technology Transfer (STTR) programs will help bring new ideas from lab to market and fortify the Nation's innovation ecosystem.

As part of the FW-HTF Big Idea, and in partnership with the other research directorates and offices, ENG will support convergence activities that transcend the traditional disciplinary boundaries of individual NSF directorates and offices. While financial stewardship for FW-HTF will be the responsibility of ENG, the convergence activities will be overseen and managed collaboratively by the multi-directorate/office FW-HTF leadership team. These activities will enable pursuit of fundamental research on advancing cognitive and physical capabilities in the context of human-technology interactions and the development of a 21st-century workforce capable of adapting to a changing employment landscape. For more information about the Big Ideas, see the narratives in the NSF-Wide Investments chapter.

ENG provides 41 percent of the federal funding for basic research at academic institutions in the engineering disciplines.

Major Investments

ENG Major Investments
(Dollars in Millions)

Area of Investment[1,2]	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Advanced Manufacturing	$138.14	-	$140.00	$1.86	1.3%
Future Manufacturing	-	-	*20.00*	*20.00*	*N/A*
Advanced Wireless	21.00	-	23.00	2.00	9.5%
Artificial Intelligence	119.92	-	159.19	39.27	32.7%
Bioeconomy	95.00	-	96.00	1.00	1.1%
IUSE	0.53	-	4.43	3.90	731.3%
Microelectronics and Semiconductors	56.11	-	55.00	-1.11	-2.0%
NSF I-Corps™	17.33	-	14.63	-2.70	-15.6%
Quantum Information Science	10.19	-	27.84	17.65	173.2%
SaTC	3.25	-	3.03	-0.22	-6.8%
NSF's Big Ideas					
FW-HTF Stewardship	*29.96*	-	*45.00*	*15.04*	*50.2%*

[1] Major investments may have funding overlap and thus should not be summed.

[2] This table reflects support for selected areas of ENG's investments. In other directorate narratives, the selected areas of investment displayed may differ and thus should not be summed across narratives.

- Advanced Manufacturing: ENG research accelerates advances in manufacturing with emphasis on multidisciplinary research that fundamentally alters and transforms manufacturing capabilities, methods, and practices. The FY 2021 Request includes $20.0 million in support of Future

Manufacturing research under the advanced manufacturing umbrella. Future manufacturing is defined as fundamental research to enable manufacturing that (a) does not exist or is not possible today or (b) exists or is possible only at such small scales that it is not viable for mass production. Continued investments in advanced manufacturing include research on highly connected cyber-physical systems in smart processing and cyber manufacturing systems, and activities that develop new methods, processes, analyses, tools, or equipment for new or existing manufacturing products, supply chain components, or materials. ENG's investments will enable new functionalities that will increase the efficiency and sustainability of the production of the next generation of products and services. These developments will yield advantages such as reduced time to market, new performance attributes, improved small-batch production, cost and energy savings, and reduced environmental impact from the manufacturing of products.

- Advanced Wireless: ENG, together with other NSF directorates and offices, will invest in fundamental research, infrastructure, and education to advance knowledge gaps and innovate in areas critical to future generations of wireless technologies and networks beyond 5G to help make wireless communication faster, smarter, more responsive, and more robust. ENG funding will enable new wireless sensors, devices, circuits, protocols, networks and systems; artificial intelligence and inference on mobile devices; human-machine-network interactions; dynamic spectrum allocation and sharing; and the integration of future wireless with energy, transportation, manufacturing, and other systems involving the internet-of-things.
- AI: ENG, together with other NSF directorates and offices, will increase support for AI research and development. A key focal point will be support for AI Institutes, a center-scale activity that will span (a) foundational areas of machine learning, computer vision, natural language processing, and autonomy, along with safety, security, robustness, and explainability of AI systems; (b) translational research at the intersection of AI and various science and engineering domains supported by NSF as well as sectors such as agriculture, advanced manufacturing, transportation, and personalized medicine; (c) workforce development, including growing human capital and institutional capacity to nurture a new generation of ethical AI researchers and practitioners; and (d) advanced computing infrastructure, including access to data and computing capabilities.
- Bioeconomy: ENG, together with other NSF directorates and offices, will invest in fundamental research, infrastructure, and education to understand and harness biological processes for societal benefit. ENG investment areas related to the bioeconomy include synthetic biology, biotechnology, engineering biology, metabolic engineering, tissue engineering, biomechanics, the microbiome, and the development of new types of biomaterials, bio-based microelectronics, and biomanufacturing. ENG also supports research on the social and environmental implications of synthetic biology and other biotechnologies. ENG investments will enable future innovations in the health therapeutics, biopharmaceutical, biochemical, and biotechnology industries.
- IUSE: ENG's investment in the NSF-wide IUSE initiative, which integrates the agency's investments in undergraduate education, will continue as support for the IUSE/Professional Formation of Engineers: Revolutionizing Engineering Departments (PFE:RED) solicitation moves to a biennial cycle. PFE:RED enables research and innovations leading to and propagating interventions that improve both the quality and quantity of engineering graduates.
- Microelectronics and Semiconductors: ENG, together with other NSF directorates and offices, will support research to address fundamental science and engineering questions on the concepts, materials, devices, circuits, and platforms necessary to sustain progress in semiconductor and microelectronic technologies. Research in semiconductors and microelectronics is critical to future advances and security in information technology, communications, sensing, smart electric grid, transportation, health, advanced manufacturing, and other areas. The investment will strengthen America's capabilities and capacity for revolutionary microelectronics design, architecture, and fabrication, as well as high-performance computing. New discoveries will enable the nation to overcome crucial scientific barriers for emerging technologies such as artificial intelligence, quantum technologies, and interconnected

autonomous systems, and they will strengthen U.S. scientific leadership, economic prosperity, and national security.

- I-Corps™: ENG, in partnership with other directorates, will continue to support the NSF-wide I-Corps™ program, which connects NSF-funded science and engineering research with the technological, entrepreneurial, and business communities. It fosters a national innovation ecosystem that links scientific discovery with technology development, societal needs, and economic opportunities.
- QIS: ENG, together with other NSF directorates and offices, will increase support for quantum information science and engineering research. ENG's QIS investments strongly align with the *National Quantum Initiative Act* (P.L. 115-368) to consolidate and expand U.S.' global leadership in fundamental quantum research. QIS research will deliver proof-of-concept devices, applications, tools, or systems with a demonstrable quantum advantage over their classical counterparts. Research in QIS examines uniquely quantum phenomena that can be harnessed to advance information processing, transmission, measurement, and fundamental understanding in ways that classical approaches can only do much less efficiently, or not at all. Current and future QIS applications differ from prior applications of quantum mechanics, such as the laser, transistor, and magnetic resonance imaging, by using distinct quantum phenomena—superposition and entanglement—that do not have classical counterparts. QIS research activities will also address education and workforce development needs, broadening research collaborations, promoting innovative team- building activities, and stimulating cross-disciplinary curriculum development and training to provide a quantum-smart workforce.
- SaTC: ENG support for SaTC will focus on the engineering aspects of the NITRD Strategic Plan for the Federal Cybersecurity Research and Development Program.[1] NITRD's research thrusts cover a set of interrelated priorities for U.S. government agencies that conduct or sponsor research and development in cybersecurity.
- FW-HTF: ENG will steward the FW-HTF Big Idea. While financial stewardship for this Emerging Frontiers and Multidisciplinary Activities (EFMA) investment will be the responsibility of ENG, the convergence activities will be overseen and managed collaboratively by the multi-directorate/office FW-HTF leadership team. ENG will work closely with OIA's Convergence Accelerator (CA) for the area of FW-HTF, building on collaborative design of the CA model that draws on ENG experience in technology translation and partnerships.

ENG Funding for Centers Programs and Facilities

ENG Funding for Centers Programs

(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$71.31**	**-**	**$55.92**	**-$15.39**	**-21.6%**
Engineering Research Centers (EEC)	58.95	-	50.92	-8.03	-13.6%
STC: Emergent Behaviors for Integrated Cellular Systems (CBET)[1]	3.70	-	-	-3.70	-100.0%
STC: Engineering Mechano-Biology (CMMI)	4.96	-	5.00	0.04	0.7%
STC: Energy Efficient Electronics Systems (ECCS)[1]	3.70	-	-	-3.70	-100.0%

[1] NSF's support for 2010 class of STCs will conclude in FY 2020 as planned.

For additional information on NSF's centers programs, please see the NSF-Wide Investments chapter.

[1] www.nitrd.gov/pubs/FY2019-Cybersecurity-RD-Roadmap.pdf

ENG Funding for Major Multi-User Facilities
(Dollars in Millions)

	FY 2019 Actual[1]	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$11.57**	**-**	**$10.95**	**-$0.62**	**-5.4%**
Natural Hazards Engineering Research Infrastructure (NHERI)	11.57	-	10.95	-0.62	-5.4%

[1] Includes $8.50 million to upgrade the LHPOST facility. Excluded is $8.93 million of FY 2019 O&M costs obligated in FY 2018.

For detailed information on individual facilities, please see the Facilities and the Major Research Equipment and Facilities Construction chapters.

Funding Profile

ENG Funding Profile

	FY 2019 Actual Estimate	FY 2020 (TBD)	FY 2021 Estimate
Statistics for Competitive Awards:			
Number of Proposals	9,023	-	10,000
Number of New Awards	2,379	-	2,200
Funding Rate	26%	N/A	22%
Statistics for Research Grants:			
Number of Research Grant Proposals	5,932	-	5,900
Number of Research Grants	1,642	-	1,500
Funding Rate	28%	N/A	25%
Median Annualized Award Size	$116,667	-	$116,000
Average Annualized Award Size	$135,094	-	$135,000
Average Award Duration, in years	2.7	-	2.7

ENG investments support fundamental engineering research, engineering education, and innovation, as well as research infrastructure such as facilities. In FY 2021, funding for centers accounts for approximately eight percent of ENG’s non-SBIR/STTR Request. In FY 2021, funding for facilities is under two percent of ENG’s non-SBIR/STTR Request.

Program Monitoring and Evaluation

ENG uses evidence and evaluation to build capacity for decision-making and improve program outcomes. Each year, the directorate collects evidence through workshops, surveys and other means to help identify emerging areas, learn about program results, and get other input from the community. ENG also periodically conducts reviews and evaluations to understand program effectiveness. Together, these measures help ENG make programs more strategic and impactful.

Evidence and Surveys

- In March 2019, IIP began administering a Baseline Monitoring Survey to companies that received a SBIR/STTR Phase I award after May 2018. The survey results will be used to create a performance baseline for recent SBIR/STTR awardees. The survey data allows IIP to benchmark across Phase I

companies, understand how successful small businesses differ, and identify potential failure modes to inform future initiatives supporting current and future small businesses. As of January 2020, more than 450 Phase I awardees have completed the survey. IIP will continue administering the survey to understand the impacts of the programs on these companies over time.
- Starting in March 2019, IIP made a significant change to the SBIR/STTR proposal submission process by requiring that small businesses or entrepreneurs submit a three-page Project Pitch prior to submitting a ful+l proposal. Pitch submitters learn within three weeks if their idea aligns with program objectives and receive program guidance. The new process offers real-time assistance to startups, advances the funding process, and accelerates the development of new ventures. Between March 2019 and January 2020, more than 4,500 small businesses or entrepreneurs completed the Project Pitch process. Applicants were surveyed to inform ongoing refinements of the Project Pitch process as NSF continues to provide critical support to the technology small business and startup communities. Initial analysis indicates that most Pitch submitters found the process easy. Additionally, most SBIR/STTR applicants found the feedback provided by NSF to be helpful and were satisfied with the wait time to get feedback.

Workshops and Reports
- In March 2019, an ECCS-supported workshop on "Reconfigurable Sensor Systems Integrated with Artificial Intelligence and Data Harnessing to Enable Personalized Medicine" was held. The focus of the workshop was to determine future strategies for advancing the fundamental understanding and engineering of reconfigurable sensor systems by integrating hardware with data harnessing, real-time learning, and artificial intelligence capabilities. The workshop report,[2] published in fall 2019, will inform ECCS' plans and priorities in Reconfigurable Sensor Systems enabling Personalized Medicine.
- In March 2019, NSF's Disrupting Illicit Supply Networks program, which began in FY 2018, had two follow-up activities: (1) NSF (ENG, CISE, and SBE), led by CMMI, issued a dear colleague letter[3] for research proposals with six new awards funded in FY 2019; (2) a new workshop[4] brought together operations researchers, computer scientists, social scientists, business researchers, geographers, social service agency representatives, and federal agencies to increase understanding of both the nature, and the challenges to disruption, of illicit supply chains. NSF is currently assessing input from the workshops, PIs, other federal agencies, and NGOs for broader interagency research opportunities.
- In May 2019, an ECCS-funded workshop on the interface between machine learning (ML) and dynamics and control took place at MIT.[5] While ML has had tremendous impact in areas such as computer vision and language translation, over the next decade the explosion of real-time data (from devices that sense and control the physical world) requires a convergence of research areas such as ML, model-based dynamical systems, and control and decision theory. This activity will impact planned funding activities in priority areas such as artificial intelligence and the HDR Big Idea.
- In June 2019, NSF submitted its first report[6] to Congress about the I-Corps™ program. The report was developed in response to the *American Innovation and Competitiveness Act (AICA)* (P.L. 114-329), which requires NSF to develop program metrics and deliver a report to Congress every two years.
- In July 2019, ENG and the American Society for Engineering Education (ASEE) held a Visioning Summit to engage various engineering communities in determining mechanisms through which the fundamental engineering research community's priorities may be identified. Attendees learned about a variety of mechanisms currently used by industry and academia to identify important priorities and trends; collecting this information in one place will be useful for the engineering community and help develop an evidence base for decision making. In late 2019, ASEE published a summit report.[7]

[2] https://assistcenter.org/wp-content/uploads/2019/09/NSFWorkshop_Report-082119-v2.pdf
[3] www.nsf.gov/pubs/2019/nsf19049/nsf19049.jsp
[4] www.eventbrite.com/e/gmu-nsf-conference-on-disrupting-operations-of-illicit-supply-networks-registration-57803528911
[5] https://l4dc.mit.edu/
[6] www.nsf.gov/news/special_reports/i-corps/pdf/I-CorpsReport--6_4_19FINAL_508.pdf
[7] https://engresearchvisioning.asee.org/wp-content/uploads/2019/11/ERFVS-Workshop-Summary-lo-res.pdf

- At the end of FY 2019, CBET, together with the Department of Energy (DOE) Offices of Fossil Energy and Science and the DOE Office of Energy Efficiency and Renewable Energy, co-funded a consensus study by the National Academies of Sciences, Engineering, and Medicine. The three-year study will survey the current state of the chemical engineering discipline and its contributions to society as well as articulate a vision for the future of the field. The main objective of the study is to outline a vision and strategy for chemical engineering research, innovation, and education over the next thirty years.
- In October 2019, an ECCS-funded workshop on security in Radio Frequency (RF)/analog microelectronics and electromagnetics[8] was held to explore the needs and challenges involved in ensuring security in future analog hardware that operates over the range from direct current (DC) to terahertz (THz) frequencies. The workshop helped identify areas for future investment in ECCS core programs and special solicitations. Workshop outcomes should impact planned funding activities in semiconductor microelectronics, advanced wireless, machine-learning enhanced engineered systems, manufacturing, and other priority areas, as well as HDR Big Idea-supported programs.
- In FY 2020, IIP expects to complete the migration of the data collection and management process for the Industry-University Cooperative Research Center (IUCRC) program; the transition was delayed due to the government shutdown. One goal of this migration is to build an in-house data ecosystem for the IUCRC program that entails collecting, organizing, and managing internal and external data, including annual survey data. The combination of data sources will provide a holistic view of the program and enable customized analyses on a center level.

Evaluations and Reviews

- In FY 2016, the NSF's Evaluation and Assessment Capability office initiated a study of the I-Corps™ Teams program to assess its impacts on teams that completed the entrepreneurial training and on academic culture. The analysis used quantitative data from surveys and case studies developed from in-depth interviews and site visits. Completed in FY 2019, the evaluation advised IIP to modify the longitudinal survey questions to better capture all potential commercialization outcome metrics.
- In FY 2019, the National Nanotechnology Coordinated Infrastructure (NNCI) program went through a review of its first five years. Results provided ECCS with evidence-based data to inform future decisions regarding NNCI sites and other investments. In addition, the NNCI facility has a metrics and assessment committee with a defined common set of site and network metrics based on usage data.
- In FY 2019, the National Center for Science and Engineering Statistics (NCSES) began efforts to advance the use of its Data for Evidence-based Research and Evaluation. As part of this effort, the ENG Engineering Research Center (ERC) program will clarify its data collection requirements to make full use of NCSES data. Linkage of the dataset will allow longitudinal evaluation of the ERC program impacts on student participants.

Committees of Visitors (COV)[9]

- In FY 2019, COVs reviewed CBET and CMMI for the period of FY 2015 through FY 2018. The COVs presented their reports to the ENG Advisory Committee at its October 2019 meeting.
- In FY 2020, COVs will review EEC and IIP.
- In FY 2022, COVs will review ECCS and EFMA.

The Performance and Management chapter provides details regarding the periodic reviews of programs and portfolios of programs by external Committees of Visitors and directorate Advisory Committees. Please see this chapter for additional information.

[8] www-mtl.mit.edu/wpmu/nsfworkshop2019/
[9] www.nsf.gov/od/oia/activities/cov/covs.jsp#eng

People Involved in ENG Activities

Number of People Involved in ENG Activities

	FY 2019 Actual Estimate	FY 2020 (TBD)	FY 2021 Estimate
Senior Researchers	9,149	-	8,400
Other Professionals	1,935	-	1,800
Postdoctoral Associates	430	-	400
Graduate Students	7,621	-	7,000
Undergraduate Students	4,298	-	4,000
Total Number of People	**23,433**	**-**	**21,600**

DIVISION OF CHEMICAL, BIOENGINEERING, ENVIRONMENTAL, AND TRANSPORT SYSTEMS (CBET)

$160,290,000
-$30,180,000 / -15.8%

CBET Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual: Amount	Change over FY 2019 Actual: Percent
Total	**$190.47**	**-**	**$160.29**	**-$30.18**	**-15.8%**
Research	**185.39**	**-**	**154.95**	**-30.44**	**-16.4%**
Centers Funding (total)	3.70	-	-	-3.70	-100.0%
STC: Emergent Behaviors for Integrated Cellular Systems[1]	3.70	-	-	-3.70	-100.0%
Education	**1.40**	**-**	**1.90**	**0.50**	**35.9%**
Research Infrastructure	**3.68**	**-**	**3.44**	**-0.24**	**-6.5%**
National Nanotechnology Coordinated Infrastructure (NNCI)	3.68	-	3.44	-0.24	-6.5%

[1] NSF's support for 2010 class of STCs will conclude in FY 2020 as planned.

About CBET

CBET supports research to enhance and protect U.S. national health, energy, food, water, environment, process manufacturing, and security. Through CBET, the physical, chemical, life, and social sciences are integrated in engineering research and education, resulting in advances in the rapidly evolving fields of biotechnology, bioengineering, biomanufacturing, advanced materials, environmental engineering, and sustainable energy. CBET also invests in areas that involve the transformation and/or transport of matter and energy by chemical, thermal, or mechanical means. CBET investments contribute significantly to the knowledge base and to the workforce development of major U.S. economy components, such as chemicals, pharmaceuticals, medical devices, specialty chemicals, and materials for advanced manufacturing, natural gas and petroleum production, food, textiles, utilities, and microelectronics.

CBET supports the chemical, environmental, biomedical, mechanical (transport), and civil (environmental) engineering disciplines. To serve these communities and achieve its goals, CBET is organized into four thematic clusters: Chemical Process Systems; Engineering Biology and Health; Environmental Engineering and Sustainability; and Transport Phenomena.

In general, 82 percent of the CBET portfolio is available to support new research grants. The remaining 18 percent supports research grants made in prior years.

DIVISION OF CIVIL, MECHANICAL, AND MANUFACTURING INNOVATION (CMMI) **$200,540,000**
-$37,370,000 / -15.7%

CMMI Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$237.91**	**-**	**$200.54**	**-$37.37**	**-15.7%**
Research	**220.85**	**-**	**184.74**	**-36.11**	**-16.4%**
Centers Funding (total)	4.96	-	5.00	0.04	0.7%
STC: Engineering Mechano-Biology	4.96	-	5.00	0.04	0.7%
Education	**2.79**	**-**	**2.33**	**-0.46**	**-16.4%**
Facilities	**11.57**	**-**	**10.95**	**-0.62**	**-5.4%**
Natural Hazards Engineering Research Infrastructure (NHERI)[1]	11.57	-	10.95	-0.62	-5.4%
Other Research Infrastructure	**2.70**	**-**	**2.52**	**-0.18**	**-6.7%**
Center for High Energy X-ray Science (CHEXS)	0.80	-	0.75	-0.05	-6.3%
National Nanotechnology Coordinated Infrastructure (NNCI)	1.90	-	1.77	-0.13	-6.8%

[1] FY 2019 includes $8.50 million to upgrade the LHPOST facility. Excluded is $8.93 million of FY 2019 O&M costs obligated in FY 2018.

About CMMI

CMMI funds fundamental research in support of the Foundation's strategic goals directed at advances in civil, mechanical, industrial, systems, manufacturing, and materials engineering. In addition, the division has a focus on the reduction of risks and damage resulting from earthquakes, wind, and other hazards. CMMI encourages discoveries enabled by cross-cutting technologies such as adaptive systems, artificial intelligence, nanotechnology, and high-performance computational modeling and simulation.

The division supports cross-disciplinary research partnerships at the intersections of traditional research disciplines to achieve transformative research results. CMMI investments create innovative manufacturing technology that does not exist today (such as future manufacturing); enable the design and analysis of complex engineered systems; enhance the sustainability and resilience of U.S. infrastructure (for example, buildings, transportation, and communication networks); help protect the Nation from extreme natural and human-induced events; and apply engineering principles to improve the Nation's service and manufacturing enterprise systems, such as healthcare.

CMMI also provides funding and management of NHERI and contributes to the directorate's annual operations support of the CHEXS facility.

In general, 82 percent of the CMMI portfolio is comprised of new research grants and 18 percent supports continuing grants.

DIVISION OF ELECTRICAL, COMMUNICATIONS, AND CYBER SYSTEMS (ECCS)

$103,740,000
-$14,290,000 / -12.1%

ECCS Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$118.03**	**-**	**$103.74**	**-$14.29**	**-12.1%**
Research	**111.92**	**-**	**97.20**	**-14.72**	**-13.2%**
Centers Funding (total)	3.70	-	-	-3.70	-100.0%
STC: Energy Efficient Electronics Systems[1]	3.70	-	-	-3.70	-100.0%
Education	**0.67**	**-**	**1.57**	**0.90**	**134.5%**
Research Infrastructure	**5.44**	**-**	**4.97**	**-0.47**	**-8.6%**
Center for High Energy X-ray Science (CHEXS)	0.10	-	0.09	-0.01	-10.0%
National Nanotechnology Coordinated Infrastructure (NNCI)	5.34	-	4.88	-0.46	-8.6%

[1] NSF's support for 2010 class of STCs will conclude in FY 2020 as planned.

About ECCS

ECCS supports enabling and transformative research at the nano, micro, and macro scales that fuels progress in engineering system applications with high societal impacts. The division's programs encompass novel electronic, photonic, quantum, and magnetic devices (such as semiconductors integrated with biological structures), and the integration of these devices into circuit and system environments, intelligent systems, control, and networks.

ECCS investments in artificial intelligence research for real-time learning and decision-making will help enable safe, reliable, and efficient data-enabled engineering systems. Breakthroughs in devices and systems advance applications spanning cyber and communications technologies (such as 5G networks and spectrum efficiency and security), energy and power, healthcare, transportation, robotics, advanced manufacturing, and other systems-related areas.

The division also provides funding, in partnership with other NSF directorates, and management of the National Nanotechnology Coordinated Infrastructure (NNCI).

In general, 82 percent of the ECCS portfolio is comprised of new research grants and 18 percent supports continuing grants.

DIVISION OF ENGINEERING EDUCATION AND CENTERS (EEC) $89,490,000
-$13,270,000 / -12.9%

EEC Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$102.76**	**-**	**$89.49**	**-$13.27**	**-12.9%**
Research	**79.27**	**-**	**74.27**	**-5.00**	**-6.3%**
Centers Funding (total)	58.95	-	50.92	-8.03	-13.6%
Engineering Research Centers	58.95	-	50.92	-8.03	-13.6%
Education	**23.49**	**-**	**15.22**	**-8.27**	**-35.2%**

About EEC

EEC integrates disciplinary basic research and education conducted in other ENG divisions and across NSF into strategic frameworks that address societal grand challenges and promote innovation. Research included in the EEC portfolio spans both the physical/life sciences and engineering, from nanostructured materials to new device concepts, subsystems, and systems. Applications range across a wide spectrum, such as energy, medicine, telecommunications, nanoelectronics, manufacturing, civil infrastructure, the environment, computer networks, cybersecurity, and others. Also included are formal scholarly studies in the professional formation of engineers, which can lead to innovations in engineering education and career development.

The complex, integrative role of EEC requires a comprehensive infrastructure of people, equipment, and centers. Creative and effective approaches to developing the engineering workforce are vital, as a lack of properly prepared engineers is a critical barrier to a healthy U.S. economy. EEC invests in faculty, graduate and undergraduate students, post-doctoral scholars, and K–12 teachers. As nontraditional students—such as part-time, delayed enrollment, veteran, and others—comprise more than 70 percent of the general undergraduate population, EEC is also defining alternative pathways for these students, especially veterans, to successfully earn degrees in engineering.

The programs in EEC are administratively managed within four categories: (1) Centers and Networks; (2) Engineering Education Research; (3) Engineering Workforce Development; and (4) Broadening Participation in Engineering. The Centers and Networks category is comprised of the signature Engineering Research Centers (ERC) program.

The ERC program provides the framework for interdisciplinary research and education, development, and technology transfer in partnership with academia, industry, and government. The FY 2021 funding level supports 13 centers. The total includes funding for three 4th-generation (Gen-4), Class of 2020, ERCs that will advance convergence engineering research to tackle high-impact challenges that have the potential to benefit U.S. security, prosperity, health, and society. The 2020 ERCs will implement strategies for effective team formation, diversity and inclusion, and engagement with stakeholder communities to maximize their impacts. To build capacity for a new generation of convergent engineering research centers, ENG funded planning grants for engineering research collaborations designed to create societal benefits, providing 61 awards in FY 2018 and 41 awards in FY 2019.

Engineering Education programs advance new productive engineering pedagogy and learning strategies in traditional and non-traditional environments. This category also includes EEC's participation in the NSF-wide activity, IUSE, which integrates the agency's investments in undergraduate education. Engineering Workforce Development includes programs such as Research Experiences for Undergraduates (REU) and Research Experiences for Teachers (RET). Broadening Participation in Engineering supports research and activities that enhance opportunities for underrepresented groups by addressing structural inequalities and biases within educational and workforce systems. This category also includes EEC's engagement with the NSF INCLUDES Big Idea, which integrates the agency's investments to build on and scale up what works in broadening participation programs.

In general, 22 percent of the EEC portfolio is comprised of new research grants. The remaining 78 percent funds continuing grants and cooperative agreements made in previous years. This high fraction of multi-year commitments is primarily a consequence of centers funding, which includes awards made as five-year cooperative agreements.

DIVISION OF INDUSTRIAL INNOVATION AND PARTNERSHIPS (IIP) $257,900,000
-$10,770,000 / -4.0%

IIP Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$268.67**	**-**	**$257.90**	**-$10.77**	**-4.0%**
Research	**268.67**	**-**	**257.54**	**-11.13**	**-4.1%**
SBIR/STTR, including Operations	211.66	-	209.25	-2.41	-1.1%
SBIR	181.87	-	179.06	-2.81	-1.5%
STTR	24.78	-	25.19	0.41	1.6%
SBIR/STTR Operations	5.00	-	5.00	-	-
Education	**-**	**-**	**0.36**	**0.36**	**N/A**

About IIP

IIP contributes to the NSF innovation ecosystem by: (1) supporting technical innovation research that builds on fundamental research discoveries that exhibit potential for societal and economic impact; (2) encouraging research partnerships between academia and industry; and (3) offering hands-on experience in the innovation process to current and future hi-tech entrepreneurs and innovators.

IIP is home to two cross-agency small business research programs, the SBIR and STTR programs. These programs seek to transform scientific discovery into societal and economic benefit by catalyzing private sector commercialization of deep technological innovations. SBIR/STTR programs provide the opportunity for startups and small businesses to undertake cutting-edge, high-quality scientific research and development to determine the scientific and technical feasibility of a new concept or innovation that could be developed into new products, processes, or services for profound societal impact. SBIR/STTR technology topics draw upon the breadth of NSF scientific and engineering research disciplines and are aligned with national and societal priorities.

IIP also supports academic research through three industry-university research programs: Industry-University Cooperative Research Centers (IUCRC), Partnerships for Innovation (PFI), and Grant Opportunities for Academic Liaison with Industry (GOALI)/Non-Academic Research Internships for Graduate Students (INTERN). These programs aim to stimulate academia–industry partnerships, leverage industrial support, accelerate technology commercialization, and empower future generations in science and engineering. University grantees in these programs collaborate with industry to create enabling technologies that meet national needs, such as managing the electrical power system, enhancing advanced manufacturing, improving biological and biomedical processing, and supporting new information and communications technologies.

IIP also leads the I-Corps™ program that connects NSF-funded science and engineering research with the technological, entrepreneurial, and business communities, and fosters a national innovation ecosystem that links scientific discovery with technology development, societal needs, and economic opportunities.

In general, 97 percent of the IIP portfolio is comprised of new research grants and 3 percent supports continuing grants.

OFFICE OF EMERGING FRONTIERS AND MULTIDISCIPLINARY ACTIVITIES (EFMA) — $97,820,000 +$24,520,000 / 33.4%

EFMA Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$73.30**	**-**	**$97.82**	**$24.52**	**33.4%**
Research	**69.17**	**-**	**97.64**	**28.47**	**41.2%**
Education	**4.03**	**-**	**0.09**	**-3.94**	**-97.8%**
Research Infrastructure	**0.10**	**-**	**0.09**	**-0.01**	**-10.0%**
Center for High Energy X-ray Science (CHEXS)	0.10	-	0.09	-0.01	-10.0%

About EFMA

EFMA strategically pursues and supports projects in important emerging areas. The office also provides support to high impact multidisciplinary education and learning platform programs such as Germination of Research Ideas for Large Opportunities and Critical Societal Needs (GERMINATION), Research Experience and Mentoring (REM) and REU supplements; contributes to the directorate's annual operations support of NSF facilities such as CHEXS; and supports special studies such as the Visioning Framework for Engineering Research.

Funding for the FW-HTF Big Idea ($45.0 million) will support convergence activities that transcend the traditional disciplinary boundaries of individual NSF directorates and offices. While financial stewardship for this NSF investment will be the responsibility of ENG, the convergence activities will be overseen and managed collaboratively by the multi-directorate/office FW-HTF leadership team. These activities will enable pursuit of fundamental research on advancing cognitive and physical capabilities in the context of human-technology interactions, and the development of a 21st-century workforce capable of adapting to a changing employment landscape.

A major activity in EFMA is the Emerging Frontiers in Research and Innovation (EFRI) program. Each year EFRI funds interdisciplinary projects at the frontiers of engineering with potential for major impacts on national needs and/or grand challenges, particularly in areas that may lead to breakthrough technologies and strengthen the economy's technical underpinnings. EFRI is intended to have the necessary flexibility to target long-term challenges, while retaining the ability and agility to adapt as new challenges demand.

- In FY 2018 and FY 2019, EFRI invested in two topics: Chromatin and Epigenetic Engineering to advance the engineering of biology at the molecular and cellular levels; and Continuum, Compliant, and Configurable Soft Robotics Engineering (C3 SoRo) to create robots that are safer, more adaptable, and more compatible with human collaborators than are today's rigid ones.
- Two new topics are debuting in FY 2020 and will continue in FY 2021.
    - Distributed Chemical Manufacturing will enable the development of modular process plants able to take advantage of distributed feedstocks and product delivery needs, or to address environmental remediation problems at the source.
    - Engineering the Elimination of End-of-Life Plastics (E3P) will create a scientific foundation for viable solutions to the capture, management, and elimination of end-of-use plastics.

In general, 91 percent of the EFMA portfolio is comprised of new research grants, and about 9 percent supports continuing increments for grants made in previous years.

DIRECTORATE FOR GEOSCIENCES (GEO) **$836,610,000**
-$133,270,000 / -13.7%

GEO Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Atmospheric and Geospace Sciences (AGS)	$303.41	-	$234.45	-$68.96	-22.7%
Earth Sciences (EAR)	181.96	-	168.24	-13.72	-7.5%
Integrative and Collaborative Education and Research (ICER)	113.79	-	94.71	-19.08	-16.8%
Ocean Sciences (OCE)	370.73	-	339.21	-31.52	-8.5%
Total	**$969.88**	**-**	**$836.61**	**-$133.27**	**-13.7%**

About GEO

GEO supports basic research that advances the frontiers of knowledge and drives technological innovation while improving our understanding of the many processes that create and sustain vital natural resources on which society depends. Home to NSF's atmospheric and geospace, earth, and ocean research activities and providing administrative oversight to the Office of Polar Programs, GEO investigates diverse Earth processes including the planet's water cycle, interactions across the land-ocean interface, the behavior of ice sheets, and geologic processes responsible for hydrocarbon energy sources and strategic minerals. Earth system predictability is a cornerstone of the basic research supported by GEO; lives are saved and property is preserved by better forecasting and understanding of natural phenomena and environmental hazards such as earthquakes, tornadoes, drought, and solar storms. GEO-supported research improves society's preparation for the effects of these and other disruptive natural events, and GEO prioritizes support for interdisciplinary studies that contribute directly to national research priorities such as Earth system predictability, which includes mitigating the impacts of hazardous events and understanding future availability and distribution of fresh water.

Leveraging the knowledge and techniques of many other disciplines, GEO strongly promotes the growth of convergence research across all fields of science. GEO activities support and promote several of NSF's Big Ideas. GEO is the steward of funds designated for NSF's NNA Big Idea investments. OPP within GEO, in coordination with ENG and SBE, manages NSF's NNA Big Idea, and GEO's ICER division stewards $30.0 million to support crosscutting NNA research. GEO programs also contribute to HDR through the EarthCube activity. As observational sciences, geoscience relies on vast archives of data to forge new knowledge about the Earth. GEO also participates in URoL, primarily with focuses on microbiomes in the aquatic realm. For more information about the Big Ideas, see the narratives in the NSF-Wide Investments chapter.

GEO provides about 60 percent of the federal funding for basic research at academic institutions in the atmospheric, earth, and ocean sciences.

Major Investments

GEO Major Investments

(Dollars in Millions)

Area of Investment[1,2]	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Improving Undergraduate STEM Education (IUSE)	6.00	-	5.42	-0.58	-9.7%
NSF Innovation Corps (I-Corps™)	0.60	-	0.60	-	-
Coastlines and People (CoPe)	6.00	-	15.00	9.00	150.0%
NSF's Big Ideas					
NNA Stewardship	*30.00*	-	*30.00*	-	-

[1] Major investments may have funding overlap and thus should not be summed.

[2] This table reflects support for selected areas of investment. The same table in other directorate/office narratives may not present the same areas; thus funding should not be summed

- IUSE: Funding for the NSF-wide IUSE activity continues to support development of the next generation of geoscientists.
- I-Corps™: GEO will continue support for the NSF-wide I-Corps™ program that connects NSF-funded science and engineering research with the technological, entrepreneurial, and business communities.
- CoPe: CoPe was a new program in FY 2019 and received broad community interest. Through this program, GEO supports projects to build capacity and explore research to understand the impacts of coastal environmental variability and natural hazards on populated coastal regions. Improved Earth system prediction is a major CoPe objective.
- NNA: GEO provides stewardship of the NNA Big Idea. NNA fosters innovations in Arctic observational networks and fundamental convergence research across the social, natural, environmental, and computing and information sciences and engineering that address the intersection of natural, social, and built systems. Improved Earth system prediction is a major NNA objective.

GEO Funding for Centers Programs and Facilities

GEO Funding for Centers Programs

(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$3.70**	**-**	**-**	**-$3.70**	**-100.0%**
STC: Center for Dark Energy Biosphere Investigations (OCE)[1]	3.70	-	-	-3.70	-100.0%

[1] The Center for Dark Energy Biosphere Investigations sunsets as planned.

For additional information on NSF's centers programs, please see the NSF-Wide Investments chapter.

GEO Funding for Major Multi-User Facilities

(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$359.08**	**-**	**$307.55**	**-$51.53**	**-14.4%**
Academic Research Fleet (ARF)[1]	85.32	-	80.00	-5.32	-6.2%
Arecibo Observatory[2]	4.44	-	1.50	-2.94	-66.2%
Geodetic Facility for the Advancement of Geoscience (GAGE)[3]	5.81	-	11.35	5.54	95.2%
International Ocean Discovery Program (IODP)[4]	53.00	-	47.00	-6.00	-11.3%
National Center for Atmospheric Research (NCAR)[5]	152.44	-	103.70	-48.74	-32.0%
Ocean Observatories Initiative (OOI)	44.01	-	43.00	-1.01	-2.3%
Seismological Facility for the Advancement of Geoscience (SAGE)[3]	14.06	-	21.00	6.94	49.3%

[1] Includes ship operations and upgrade support. The FY 2019 Actual includes $3.0 million for continuity of operations into FY 2020.

[2] The FY 2019 Actual includes $1.50 million for continuity of operations into FY 2020. It excludes $890,000 of FY 2019 O&M costs obligated in FY 2018.

[3] The FY 2019 Actual for GAGE and SAGE reflect part of an operating year as funding for these cooperative agreements were re-phased for continuity of operations into FY 2020.

[4] FY 2019 Actual includes $5.0 million for continuity of operations into FY 2020.

[5] The FY 2019 Actual includes $17.80 million for continuity of operations into FY 2020 as well as $30.94 million in funds re-obligated from prior award.

For information on continuity of operations funding, see the opening narrative of the Facilities chapter. For detailed information on individual facilities, please see the Facilities and the Major Research Equipment and Facilities Construction chapters.

Funding Profile

GEO Funding Profile

	FY 2019 Actual Estimate	FY 2020 (TBD)	FY 2021 Estimate
Statistics for Competitive Awards:			
Number of Proposals	3,643	-	3,700
Number of New Awards	1,366	-	1,200
Funding Rate	37%	N/A	32%
Statistics for Research Grants:			
Number of Research Grant Proposals	3,244	-	3,300
Number of Research Grants	1,149	-	1,000
Funding Rate	35%	N/A	30%
Median Annualized Award Size	$151,886	-	$152,000
Average Annualized Award Size	$218,727	-	$220,000
Average Award Duration, in years	2.9	-	3.0

In FY 2021, the number of research grant proposals is expected to increase as CoPe activities expand, and GEO expects to award about 1,000 research grants. Average annual award size and duration are not expected to materially deviate through FY 2021.

Program Monitoring and Evaluation

External Program Evaluations and Studies

- In FY 2020, the National Academies of Sciences, Engineering, and Medicine will initiate a study that develops a new vision for a systems approach to studying the Earth and the facilities, infrastructure, mechanisms, computation, workforce development, and agency collaborations needed to support that vision. Envisioned as a sixteen-month activity, this vision for a systems approach will inform research activities across GEO.
- In the summer of 2020, EAR anticipates delivery of the report on "Catalyzing Opportunities for Research in Earth Sciences" commissioned to the National Academies of Science, Engineering, and Medicine (the National Academies). The panel of experts leading the study held seven open meetings where they gathered information from the research community. The report will be peer-reviewed prior to its publication.

Workshops and Reports

In FY 2019, OCE held a facilitated "Future of Marine Seismic Capabilities Workshop" with approximately 40 representatives of the academic community and private sector to identify viable options for the continued support of the marine seismic community's need for long-term sustainable access to seismic data collection capability currently available on R/V *Marcus G. Langseth*. The workshop results provided important inputs for the development and release of solicitation NSF 20-533 "Facilitator of Marine Seismic Capabilities for the U.S. Research Community." The Facilitator, planned to be in place mid-late FY 2020, will work with researchers in identifying suitable vessels (commercial, foreign academic, or other) to support NSF-funded seismic research projects and will also be responsible for arranging and negotiating competitive lease agreements for marine seismic research activities that have been determined by NSF to be high-priority projects following the merit review process.

Committees of Visitors (COV)

In 2019, a COV reviewed research programs in OCE. The COV presented their reports[1] to the GEO Advisory Committee at the October 2019 meeting. The COV made several recommendations, including expanding opportunities to support mid-size projects, ways of improving the funding rates for some classes of proposals, and improving the proposal review process.

- In 2020, a COV will review activities in AGS.
- In 2021, COVs will review activities in EAR and GEO education and diversity programs.

The Performance and Management chapter provides details regarding the periodic reviews of programs and portfolios of programs by external Committees of Visitors and directorate Advisory Committees. Please see this chapter for additional information.

[1] www.nsf.gov/geo/acgeo_cov.jsp

People Involved in GEO Activities

Number of People Involved in GEO Activities

	FY 2019 Actual Estimate	FY 2020 (TBD)	FY 2021 Estimate
Senior Researchers	5,174	-	4,700
Other Professionals	2,928	-	2,600
Postdoctoral Associates	628	-	600
Graduate Students	2,524	-	2,300
Undergraduate Students	2,339	-	2,100
Total Number of People	**13,593**	**-**	**12,300**

DIVISION OF ATMOSPHERIC AND GEOSPACE SCIENCES (AGS) $234,450,000
-$68,960,000 / -22.7%

AGS Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$303.41**	**-**	**$234.45**	**-$68.96**	**-22.7%**
Research	**118.55**	**-**	**105.71**	**-12.84**	**-10.8%**
Education	**2.26**	**-**	**3.54**	**1.28**	**56.4%**
Infrastructure	**182.59**	**-**	**125.20**	**-57.39**	**-31.4%**
Arctic Logistics	0.25	-	-	-0.25	-100.0%
Arecibo Observatory[1]	4.44	-	1.50	-2.94	-66.2%
NCAR[2]	152.44	-	103.70	-48.74	-32.0%
Research Resources	25.47	-	20.00	-5.47	-21.5%

For information on continuity of operations funding, see the opening narrative of the Facilities chapter.

[1] The FY 2019 Actual includes $1.50 million for continuity of operations into FY 2020. It excludes $890,000 of FY 2019 O&M costs obligated in FY 2018.

[2] The FY 2019 Actual includes $17.80 million for continuity of operations into FY 2020 as well as $30.94 million in funds re-obligated from prior award.

About AGS

AGS supports fundamental research activities that lead to improved understanding of the dynamics of the sun, the physics, chemistry, and dynamics of the Earth's atmosphere and near-space environment, and how the sun interacts with the Earth's atmosphere. Improved understanding drives state-of-the-science model development and improved predictability of weather, climate, and space weather events. AGS provides support for: (1) basic science projects and (2) the acquisition, maintenance, and operation of observational and cyber-infrastructure facilities and services that enable and support modern-day atmospheric and geospace science research activities. AGS support occurs via the traditional individual investigator merit-reviewed multi-year grants, limited duration exploratory research projects, and collaborative and multi-investigator group projects.

In addition, research is conducted using world-class facilities provided by the National Center for Atmospheric Research (NCAR). Through improvements to our understanding of severe weather events, and the development of sophisticated computer models that simulate and forecast such events and their impacts, AGS helps protect life, property, and natural resources, and contributes to the establishment of a weather-ready and space weather-ready nation. AGS-supported scientists lead innovations ranging from the miniaturization of sensors that fly on CubeSats, to the development of models that provide the scientific basis of forecasting a variety of severe weather hazards. AGS also funds STEM education, fosters the success of early career scientists, and supports the continuing development of a world-class scientific and technical workforce that contributes significantly to the nation's economic vitality.

About 32 percent of the AGS portfolio is available for new research grants. The remaining 68 percent supports research grants made in prior years and the research infrastructure that supports the capabilities, creativity, and innovation of the atmospheric and geospace science community. AGS frequently participates in major NSF-wide initiatives and long-standing NSF programs, such as the Major Research Instrumentation program. AGS also partners with other programs within GEO, across other NSF directorates, and with other federal agency partners, to help ensure that the most impactful science is being funded.

DIVISION OF EARTH SCIENCES (EAR) **$168,240,000**
-$13,720,000 / -7.5%

EAR Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
Total	**$181.96**	**-**	**$168.24**	**-$13.72**	**-7.5%**
Research	**131.07**	**-**	**111.79**	**-19.28**	**-14.7%**
Education	**5.69**	**-**	**4.81**	**-0.88**	**-15.5%**
Infrastructure	**45.20**	**-**	**51.64**	**6.44**	**14.3%**
GAGE[1]	5.81	-	11.35	5.54	95.2%
NNCI	-	-	0.29	0.29	N/A
SAGE[1]	14.06	-	21.00	6.94	49.3%
Research Resources	25.32	-	19.00	-6.32	-25.0%

For information on continuity of operations funding, see the opening narrative of the Facilities chapter.

[1] The FY 2019 Actual for GAGE and SAGE reflect part of an operating year as funding for these cooperative agreements were re-phased for continuity of operations into FY 2020.

About EAR

EAR supports fundamental research into the structure, composition, and evolution of the Earth, and the life it has sustained over the four and a half billion years of Earth history. The results of this research will lead to a better understanding of Earth's changing environment (past, present, and future), the natural distribution of its mineral, water, biota, and energy resources, and provide methods for predicting and mitigating the effects of geologic hazards such as earthquakes, volcanic eruptions, floods, and landslides.

EAR supports research in geomorphology and land use, hydrologic science, geobiology and low temperature geochemistry, sedimentary geology and paleobiology, geophysics, petrology and geochemistry, tectonics, and integrated Earth systems. In addition to these fundamental research programs, EAR has an Instrumentation and Facilities program that supports community-based, shared-use facilities and the acquisition and development of instrumentation by individual investigators; and an education program that funds several activities to attract and support students and young investigators to the field of Earth science.

In general, about 49 percent of the EAR portfolio is available for new research grants. The remaining 51 percent supports research grants made in prior years and the research infrastructure needed by this community.

DIVISION OF INTEGRATIVE AND COLLABORATIVE EDUCATION & RESEARCH (ICER) **$94,71,000**
-$19,080,000 / -16.8%

ICER Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$113.79**	**-**	**$94.71**	**-$19.08**	**-16.8%**
Research	**101.24**	**-**	**89.29**	**-11.95**	**-11.8%**
Education	**12.55**	**-**	**5.42**	**-7.13**	**-56.8%**

About ICER

ICER supports novel, complex, or partnership projects in both research and education. These investments cut across traditional boundaries within the geosciences, encouraging interdisciplinary activities and responding directly to critical needs of the entire geoscience community. ICER's principal goals are to develop innovative means to initiate and support geoscience education, attract underrepresented groups to careers in the geosciences, foster the interchange of scientific information nationally and internationally, and join with other parts of NSF in major integrative research and education efforts. In addition, in partnership with several of the NSF directorates, ICER will advance the NNA Big Idea by investing funds to support convergent activities that transcend the traditional disciplinary boundaries of individual NSF directorates and offices. In FY 2021, the division will make strategic investments in multidisciplinary research areas, international activities, education, diversity, and human resource development. A continuing emphasis in FY 2021 is in the area of Coastlines and People (CoPe), which supports research focused on understanding the impacts of coastal environmental variability and natural hazards on populated coastal regions. The results of ICER investments will assist in ensuring that the U.S. has a well-educated and diverse workforce in the geosciences and in related technical fields such as resource exploration.

In general, about 82 percent of the ICER portfolio is available for new research grants with the remaining amount supporting grants made in prior years.

DIVISION OF OCEAN SCIENCES (OCE) — $339,210,000 / -$31,520,000 / -8.5%

OCE Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$370.73**	**-**	**$339.21**	**-$31.52**	**-8.5%**
Research	**170.69**	**-**	**155.41**	**-15.28**	**-9.0%**
Centers Funding (total)	3.70	-	-	-3.70	-100.0%
STC: Center for Dark Energy Biosphere Investigations[1]	3.70	-	-	-3.70	-100.0%
Education	**5.38**	**-**	**4.58**	**-0.80**	**-14.9%**
Infrastructure	**194.65**	**-**	**179.22**	**-15.43**	**-7.9%**
ARF[2]	85.32	-	80.00	-5.32	-6.2%
IODP[3]	53.00	-	47.00	-6.00	-11.3%
OOI	44.01	-	43.00	-1.01	-2.3%
Research Resources	12.32	-	9.22	-3.10	-25.2%

For information on continuity of operations funding, see the opening narrative of the Facilities chapter.

[1] The Center for Dark Energy Biosphere Investigations sunsets as planned.

[2] Includes ship operations and upgrade support. FY 2019 Actual includes $3.0 million for continuity of operations into FY 2020.

[3] FY 2019 Actual includes $5.0 million for continuity of operations into FY 2020.

About OCE

OCE supports cutting-edge research, education, and infrastructure that advances the Nation's scientific knowledge of the oceans to support the U.S. economy over the long-term, provides vital information regarding national security matters such as sea level rise, and advances U.S. leadership in ocean science and technological innovation. OCE provides support of basic, including interdisciplinary scientific research and technology development to better understand the drivers of ocean circulation and other physical and chemical parameters, biodiversity and the dynamics of marine organisms and ecosystems, and changes in the marine environment as exemplified by ocean acidification. OCE also supports research on the geology and geophysics of the ocean margins and sub-seafloor to investigate natural hazards such as earthquakes and volcanic eruptions, nearshore processes affecting the coasts, the long-term evolution of marine systems, and other fundamental ocean processes. Ocean education emphasizes the interdisciplinary nature of ocean sciences, and commonly leverages research facilities and infrastructure via telepresence to far and distant seas. Since ocean science requires access to the sea, OCE supports research vessels, deep submergence capability including submersibles and autonomous vehicles, and technologically-advanced sensors and instrumentation. Broadly speaking, research, education, and infrastructure funded by OCE addresses the central role of the oceans in a changing Earth and as a national strategic resource, as recognized by numerous reviews by external bodies (e.g., the National Academies Decadal Survey Sea Change).

In general, about 29 percent of the OCE portfolio is available for new research grants, with the remainder supporting grants made in prior years and the research infrastructure needed by this community.

DIRECTORATE FOR MATHEMATICAL AND PHYSICAL SCIENCES (MPS) **$1,448,320,000**
-$42,290,000 / -2.8%

MPS Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Astronomical Sciences (AST)	$287.01	-	$242.10	-$44.91	-15.6%
Chemistry (CHE)	247.27	-	218.71	-28.56	-11.6%
Materials Research (DMR)	302.99	-	280.22	-22.77	-7.5%
Mathematical Sciences (DMS)	237.03	-	214.79	-22.24	-9.4%
Physics (PHY)	285.23	-	257.83	-27.40	-9.6%
Office of Multidisciplinary Activities (OMA)	131.08	-	234.67	103.59	79.0%
Total	**$1,490.61**	**-**	**$1,448.32**	**-$42.29**	**-2.8%**

About MPS

Research in the foundational physical sciences is the central theme of work supported by MPS. The core areas of MPS science (astronomical sciences, chemistry, materials research, mathematical sciences, and physics) continue to advance and transform knowledge and support the development of the next generation of scientists. Science funded by MPS spans an enormous range: from the smallest objects and shortest timescales ever studied to distances and timescales that are the size and age of the universe. MPS continues to foster and support interdisciplinary scientific programs that span in scope and complexity, ranging from individual investigator awards to large, multi-user facilities. Individual investigators and small teams receive most awards, but centers, institutes, and facilities are all integral to MPS-funded research. This convergence of disciplines and various ways to organize researchers allows MPS to invest in compelling basic science that will underpin and enable advances in the technologies of the future and helping to support a strong U.S. economy for decades to come.

Through its Centers and Institutes programs, MPS will continue to support leading-edge science and the development of the next generation of scientists engaged in research covering fundamental basic science through translational science. The MPS Centers and Institutes span a broad range, from addressing challenges in fundamental mathematics to the development of new materials.

Research tools and infrastructure are key priorities that MPS will continue funding. Mid-scale research infrastructure in astronomical sciences, chemistry, materials research, and physics continue to be critical to the advancement of these disciplines. Large scale research infrastructure is also critical and provides opportunities for partnerships with international groups, other federal agencies, and private foundations, as is evidenced by facilities such as the Atacama Large Millimeter/submillimeter Array (ALMA), the Gemini Observatory, and the Large Hadron Collider (LHC). Since the major scientific breakthrough of the first direct detection of gravitational waves, by the Laser Interferometer Gravitational Wave Observatory (LIGO) in 2015, the facility reports event alerts on a regular basis. In 2017, LIGO detected for the first time a neutron star-neutron star merger, initiating the era of multi-messenger astrophysics research. With recent improvements in the instrumentation, detection of gravitational waves has become routine, with 25 candidate detections in the first four months of the observing run that began in April 2019. The Event Horizon Telescope (EHT)—a planet-scale array of eight ground-based radio telescopes forged through international collaboration—announced the successful capture of the first direct visual evidence of a supermassive black hole and its shadow on April 10, 2019. More than $28.0 million in direct funding, provided to EHT researchers from NSF over two decades, was a major factor in achieving this accomplishment. Scientists at the National High Magnetic Field Laboratory made a pivotal discovery in superconducting responses in materials—"reentrant Lazarus superconductivity" at world record ultra-high magnetic fields—that promises to finally reveal the mysteries of how superconductivity works. The Vera C. Rubin Observatory, formerly known as the Large Synoptic Survey Telescope, is an ongoing construction project and the High Luminosity Upgrade to LHC is expected to receive construction funding beginning in FY 2020. For more details about these construction projects, see the MREFC chapter. NSF's Daniel K. Inouye Solar Telescope will transition from construction to operations in FY 2020, becoming the world's most powerful solar observatory.

MPS' FY 2021 Request builds on past efforts and aligns with NSF's priorities articulated for FY 2021. There are exciting new opportunities emerging, research efforts that are maturing, and established programs and activities that continue to meet important goals and support science that will transform the Nation's future. MPS investments are influenced by the following key priorities: (a) sustaining core research programs, (b) supporting the highest priority facilities, (c) supporting early-career investigators, (d) providing funding for targeted basic research in NSF-wide investments including the NSF Big Ideas, and (e) advancing support for industries of the future, such as quantum information science (QIS), advanced manufacturing, the spectrum innovation initiative, and artificial intelligence (AI).

In partnership with other research directorates and offices, MPS will continue to provide support for the following research Big Ideas: QL, WoU, HDR, and URoL. These are the outcome of numerous community workshops and reports, as synthesized by NSF into robust and far-reaching programs. MPS is the steward of funds designated for NSF's Big Ideas QL and WoU. These convergent activities will enable pursuit of fundamental research in quantum-enabled sciences and technologies and in multi-messenger astrophysics. By exploiting quantum phenomena such as superposition, entanglement, and squeezing, QL activities will develop the foundations for and enable quantum computing, quantum sensors, quantum communications, quantum simulators, and other inherently quantum technologies. In addition, these activities will contribute to the development of the Nation's quantum-ready workforce. WoU activities will bring together fundamental research in electromagnetic waves, high-energy particles, and gravitational waves; advance the study of the universe; and grow the Nation's multi-messenger astrophysics, engineering, and data science workforce. While financial stewardship for these investments will be the responsibility of MPS, these convergent activities will be overseen and managed collaboratively by QL and WoU leadership and management teams. MPS is also the steward of funds designated for two administration priority areas, QIS and the Spectrum Innovation Initiative. For more information about the QL, WoU and QIS, see the related narratives in the NSF-Wide Investments chapter.

MPS provides approximately 49 percent of the federal funding for basic research at academic institutions in the mathematical and physical sciences.

Major Investments

MPS Major Investments
(Dollars in Millions)

Area of Investment[1,2]	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Advanced Manufacturing	$113.94	-	$113.78	-$0.16	-0.1%
Advanced Wireless[3]	-	-	$17.20	$17.20	N/A
Artificial Intelligence	23.52	-	87.34	63.82	271.3%
Bioeconomy	27.00	-	25.00	-2.00	-7.4%
BRAIN Initiative	17.04	-	7.94	-9.10	-53.4%
Microelectronics and Semiconductors	19.28	-	12.73	-6.55	-34.0%
NSF I-Corps™	1.70	-	1.61	-0.09	-5.3%
Quantum Information Science	82.50	-	180.80	98.30	119.2%
SaTC	1.70	-	0.95	-0.75	-44.1%
NSF's Big Ideas					
QL Stewardship	*30.02*	-	*50.00*	*19.98*	*66.6%*
WoU Stewardship	*30.00*	-	*30.00*	-	-

[1] Major investments may have funding overlap and thus should not be summed.
[2] This table reflects this directorate's support for selected areas of investment. In other directorate narratives, areas of investment displayed in this table may differ and thus should not be summed across narratives.
[3] Includes $17.0 million for the Spectrum Innovation Initiative.

- Advanced Manufacturing: MPS will invest in activities that develop new methods, processes, analyses, tools or equipment for new or existing manufacturing products, supply chain components, or materials. These will yield advantages such as reduced time to market, new performance attributes, improved small-batch production, cost and energy savings, and reduced environmental impact.
- Advanced Wireless—Spectrum Innovation Initiative: MPS will work alongside other NSF directorates to invest resources and research that support the development of new insights capable of making wireless communication faster, smarter, more responsive, more robust, and more secure—with profound implications for science and society. As stewards of the Spectrum Innovation Initiative, MPS will coordinate agency-wide investments that catalyze research and development in spectrum research, addressing key challenges related to an increasingly congested radio frequency environment and outdated approaches to spectrum allocation. The additional funding will primarily support three cross-cutting initiatives: (1) a novel mechanism for piloting, testing, and rolling out the most innovative approaches to dynamic spectrum sharing in specialized geographic regions, "National Radio Dynamic Zones"; (2) collaborative, center-scale institutes for sustained R&D in the most challenging areas to bring together diverse science and engineering perspectives; and (3) education and public outreach funding for the much needed workforce development specifically related to spectrum research.
- AI: Together with other NSF directorates/offices, MPS will increase support for AI research and development, with a focus on supporting basic research in machine learning and deep learning.
- Bioeconomy: MPS, together with other NSF directorates/offices, will invest in fundamental research, infrastructure, and education that advance foundational knowledge needed to understand and harness biological processes for societal benefit.
- BRAIN Initiative: MPS will continue to invest in the scientific understanding of brain complexity.
- Microelectronics and Semiconductors: MPS will support research that addresses fundamental science questions on the concepts, materials, devices, circuits, and platforms necessary to sustain progress in semiconductor-microelectronic technologies, with a focus on materials. This research is critical to future advances and security in information technology, communications, sensing, smart electric grid, transportation, health, advanced manufacturing, and other areas.
- NSF I-Corps™: Together with other NSF directorates and offices, MPS will support this program which connects NSF-funded science and engineering research with the technological, entrepreneurial,

and business communities, and fosters a national innovation ecosystem that links scientific discovery with technology development, societal needs, and economic opportunities.

- QIS: As the steward for QIS, MPS will work together with other NSF directorates and offices to increase support for quantum information science research and development. These investments align with the National Quantum Initiative[1] to coordinate and expand the United States' world-leading position in fundamental quantum research. QIS investments will deliver proof-of-concept devices, applications, tools, or systems with a demonstrable quantum advantage over their classical counterparts. Research in QIS examines uniquely quantum phenomena that can be harnessed to advance information processing, transmission, measurement, and fundamental understanding in ways that classical approaches can only do much less efficiently, or not at all. Current and future QIS applications differ from prior applications of quantum mechanics, such as lasers, transistors, and magnetic resonance imaging, by using distinct quantum phenomena—superposition and entanglement—that do not have classical counterparts.
- SaTC: MPS will continue to invest in fundamental research in cybersecurity.
- Spectrum Innovation Initiative: As the steward of this initiative, MPS will coordinate agency-wide investments that catalyze research and development in spectrum research, addressing key challenges related to an increasingly congested radio frequency environment and outdated approaches to spectrum allocation. The additional funding will primarily support three cross-cutting initiatives: (1) a novel mechanism for piloting, testing, and rolling out the most innovative approaches to dynamic spectrum sharing in specialized geographic regions, "National Radio Dynamic Zones"; (2) collaborative, center-scale institutes for sustained R&D in the most challenging areas to bring together diverse science and engineering perspectives; and (3) education and public outreach funding for the much needed workforce development specifically related to spectrum research.
- QL: MPS is the steward for QL, an NSF Big Idea that builds upon and extends our existing knowledge of the quantum world to observe, manipulate, and control, from first principles, the behavior of particles at atomic and subatomic scales. Investments will enable discoveries in both naturally occurring and engineered quantum systems and develop next-generation quantum technologies and devices for sensing, information processing, communications, and computing. Advances will unleash the potential of the Nation's quantum-based scientific enterprise to enhance our well-being, economy, and security.
- WoU: MPS is the steward for WoU, and together with GEO/OPP, will support research in the "windows"—electromagnetic waves, high-energy particles, and gravitational waves—of multi-messenger astrophysics (MMA). Through WoU investments, NSF will also grow the workforce not only for multi-messenger astrophysics but also for engineering, data science, and many other areas in our modern society.

MPS Funding for Centers and Facilities

MPS Funding for Centers Programs

(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$86.35**	**-**	**$87.66**	**$1.31**	**1.5%**
Centers for Chemical Innovation (CHE)	19.10	-	21.00	1.90	9.9%
Materials Centers (DMR)	52.51	-	52.51	-	-
STC: Center for Integrated Quantum Materials (DMR)	5.00	-	4.15	-0.85	-17.0%
STC: STC on Real-Time Functional Imaging (DMR)	5.00	-	5.00	-	-
STC: Center for Bright Beams (PHY)	4.74	-	5.00	0.26	5.5%

For additional information on NSF's centers programs, please see the NSF-Wide Investments chapter.

[1] www.congress.gov/bill/115th-congress/house-bill/6227

MPS Funding for Major Multi-User Facilities
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$362.62**	**-**	**$288.58**	**-$74.04**	**-20.4%**
Arecibo Observatory[1]	14.78	-	1.50	-13.28	-89.9%
Cornell High-Energy Synchrotron Source (CHESS)[2]	5.00	-	-	-5.00	-100.0%
Green Bank Observatory (GBO)[3]	10.26	-	7.30	-2.96	-28.8%
IceCube Neutrino Observatory (IceCube)	3.50	-	3.50	-	-
Large Hadron Collider (LHC)	16.00	-	20.00	4.00	25.0%
Laser Interferometer Gravitational Wave Observatory (LIGO)[4]	66.72	-	45.00	-21.72	-32.6%
National High Magnetic Field Laboratory (NHMFL)[5]	40.62	-	37.74	-2.88	-7.1%
National Radio Astronomy Observatory (NRAO)	95.04	-	88.13	-6.91	-7.3%
NRAO O&M [6]	*49.83*	-	*39.45*	*-10.38*	*-20.8%*
Atacama Large Millimeter Array (ALMA) O&M [7]	*45.21*	-	*48.68*	*3.47*	*7.7%*
National Solar Observatory (NSO)	18.39	-	21.79	3.40	18.5%
NSO O&M [8]	*7.89*	-	*4.25*	*-3.64*	*-46.1%*
Daniel K. Inouye Solar Telescope (DKIST) [9]	*10.50*	-	*17.54*	*7.04*	*67.0%*
National Superconducting Cyclotron Laboratory (NSCL)[10]	28.50	-	15.50	-13.00	-45.6%
NSF's National Optical-Infrared Astronomy Research Laboratory[11]	63.81	-	48.12	-15.69	-24.6%
NSF's National Optical-Infrared Astronomy Research Laboratory O&M (formerly the National Optical Astronomy Observatory (NOAO)) [12]	*29.16*	-	*22.23*	*-6.93*	*-23.8%*
Gemini Observatory (Gemini) O&M [13]	*34.65*	-	*20.89*	*-13.76*	*-39.7%*
Vera C. Rubin Observatory O&M [14]	-	-	*5.00*	*5.00*	*N/A*

For information on continuity of operations funding, see the opening narrative of the Facilities chapter.

[1] ARECIBO: FY 2019 Actual includes $12.30 million in carryover funds from the FY 2018 emergency supplemental appropriation -- Further Additional Supplemental Appropriations for Disaster Relief Requirements Act of 2018 (P.L. 115-123) -- for hurricane damage repairs and $530,000 for continuity of operations into FY 2020. It excludes $1.80 million of FY 2019 O&M costs obligated in FY 2018.

[2] CHESS: In FY 2019, NSF stewardship of CHESS ended as NSF transitioned to funding the Center for High Energy X-Ray Sciences (CHEXS), a sub-facility at CHESS operated in partnership with Cornell University. This table does not include CHEXS as it is not a major facility.

[3] GBO: Previously under "Other AST Facilities". FY 2019 Actual includes $2.17 million for continuity of operations into FY 2020.

[4] LIGO: FY 2019 Actual includes $10.47 million for Advanced LIGO Plus enhancement and $11.25 million for continuity of operations into FY 2020.

[5] NHMFL: FY 2019 Actual includes $14.20 million for continuity of operations into FY 2020. Excluded is $9.34 million of FY 2019 O&M costs obligated in FY 2018.

[6] NRAO: As of Oct. 1, 2018, the Long Baseline Observatory (LBO) was reintegrated into NRAO as the Very Long Baseline Array (VLBA) at $3.82 million in FY 2019 and $3.43 million in FY 2021. Also included in FY 2019 is $3.16 million for continuity of operations into FY 2020 and $4.0 million for development of a next generation Very Large Array (ngVLA).

[7] ALMA: The FY 2019 Actual includes $4.93 million for continuity of operations into FY 2020.

[8] NSO: FY 2019 Actual includes $3.50 million for development of DKIST level 2 (advanced) data products.

[9] DKIST: FY 2019 Actual includes $2.0 million to another awardee for cultural mitigation activities as agreed to during the DKIST environmental compliance process. Excluded is $8.0 million of FY 2019 O&M costs for DKIST obligated in FY 2018.

[10] NSCL: FY 2019 Actual includes $4.50 million for continuity of operations into FY 2020. FY 2021 is the final year of NSF stewardship of NSCL, after which NSCL will transition into the Department of Energy's Facility for Rare Isotope Beams.

[11] NSF's National Optical-Infrared Astronomy Research Laboratory was established at the start of FY 2020. The Lab encompasses operations of the Mid-Scale Observatories (MSO) and Community Science & Data Center (CSDC), which formerly comprised NOAO, together with operations of the Gemini Observatory and the Vera C. Rubin Observatory.

[12] NSF's National Optical-Infrared Astronomy Research Laboratory: FY 2019 Actual includes $5.73 million for continuity of operations into FY 2020, $2.50 million to support NSF transition activities associated with the creation of the Lab, approximately $412,000 in supplemental funding for U.S. Extremely Large Telescope program planning, and $1.18 million for other special projects.

[13] Gemini: FY 2019 Actual includes $12.99 million to enhance Gemini's adaptive optics system, software capabilities, and public information and outreach activities in the era of multi-messenger astronomy.

[14] Vera C. Rubin Observatory: Excluded is $11.10 million in FY 2019 - FY 2021 pre-operations ramp up costs obligated in FY 2018.

For detailed information on individual facilities, see the Facilities and MREFC chapters.

Funding Profile

MPS Funding Profile

	FY 2019 Actual Estimate	FY 2020 (TBD)	FY 2021 Estimate
Statistics for Competitive Awards:			
Number of Proposals	8,045	-	8,050
Number of New Awards	2,415	-	2,340
Funding Rate	30%	N/A	29%
Statistics for Research Grants:			
Number of Research Grant Proposals	7,015	-	7,000
Number of Research Grants	1,921	-	1,800
Funding Rate	27%	N/A	26%
Median Annualized Award Size	$130,000	-	$130,000
Average Annualized Award Size	$151,303	-	$150,000
Average Award Duration, in years	3.2	-	3.2

In FY 2021, the number of research grant proposals is expected to remain level with FY 2019 Actual estimates. MPS expects to award approximately 1,800 research grants to support research and infrastructure activities in both core and crosscutting areas. Average annual award size and duration as well as funding rate are not expected to materially fluctuate from FY 2019 to FY 2021. In FY 2021, MPS maintains its commitment to Science and Technology Centers, Materials Centers, and Centers for Chemical Innovation and will invest $87.66 million, accounting for roughly six percent of the total MPS budget. Operations and maintenance funding for MPS-supported major multi-user facilities comprises approximately 20 percent of MPS's FY 2021 Request.

Program Monitoring and Evaluation

External Program Evaluation and Studies

- For AST, the strategic advice of greatest impact in FY 2021 will be the Decadal Survey of Astronomy and Astrophysics.[2] This survey will be executed by the National Academies of Science, Engineering, and Medicine (the National Academies). It will outline external advice from the astronomy community regarding the level of support for a variety of observational facilities, and the balance between support of facilities and individual investigator programs.
- An external evaluation of the Centers for Chemical Innovation (CCI) Program (2004-2016) was completed in FY 2020. It is currently under review by CHE and expected to be published mid-FY 2020. The study will shape the growth of interdisciplinary team science in chemistry, while helping to inspire faculty and students at all levels to address the most pressing global STEM challenges.
- Pivotal for DMR, the National Academies published their final report on the "*Frontiers of Materials Research: A Decadal Survey.*"[3] The report identifies future directions for materials science for NSF and the U.S. Department of Energy (DOE). In addition, MPS charged the MPS Advisory Committee to form a subcommittee to assess Materials Science opportunities at the interface with Synthetic Biology. The subcommittee is expected to deliver a report of its findings in FY 2020.
- In PHY, a subcommittee of the MPS Advisory Committee was charged with studying the

[2] www.sites.nationalacademies.org/DEPS/Astro2020/index.htm
[3] www.sites.nationalacademies.org/DEPS/materials-decadal/index.htm

implementation of the Physics Frontiers Centers program and the final report was approved in August 2019.[4] The Decadal Assessment on Atomic, Molecular, and Optical Science was also completed and the pre-publication report was posted in December 2019.[5]

Workshops and Reports

In FY 2019, every MPS division sponsored or co-sponsored workshops covering an expansive range of emerging and leading-edge research topics. Examples of these workshops are below:

- MPS sponsored a workshop entitled "Broadening Participation: 2019 MPS Workshop for New Investigators" in September 2019 that targeted investigators early in their careers, from small colleges, and/or underrepresented groups, with a goal of de-mystifying the NSF merit review process and encouraging future applications to NSF opportunities and improved interactions with the foundation. A total of 98 individuals representing all MPS divisions participated in the workshop.
- In FY 2020, MPS/CHE, DOE/Basic Energy Sciences (BES)/Chemical Sciences, Geosciences and Biosciences (CSGB), and the American Chemical Society plan to initiate a consensus study through the National Academies Board on Chemical Sciences and Technologies on "Enhancing the U.S. Chemical Economy through Investments in Fundamental Research in the Chemical Sciences." Results from the study, planned for FY 2022, are expected to inform the scope of core funding activities in the chemical sciences.
- In May 2019, MPS/CHE, ENG/Chemical, Bioengineering, Environmental and Transport Systems (CBET) and DOE/BES/CSGB co-sponsored the National Academies Chemical Sciences Roundtable (CSR) on "Closing the Loop on the Plastics Dilemma"[6] and in November 2019, they co-sponsored a CSR Roundtable on "Advances, Challenges, and Long-Term Opportunities for Electrochemistry."[7] Workshop reports, expected in 2020, will outline high-priority global challenges related to sustainability in the fields of chemistry, engineering, and materials science.
- In FY 2019, through the Designing Materials to Revolutionize and Engineer our Future program, MPS, ENG, and CISE sponsored a study by The Minerals, Metals and Materials Society on creating the next-generation Materials Genome Initiative (MGI) Workforce.[8] In FY 2020 DMR, in collaboration with the National Science and Technology Council interagency subcommittee on MGI, is developing the MGI Strategic Plan 2.0, which will incorporate the MGI Workforce study.
- In October 2019, DMS sponsored a PI workshop for the Algorithms for Threat Detection (ATD) program and the Algorithms for Modern Power Systems (AMPS) program. The ATD program is a partnership between DMS and the National Geospatial Intelligence Agency and AMPS is a partnership between DMS and the Office of Electricity Delivery & Energy Reliability at DOE.
- In November 2019, the MPS/CHE, PHY, DMR and CISE/Computing and Communication Foundations (CCF) workshop report "Enabling the Quantum Leap: Quantum Algorithms for Chemistry and Materials," was published.[9] This report featured significant industrial input from IBM, Microsoft, Google, Rigetti Computing, and 1Qbit to identify targeted problems for testing quantum computers as well as to describe current and future workforce needs. A follow-up workshop is in planning for FY 2020 to continue to define and refine urgent challenges in quantum information sciences over the next several decades especially in shaping the growth of university departments and inspiring the next generation of scientists and engineers participating in quantum computing.

[4] www.nsf.gov/mps/advisory/active_subcommittees.jsp
[5] www.sites.nationalacademies.org/BPA/BPA_185654
[6] www.nas-sites.org/csr/closing-the-loop-on-the-plastics-dilemma/
[7] www.nas-sites.org/csr/advances-challenges-and-long-term-opportunities-for-electrochemistry/.
[8] www.tms.org/portal/Publications/Studies/MGIworkforce/MGIworkforce.aspx
[9] www.nsf.gov/mps/che/workshops/quantum_algorithms_for_chemistry_and_materials_report_01_21-24_2019.pdf

Committees of Visitors (COVs)
In 2019, COVs for AST, DMR, and PHY were conducted, all charged with assessing and preparing a report on division activities and priorities over the period of FY 2015 – FY 2018.

- The PHY COV convened in June 2019. The report provided recommendations related to topics including PHY's support of post-docs and grad students as well as information provided to NSF reviewers during the merit review process. The report of the 2019 COV to PHY was accepted by the MPS Advisory Committee in a virtual meeting held on August 23, 2019.[10]
- The AST COV also convened in June 2019. The COV made 15 formal recommendations. The COV report provided detailed assessments of AST's responses to the previous COV as well as to the Decadal Survey and portfolio review. The report of the 2019 COV to AST was accepted by the MPS Advisory Committee in a meeting held on October 23-24, 2019.[11]
- The DMR COV was convened in September 2019. The COV emphasized findings from the 2019 Decadal Survey and other publications that emphasized the need for the United States to remain competitive in materials research. The committee made nine recommendations to DMR, including addressing the context of materials research within the agency, exploring new partnerships, and investigating additional means to fund research infrastructure. The report of the 2019 COV to DMR was accepted by the MPS Advisory Committee in a meeting held on October 23-24, 2019.[12]
- In 2020, COVs will be conducted for CHE and DMS.

The Performance and Management chapter provides details regarding the periodic reviews of programs and portfolios of programs by external COVs and directorate Advisory Committees. Please refer to this chapter for additional information.

People Involved in MPS Activities

Number of People Involved in MPS Activities

	FY 2019 Actual Estimate	FY 2020 (TBD)	FY 2021 Estimate
Senior Researchers	8,335	-	7,900
Other Professionals	2,531	-	2,400
Postdoctoral Associates	1,868	-	1,700
Graduate Students	8,583	-	8,200
Undergraduate Students	5,510	-	5,200
K-12 Teachers	-	-	-
K-12 Students	-	-	-
Total Number of People	**26,827**	**-**	**25,400**

[10] www.nsf.gov/mps/advisory/covdocs/PHY_2019_COV_final_report.pdf
[11] www.nsf.gov/mps/advisory/covdocs/AST_COV_Report.pdf
[12] www.nsf.gov/mps/advisory/covdocs/DMR_COV_Report_Final.pdf

DIVISION OF ASTRONOMICAL SCIENCES (AST) $242,100,000
-$44,910,000 / -15.6%

AST Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
Total	**$287.01**	**-**	**$242.10**	**-$44.91**	**-15.6%**
Research	**68.60**	**-**	**61.57**	**-7.03**	**-10.2%**
Education	**4.43**	**-**	**4.69**	**0.26**	**5.9%**
Infrastructure	**213.98**	**-**	**175.84**	**-38.14**	**-17.8%**
Arecibo Observatory[1]	14.25	-	1.50	-12.75	-89.5%
AST Portfolio Review Implementation	0.14	-	-	-0.14	-100.0%
GBO[2]	10.26	-	7.30	-2.96	-28.8%
Midscale Research Infrastructure	15.59	-	1.00	-14.59	-93.6%
NRAO	86.95	-	88.13	1.18	1.4%
NRAO O&M[3]	*46.67*	-	*39.45*	*-7.22*	*-15.5%*
Atacama Large Millimeter Array (ALMA) O&M[4]	*40.28*	-	*48.68*	*8.40*	*20.9%*
NSO	18.39	-	21.79	3.396	18.5%
NSO O&M[5]	*7.89*	-	*4.25*	*-3.64*	*-46.2%*
Daniel K. Inouye Solar Telescope (DKIST)[6]	*10.50*	-	*17.54*	*7.04*	*67.0%*
NSF's National OIR Astronomy Research Laboratory[7]	58.08	-	48.12	-9.96	-17.1%
NSF's National Optical-Infrared Astronomy Research Laboratory O&M (formerly the National Optical Astronomy Observatory (NOAO))[8]	*23.43*		*22.23*	*-1.20*	*-5.1%*
GEMINI Observatory (Gemini) O&M[9]	*34.65*	-	*20.89*	*-13.76*	*-39.7%*
Vera C. Rubin Observatory O&M (formerly the Large Synoptic Survey	-	-	*5.00*	*5.00*	*N/A*
Research Resources	10.31	-	8.00	-2.31	-22.4%

For information on continuity of operations funding, see the opening narrative of the Facilities chapter.

[1] ARECIBO: FY 2019 Actual includes $12.30 million in carryover funds from the FY 2018 emergency supplemental appropriation -- Further Additional Supplemental Appropriations for Disaster Relief Requirements Act of 2018 (P.L. 115-123) -- for hurricane damage repairs. It excludes $1.80 million of FY 2019 O&M costs obligated in FY 2018. Funding for continuity of operations into FY 2020 ($530,000) was provded by OMA.

[2] GBO: Previously under "Other AST Facilities". Funding for continuity of operations into FY 2020 ($2.17 million) was provded by OMA.

[3] NRAO: As of Oct. 1, 2018, the Long Baseline Observatory (LBO) was reintegrated into NRAO as the Very Long Baseline Array (VLBA) at $3.82 million in FY 2019 and $3.43 million in FY 2021. Also included in FY 2019 is $4.0 million for development of a next generation Very Large Array (ngVLA). Funding for continuity of operations into FY 2020 ($3.16 million) was provded by OMA.

[4] ALMA: Funding for continuity of operations into FY 2020 ($4.93 million) was provded by OMA.

[5] NSO: FY 2019 Actual includes $3.50 million for development of DKIST level 2 (advanced) data products.

[6] DKIST: FY 2019 Actual includes $2.0 million to another awardee for cultural mitigation activities as agreed to during the DKIST environmental compliance process. Excluded is $8.0 million of FY 2019 O&M costs for DKIST obligated in FY 2018.

[7] NSF's National Optical-Infrared Astronomy Research Laboratory was established at the start of FY 2020. The Lab encompasses operations of the Mid-Scale Observatories (MSO) and Community Science & Data Center (CSDC), which formerly comprised NOAO, together with operations of the Gemini Observatory and the Vera C. Rubin Observatory.

[8] NSF's National Optical-Infrared Astronomy Research Laboratory: FY 2019 Actual includes $2.50 million to support NSF transition activities associated with the creation of the Lab, approximately $412,000 in supplemental funding for U.S. Extremely Large Telescope program planning, and $1.18 million for other special projects. Funding for continuity of operations into FY 2020 ($5.73 million) was provded by OMA.

[9] Gemini: FY 2019 Actual includes $12.99 million to enhance Gemini's adaptive optics system, software capabilities, and public information and outreach activities in the era of multi-messenger astronomy.

[10] Vera C. Rubin Observatory: Excluded is $11.10 million in FY 2019 - FY 2021 pre-operations ramp up costs obligated in FY 2018.

About AST

AST is the federal steward for ground-based astronomy in the United States, funding research via cooperative agreements for the operation of large telescope facilities and through awards to individual investigators and small research groups. The telescope facilities provide world-leading, one-of-a-kind observational capabilities on a competitive basis to thousands of astronomers each year. These facilities also enable scientific advances by ensuring enormous volumes of data are available to researchers. AST supports the development of advanced technologies and instrumentation and manages the electromagnetic spectrum for scientific use by the entire NSF community.

The AST portfolio includes research to understand the origins and characteristics of planets, stars, and galaxies, as well as the structure that has evolved in the universe since its origin more than 13 billion years ago. The results of this research will lead to a better understanding of the cosmos, the possibility of life existing on planets circling other stars, and the nature of the mysterious dark matter and dark energy that comprise more than 95 percent of the mass-energy of the universe. AST also supports research intended to probe the universe through several powerful and diverse “windows”—electromagnetic waves, high-energy particles, and gravitational waves.

In general, about 22 percent of the AST portfolio is available for new research grants. About 73 percent of AST’s budget supports the instrumentation and facilities needed for progress at the frontiers of observational astronomy, while 27 percent supports the research of individual investigators. Through the MREFC appropriation, AST also oversees the construction of the Vera C. Rubin Observatory. For detailed information on AST's individual facilities, see the Facilities chapter. For detailed information on the construction of the Vera C. Rubin Observatory, see the MREFC chapter.

DIVISION OF CHEMISTRY (CHE) **$218,710,000**
-$28,560,000 / -11.6%

CHE Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$247.27**	**-**	**$218.71**	**-$28.56**	**-11.6%**
Research	**223.36**	**-**	**207.16**	**-16.20**	**-7.3%**
Centers Funding (total)	19.07	-	21.00	1.93	10.1%
Centers for Chemical Innovation	*19.07*	-	*21.00*	*1.93*	*10.1%*
Education	**5.47**	**-**	**3.57**	**-1.90**	**-34.7%**
Infrastructure	**18.44**	**-**	**7.98**	**-10.46**	**-56.7%**
Midscale Research Infrastructure	5.50	-	0.60	-4.90	-89.1%
NHMFL	1.73	-	1.73	-	-
National Nanotechnology Coordinated Infrastructure (NNCI)	0.30	-	-	-0.30	-100.0%
Research Resources	10.91	-	5.65	-5.26	-48.2%

About CHE

CHE supports discovery research and workforce development in chemistry that have the potential to be transformative to major commercial sectors of the U.S. economy: energy, pharmaceuticals, medical applications, plastics, electronics, food, agriculture, and transportation. CHE investments also support highly competitive and rapidly evolving fields that include advanced manufacturing, quantum information sciences, data mining and artificial intelligence, and sensor and instrument development. Experimental, computational and theoretical chemical research is integrated into core programs focused on new synthetic and catalytic methods; measurement/imaging tool and technique development; understanding the structure, dynamics and mechanistic relationships between function and reactivity; environmental chemical sciences; the chemistry of biological processes; and macromolecular, supramolecular and nanochemistry leading to higher ordered structures and materials. CHE programs have a strong emphasis on sustainability and the protection of natural resources. The division uses multiple funding mechanisms to support individuals and team science as well as interdisciplinary user facilities.

CHE encourages researchers to apply chemical understanding and tools to other fields, including biology, engineering, materials research, geosciences, mathematics/statistics, computing, and social sciences. Investments across fields not only expedite chemical learnings, invention, and innovation, but also have significant ramifications for training and employment of the workforce of the future.

In general, about 74 percent of the CHE portfolio is available to support new research grants. The remaining 26 percent supports research grants made in prior years and the research infrastructure needed by the chemistry community.

DIVISION OF MATERIALS RESEARCH (DMR)

$280,220,000
-$22,770,000 / -7.5%

DMR Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$302.99**	**-**	**$280.22**	**-$22.77**	**-7.5%**
Research	**245.73**	**-**	**215.34**	**-30.39**	**-12.4%**
Centers Funding (total)	62.51	-	61.66	-0.85	-1.4%
Materials Centers	*52.51*	-	*52.51*	-	-
STC: Center for Integrated Quantum Materials	*5.00*	-	*4.15*	*-0.85*	*-17.0%*
STC: STC on Real-Time Functional Imaging	*5.00*	-	*5.00*	-	-
Education	**5.92**	**-**	**2.00**	**-3.92**	**-66.2%**
Infrastructure	**51.34**	**-**	**62.88**	**11.54**	**22.5%**
Center for High Energy X-Ray Sciences (CHEXS)[1]	5.00	-	9.00	4.00	80.0%
CHESS[1]	5.00	-	-	-5.00	-100.0%
Center for High Resolution Neutron Scattering (CHRNS)	2.79	-	3.00	0.21	7.5%
Midscale Research Infrastructure	-	-	11.00	11.00	N/A
NHMFL[2]	34.89	-	36.01	1.12	3.2%
NNCI	2.58	-	2.42	-0.16	-6.2%
Research Resources	1.08	-	1.45	0.37	34.3%

For information on continuity of operations funding, see the opening narrative of the Facilities chapter.

[1] In FY 2019, NSF stewardship of the CHESS ended as NSF transitioned to funding the CHEXS, a sub-facility at CHESS that is operated in partnership with Cornell University.

[2] NHMFL: FY 2019 Actual includes $10.20 million for continuity of operations into FY 2020; $4.0 million was provdied by OMA. Excluded is $9.34 million of FY 2019 O&M costs obligated in FY 2018.

About DMR

Materials Research is the field of science where physics, chemistry, materials science, and engineering naturally converge in the pursuit of understanding the properties of materials and the phenomena they host. Materials are abundant and pervasive, serving as critical building blocks in technology and innovation. This research impacts life and society, as it shapes our understanding of the world and enables significant advances in electronics, communications, transportation, and health-related fields. The development and deployment of advanced materials are major drivers of U.S. economic growth.

DMR invests in the discovery of new materials and the explanation of materials phenomena, and in the development of the next generation of materials scientists. DMR supports fundamental experimental and theoretical materials research and education via programs focused on condensed matter physics, solid-state and materials chemistry, and the science of materials that are ceramic, metallic, polymeric, nanostructured, biological, electronic, photonic, and multifunctional. This enterprise is dependent on investments across scales, including single investigators, teams, and centers; singularly focused research and areas requiring interdisciplinarity; and infrastructure ranging from small instruments to large-scale facilities. DMR supports materials-relevant instrumentation and technique development broadly in x-ray and neutron science as well as in nanofabrication. Specifically, DMR investments have contributed to U.S. leadership in high-field magnet science and further aims at democratizing national access to high-magnetic fields.

In general, about 38 percent of the DMR portfolio is available to support new research grants. The remaining 62 percent supports research grants made in prior years and the research infrastructure needed by the materials research community.

DIVISION OF MATHEMATICAL SCIENCES (DMS) **$214,790,000**
-$22,240,000 / -9.4%

DMS Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
Total	**$237.03**	**-**	**$214.79**	**-$22.24**	**-9.4%**
Research	**225.45**	**-**	**205.31**	**-20.14**	**-8.9%**
Education	**11.58**	**-**	**9.48**	**-2.10**	**-18.1%**

About DMS

DMS provides the major U.S. federal support for fundamental research at the frontiers of mathematical sciences. Modern communication systems, medicine, manufacturing, energy, transportation, finance, and national security all rely on advances in the mathematical sciences. DMS investments support research at the forefront of fundamental, applied and computational mathematics, and statistics that accelerates discovery and innovation. DMS partnerships with science and engineering in turn inspire development of effective mathematical and statistical theories and methodologies applicable to future national priority areas. The advancement of future researchers in the mathematical sciences, through dedicated training opportunities, remains a DMS priority.

DMS also supports the Mathematical Sciences Research Institutes program, which advances mathematics and statistics research through thematic programs and workshops on current and emerging trends.

Through strong partnerships, DMS can expand the impact of its research investments, including a partnership with CISE on data science through the Transdisciplinary Research in Principles of Data Science program. DMS also partners with the NIH on two programs in biosciences: the Joint DMS/National Institute of General Medical Sciences Initiative to Support Research at the Interface of the Biological and Mathematical Sciences, and the Joint DMS/National Library of Medicine Initiative on Generalizable Data Science Methods for Biomedical Research. Other partnerships include a program with the National Geospatial Intelligence Agency to develop the next generation of mathematical and statistical algorithms for analysis of large datasets; and a program on algorithms for modern power systems with DOE. Another program with the Simons Foundation and BIO supports research centers on the Mathematics of Complex Biological Systems.

In general, about 54 percent of the DMS portfolio is available to support new research grants each year. The remaining 46 percent supports research grants made in prior years.

DIVISION OF PHYSICS (PHY)

$257,830,000
-$27,400,000 / -9.6%

PHY Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
Total	**$285.23**	**-**	**$257.83**	**-$27.40**	**-9.6%**
Research	**163.37**	**-**	**162.81**	**-0.56**	**-0.3%**
Centers Funding (total)	4.74	-	5.00	0.26	5.5%
STC: Center for Bright Beams	*4.74*	*-*	*5.00*	*0.26*	*5.5%*
Education	**5.52**	**-**	**4.56**	**-0.96**	**-17.5%**
Infrastructure	**116.33**	**-**	**90.46**	**-25.87**	**-22.2%**
IceCube	3.50	-	3.50	-	-
LHC	16.00	-	20.00	4.00	25.0%
LIGO[1]	55.47	-	45.00	-10.47	-18.9%
Midscale Research Infrastructure	13.34	-	6.46	-6.88	-51.6%
NSCL[2]	28.00	-	15.50	-12.50	-44.6%
Research Resources	0.02	-	-	-0.02	-100.0%

For information on continuity of operations funding, see the opening narrative of the Facilities chapter.

[1] LIGO: FY 2019 Actual includes $10.47 million for Advanced LIGO Plus enhancement. Funding for continuity of operations into FY 2020 ($11.25 million) was provded by OMA.

[2] NSCL: FY 2019 includes $4.0 million for continuity of operations into FY 2020; $500,000 was provided by OMA. FY 2021 is the final year of NSF stewardship of NSCL, after which NSCL will transition into the Department of Energy's Facility for Rare Isotope Beams.

About PHY

PHY supports fundamental research addressing frontier areas of physics that lead to the understanding of the make-up of the universe, from the formation of stars and galaxies to the principles of life processes on Earth. This research covers a range of physics subfields: atomic, molecular, optical and plasma physics, elementary particle physics, gravitational physics, nuclear physics, particle and nuclear astrophysics, physics of living systems, physics at the information frontier, and theoretical physics.

PHY is the primary supporter of all U.S. research in gravitational physics and the leading supporter of fundamental research in atomic, molecular, and optical physics in the United States. PHY is a major partner with DOE in support of elementary particle physics, nuclear physics, and plasma physics. PHY also has the only U.S. program designed for the support of physics research in living systems. The development of the most advanced cutting-edge computational resources, innovative technology, and new instrumentation is a key part of physics research. Tools developed by the physics community continuously have major impacts in other scientific and engineering fields, allowing PHY to contribute in major ways to emerging new frontiers such as QIS and AI.

In general, about 17 percent of the PHY portfolio is available for new research grants. The remaining 83 percent is used primarily to fund continuing grants made in previous years and to support operations and maintenance for four facilities that are a key part of the division portfolio (about 33 percent). Through the MREFC appropriation, PHY also oversees the construction of HL-LHC. For detailed information on PHY's individual facilities, see the Facilities chapter. For detailed information on the construction of HL-LHC, see the MREFC chapter.

OFFICE OF MULTIDISCIPLINARY ACTIVITIES (OMA) **$234,670,000**
+$103,590,000 / 79.0%

OMA Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$131.08**	**-**	**$234.67**	**$103.59**	**79.0%**
Research	**94.16**	**-**	**234.67**	**140.51**	**149.2%**
Spectrum Innovation Initiative	-	-	17.00	17.00	N/A
NSF's Big Ideas	60.02	-	80.00	19.98	33.3%
QL	*30.02*	-	*50.00*	*19.98*	*66.6%*
WoU	*30.00*	-	*30.00*	-	-
Education	**6.68**	**-**	**-**	**-6.68**	**-100.0%**
Infrastructure[1]	**30.24**	**-**	**-**	**-30.24**	**-100.0%**

For information on continuity of operations funding, see the opening narrative of the Facilities chapter.
[1] Reflects funding for MPS facilities as one-time support for continuity of operations into FY 2020.

About OMA

In partnership with MPS division and programs, OMA strategically invests in research and education to support novel, challenging, or complex projects of varying scale that are not readily accommodated by traditional organizational structures and procedures.

OMA funding priorities continue to focus on MPS-relevant Big Ideas: QL, WoU, HDR, and URoL. As the steward for QL, OMA will support investments from all MPS divisions, BIO, ENG, CISE and OISE that engage several relevant disciplines in a convergent and interdependent manner to advance quantum science and technology. Societal benefits of this science and technology are expected to be significant, as it is poised to include proof-of-concept devices, applications, tools, or systems with a demonstrable quantum advantage over their classical counterparts. MPS is also the steward for WoU, supporting AST, PHY, and GEO/OPP in activities that bring together fundamental research in electromagnetic waves, high-energy particles, and gravitational waves; advance the study of the universe; and grow the nation's multi-messenger astrophysics, engineering, and data science workforce. In addition to the Big Ideas, OMA is the steward for other administration priorities, including QIS and the Spectrum Innovation Initiative. OMA will also invest in other multidisciplinary research that advances the basic foundations of mathematical and physical sciences. OMA will foster broadening participation through support of HBCUs and other MSIs and will continue to place high priority on the Alliances for Graduate Education and the Professoriate Graduate Research Supplement program and the MPS Graduate Research Supplements to Veterans program.

In general, about 60 percent of the OMA portfolio is available to support new research grants. The remaining 40 percent supports multidisciplinary research infrastructure and education activities needed by the MPS community.

DIRECTORATE FOR SOCIAL, BEHAVIORAL AND ECONOMIC SCIENCES (SBE)

$246,840,000
-$24,330,000 / -9.0%

SBE Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Division of Behavioral and Cognitive Sciences (BCS)	$94.35	-	$85.14	-$9.21	-9.8%
Division of Social and Economic Sciences (SES)	96.43	-	86.66	-9.77	-10.1%
National Center for Science and Engineering Statistics (NCSES)	54.23	-	52.11	-2.12	-3.9%
SBE Office of Multidisciplinary Activities (SMA)	26.16	-	22.93	-3.23	-12.4%
Total	**$271.17**	**-**	**$246.84**	**-$24.33**	**-9.0%**

About SBE

SBE research occurs in core areas such as economics, neuroscience, and statistics, as well as multidisciplinary activities such as those described in NSF's Big Ideas.

SBE researchers examine a wide range of fundamental questions about human brains, behaviors, and institutions. SBE provides approximately 62 percent of the federal funding for basic research at academic institutions in the social, behavioral, and economic sciences. This work strengthens knowledge that innovators in the private and public sector use. SBE researchers' findings have the potential to help grow the economy, secure the homeland, improve the health and safety of American families, and increase the competitiveness of America's farms, offices, and factories.

SBE seeks to invest in the next generation of truly transformative and socially beneficial science. SBE support for early career investigators, undergraduates, graduate students, and post-doctoral research fellowships trains and prepares young scholars to develop rigorous and effective new ways to capitalize on the increasing availability of massive amounts of data to advance knowledge about human behavior—for example, to use and combine data from surveys, administrative records, brain imaging, and biospecimen analysis, as well as output from behavioral, environmental, and geographic sensors. As young scientists embark on their careers, they bring novel and far reaching ideas into play that seed the next harvest of discoveries in the social, behavioral, and economic sciences.

NCSES, a federal statistical agency within SBE, provides statistical information about the United States' science and engineering (S&E) enterprise, often with a global context. NCSES collects, analyzes, and disseminates data on research and development (R&D), the S&E workforce, the condition and progress of science, STEM education, and U.S. competitiveness in science, engineering, and technology R&D. NCSES is the Nation's leading provider of statistical data on the S&E enterprise.

SBE's FY 2021 Request is shaped by three guiding principles:

1. Support fundamental research that advances key national priorities. The research emphases include enhancing national security and preparedness; strengthening American infrastructure; creating new economic opportunities for populations adversely affected by change; and empowering American innovation through research in artificial intelligence (AI) with a focus on worker productivity and well-being in a growing range of work environments, including industries of the future (e.g. AI, future manufacturing); reliability of information networks; and improving quality of life for communities across the country.

2. Support NCSES, one of only thirteen principal statistical agencies across the federal government. Continued investment in NCSES supports NSF's mission by collecting and disseminating and serving as a clearinghouse for comprehensive and reliable data on R&D trends, educational pathways and experiences of and opportunities for the Nation's science and engineering workforce, measures of national competitiveness and innovation, and the condition and progress of STEM education in the United States.
3. Support and advance NSF's Big Ideas and other cross-directorate activities, particularly those for which understanding human perception, cognition, behavior, action, and adaptive strategies are necessary to produce transformative societal benefits.

SBE's FY 2021 Request of $246.84 million will be used to prioritize and maximize support for investments in SBE's disciplinary and interdisciplinary programs as well as its support for NSF-wide activities.

The FY 2021 Request includes continued support for investments that integrate the social, behavioral, and economic sciences into multi-directorate and multi-disciplinary activities that address issues of major scientific, national, and societal importance. These priority investments include Secure and Trustworthy Cyberspace (SaTC); AI-related research; and fundamental research in data science and engineering.

At the FY 2021 Request level, SBE will continue to support foundational research in the Big Ideas including FW-HTF, URoL, HDR, and NNA.

The FW-HTF Big Idea will engage research communities to explain how constantly evolving technologies are changing the world of work and the lives of workers, and how people can in turn shape those technologies to human benefit. SBE's existing disciplinary and interdisciplinary programs support basic research that comprises the intellectual underpinnings for FW-HTF, including the opportunities and constraints of human capability, AI, machine learning, information processing, decision-making, human adaptation to technology, responsible and ethical use of data, the effect of technological change on the workforce, and the development of industries of the future. SBE research in this domain supports efforts to improve lifelong learning and to integrate human values and social dynamics into the algorithms and technologies that are transforming modern life. SBE is partnering with CISE, ENG, OIA, and EHR on this Big Idea.

The URoL Big Idea includes foundational SBE research on topics such as human genetic variation; the emergence of phenotype from gene-environment interactions; the human microbiome and its co-evolution with its human hosts; and the ethical and social implications and societal acceptance of new scientific technologies, such as tools for genetic engineering and synthetic biology. All NSF Directorates, OIA, and OISE participate in URoL.

Support for the HDR Big Idea includes SBE foundational research on machine learning, data analytics, computational simulations, technologies, human networks, and statistical methodologies. Understanding human dynamics is also critical in the area of cybersecurity and cyberinfrastructure. HDR encompasses a wide range of data-centered activities and SBE actively collaborates with CISE on many projects in this domain, such as the Partnership for Artificial Intelligence. More generally, SBE partners with CISE, EHR, MPS, ENG, and other directorates to build the knowledge required to convert unprecedented changes in computing power into transformative practices and usable technologies that can improve quality of life for all.

The NNA Big Idea seeks to advance understanding and explanation of the rapid and complex environmental and social changes in the Arctic region and to provide the tools and knowledge that will enable resilience in this important part of the world. Changes in the Arctic provide new opportunities for commerce and new challenges for people and communities in the region. SBE's partnership with other NSF directorates can help Americans more effectively understand and adapt to this new world. Specifically, SBE sciences are critical in understanding the opportunities, challenges, and adaptive capacities of individuals who, and communities that, will be affected by ongoing Arctic change.

In addition to its support of the NSF Big Ideas, SBE's FY 2021 Request continues its commitment to broad and dynamic partnerships across the Foundation that address fundamental scientific questions with broad public impact. These partnership programs include BRAIN, NSF I-Corps™, SaTC, and Smart and Connected Communities. Understanding the human element is essential to safety, security, growth, and well-being. SBE is committed to supporting the science that will help America's innovators improve quality of life for all its citizens.

SBE will continue in FY 2021 to support the next generation of scholars poised to produce transformative and societally beneficial science. SBE provides support for early career investigators (CAREER); undergraduates (Research Experiences for Undergraduates); graduate students (Doctoral Dissertation Research Improvement Grants); and post-doctoral researchers (SBE Postdoctoral Research Fellowships (SPRF)).

Finally, SBE's FY 2021 Request includes continued support for NCSES. Consistent with the President's Management Agenda, SBE support will help NCSES modernize systems and data tools, including projects that will address requirements of the Foundations for Evidence-Based Policymaking Act of 2018, P.L. 115-435[1] (Evidence Act). SBE is also committed to supporting NSF's transition to meeting other requirements associated with the Evidence Act, including having NCSES' Division Director serve as the Foundation's Statistical Official.

Major Investments

SBE Major Investments

(Dollars in Millions)

Area of Investment [1,2]	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
Artificial Intelligence	$12.25	-	$20.44	$8.19	66.9%
BRAIN Initiative	7.30	-	5.00	-2.30	-31.5%
NSF I-Corps™	0.50	-	0.47	-0.03	-6.0%
NCSES	54.23	-	52.11	-2.12	-3.9%
SaTC	4.00	-	3.80	-0.20	-5.0%
Strengthening American Infrastructure	-	-	6.00	6.00	N/A

[1] Major investments may have funding overlap and thus should not be summed.

[2] This table reflects this directorate's support for selected areas of investment. In other directorate narratives, areas of investment displayed in this table may differ and thus should not be summed across narratives.

- AI: SBE will increase support for AI research in FY 2021. Key areas of investment include such activities as advancing machine learning (ML); developing natural language processing models; integrating ML advances using big data with learning mechanisms developed in cognitive science; developing new statistical inferences and algorithms for the analysis of large data sets; and understanding the ethical, legal and societal implications (ELSI) of AI. SBE's AI investment includes support for National AI Research and Development Institutes as well as other AI-related research as defined by the Networking and Information Technology R&D (NITRD) report published annually with

[1] www.congress.gov/115/plaws/publ435/PLAW-115publ435.pdf

the President's Budget.

- BRAIN: SBE will continue support of research advancing an integrative and comprehensive understanding of the brain and its function in context and in action. Investments will support cognitive science, augmented intelligence, and neuroscience as well as new research at the interface of computational and engineering science, cognitive science, and education research. Specific investments include Integrative Strategies for Understanding Neural and Cognitive Systems and Collaborative Research in Computational Neuroscience, which is an activity in partnership with the National Institutes of Health, BIO, CISE, ENG, MPS, OISE, and several international research funding agencies.
- I-Corps™: In FY 2021, SBE will support this multiyear effort to strengthen collaboration between SBE scientists in academia and the technological, entrepreneurial, and business communities and practitioners. SBE supports researchers in developing, implementing, and improving processes by which innovators can bring scientific advances to market and help scientists more effectively benefit the public.
- SaTC: SBE will sustain its investment in SaTC to support foundational research on human beings that can improve and strengthen efforts to increase cybersecurity. SBE research can contribute to society's attempts to build infrastructure that facilitates innovation at the same time that it protects individuals, families, communities, and a full array of private and public sector institutions.
- Strengthening American Infrastructure: In FY 2021, SBE will support an investment that links experts on physical, computational, and material aspects of infrastructure design with scientists whose fundamental research explains how humans will—and will not—use infrastructure that we build. This approach to infrastructure is a critical component to building better, smarter, and more cost-effective roads, electric grids, and hospitals. Improving infrastructure in these ways can spur private-sector innovation, grow the economy, and is essential to national competitiveness.

Funding Profile

SBE Funding Profile

	FY 2019 Actual Estimate	FY 2020 (TBD)	FY 2021 Estimate
Statistics for Competitive Awards:			
Number of Proposals	3,733	-	3,700
Number of New Awards	871	-	800
Funding Rate	23%	N/A	22%
Statistics for Research Grants:			
Number of Research Grant Proposals	2,651	-	2,700
Number of Research Grants	545	-	500
Funding Rate	21%	N/A	19%
Median Annualized Award Size	$128,375	-	$128,400
Average Annualized Award Size	$153,798	-	$153,800
Average Award Duration, in years	2.9	-	2.9

SBE supports investment in core research and education activities as well as research infrastructure.

Program Monitoring and Evaluation

External Program Evaluations and Studies

- In FY 2020, NCSES is sponsoring a study with the National Academy of Sciences Committee on National Statistics related to transparency and reproducibility. NCSES hopes to use the outcome of this study to help shape the Federal Statistical System's approach to these topics in the future.

- Over FY 2020, NCSES is sponsoring and leading a study to inform the development of a virtual Research Data Center (RDC) for the Federal Statistical RDC system that can be used to inform the decision making of the Interagency Council on Statistical Policy. This study brings together various participants from different federal agencies and academia to NSF to link different data sets and provide training on those linked data sets—while building capacity for researchers and analysts inside and outside the Federal Statistical System.

Workshops and Reports

- In FY 2019, SBE's Science of Science and Innovation Policy Program partnered with the Department of Defense to co-sponsor a National Academies of Science, Engineering, and Medicine (the National Academies) study, Science and Innovation Leadership for the 21st Century: Challenges and Strategic Implications for the United States. The National Academies ad hoc committee will explore the implications of the loss of U.S. economic capability and leadership relative to other countries on issues such as national security, unemployment or underemployment of the U.S. workforce, and international development and global stability. Its consensus report will provide findings and recommendations for research and federal government actions to address these challenges.
- In FY 2019, NCSES hosted a workshop for staff on key components of the Evidence Act relevant to NCSES and NSF. Workshop attendees explored NCSES' alignment with the Evidence Act, the Federal Data Strategy,[2] and current information quality guidelines for statistical agencies. Breakout sessions provided a forum for NCSES staff and others in attendance to engage in more detailed and specific brainstorming around planning efforts, tactics, best practices, and lessons learned.
- In FY 2019, NCSES led a federal government workshop—as part of a community of practice—on R&D. The goal of the workshop was to engage this community on the definitions and different ways in which R&D is measured across NCSES surveys and publications.
- In FY 2020, SBE is funding an expert meeting to provide insight on the primary data science needs for SBE disciplines conducted by the National Academies. The meeting will serve to guide growth of the Human Networks and Data Science program within the BCS Division.
- In FY 2020, NCSES released the Summary Report for *Science and Engineering Indicators*, meeting its Congressional mandate. This biennial report to Congress provides a broad base of quantitative information about U.S. science, engineering, and technology.
- In FY 2020, NCSES released *Doctorate Recipients from U.S. Universities*.[3] This annual report provides the major trends in doctoral education, organized into themes highlighting important questions about doctorate recipients.
- SES-Supported Workshops:
    - "Knowledge Convergence and Divergence in Team Performance." During 2019-2021, this team science project will evaluate the pros and cons of convergence science in the context of the SaTC Socio-Technical Interdisciplinary Collaborations program. Interviews and surveys of the approximately 100 teams that were funded starting in 2013 will be conducted, measuring the success of these teams using such indicators as publications, future awards, and co-publication.
    - "Human Technology Partnerships and the Changing Nature of Work." In the spring of 2020 in Evanston, IL, this workshop will help determine a research agenda to integrate the sciences of human organizing, technologies, and data science to meet challenges at the human-artificial intelligence interfaces in workplace contexts.
    - "NBER Summer Institute 2020." The National Bureau of Economic Research presents sessions that outline new economic research, identify upcoming challenges for government and other programs, and report on evaluations of government programs in contexts ranging from aging; asset pricing;

[2] https://strategy.data.gov/
[3] https://ncses.nsf.gov/pubs/nsf20301/

big data and high-performance computing for financial economics; capital markets; children; corporate finance; crime; development of the American economy; economic growth; environment and energy; health care and health economics; household finance; labor studies; national security; productivity, development, and entrepreneurship; real estate; and risks of financial institutions.
- "SBE's Major Surveys." In 2020, the fourth in the series of meetings will take place that will focus on advances and challenges facing the collection of social, behavioral, and economic data from U.S. residents. In 2019, the meeting focused on data and respondent privacy, opportunities for collaborations across independent surveys, mode issues and opportunities for survey data collection (web, video interviews, etc.), interactions with stakeholders and data users, and increasing and addressing diversity among survey respondents.

Committees of Visitors (COV)
- In 2019, a COV assessed the BCS Division's merit review process and presented their report to the SBE Advisory Committee in December 2019. The COV concluded that, "Program management, assessment processes, and stewardship of funds were effective and professional." Based on feedback and recommendations from the COV concerning additional feedback to reviewers; the Division is evaluating best practices for helping researchers improve their proposals. In addition, and more broadly in response to other COV inputs, BCS is reviewing emerging areas of research, strategies for open science, and ways to optimize communication with both the research community and the general public.
- In FY 2020, a COV will review SES and SMA. Final results from the COV assessment are expected in FY 2020, with a formal presentation to the SBE AC in its fall 2020 meeting. Results of the 2020 COV, combined with the 2019 BCS COV assessment, will be used to inform the SBE Directorate's consideration and review of merit review practices.

The Performance and Management chapter provides details regarding the periodic reviews of programs and portfolios of programs by external Committees of Visitors and directorate Advisory Committees. Please see this chapter for additional information.

People Involved in SBE Activities

Number of People Involved in SBE Activities

	FY 2019 Actual Estimate	FY 2020 (TBD)	FY 2021 Estimate
Senior Researchers	1,713	-	1,560
Other Professionals	332	-	300
Postdoctoral Associates	197	-	180
Graduate Students	1,478	-	1,350
Undergraduate Students	1,137	-	1,030
Total Number of People	**4,857**	**-**	**4,420**

DIVISION OF BEHAVIORAL AND COGNITIVE SCIENCES (BCS) **$85,140,000**
-$9,210,000 / -9.8%

BCS Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$94.35**	**-**	**$85.14**	**-$9.21**	**-9.8%**
Research	**91.14**	**-**	**81.78**	**-9.36**	**-10.3%**
Education	**1.63**	**-**	**0.42**	**-1.21**	**-74.2%**
Infrastructure	**1.59**	**-**	**2.94**	**1.35**	**85.4%**
Research Resources	1.59	-	2.94	1.35	85.4%

About BCS

BCS supports research that provides information, empirical data, and scientific theory that inform the understanding of pressing national issues. BCS-supported research addresses how thought and behavior respond to changing situations, environmental characteristics, and cultural differences, providing critical bases for improving disaster response and supporting key aspects of improved security and preparedness. In addition, BCS-funded activities help to understand the potential sources of bias in human interaction and examine how to improve technology performance in the context of interacting with humans.

BCS supports fundamental research that examines the sources of the human condition, the character of thinking and behavior. The programs examine these issues at multiple levels of analysis, ranging from genetics and brain activity to social, cultural, and environmental contexts. Core analyses of human language, perception, and cognition are critical to understanding human behavior and to the development of advanced technologies that support human functioning. BCS-supported research is essential to understanding and developing new approaches to learning, decision making, and problem solving for individuals and groups. For example, through its Science of Learning and Augmented Intelligence program, BCS research explores how new technologies, especially artificial intelligence, can enhance human cognition and productivity.

BCS manages infrastructure-related activities in Human Networks and Data Science, which seek to advance relevant analytical techniques and develop user-friendly, large-scale, next-generation data resources to improve quality of life for all Americans. These activities are complemented by active involvement in funding competitions and development of partnerships that support collaborative and cross-disciplinary projects that increase understanding of the human brain, mind, and behavior.

In general, about 80 percent of the BCS portfolio is available to support new research grants. The remaining 20 percent supports research grants made in prior years and the research infrastructure needed by this community.

DIVISION OF SOCIAL AND ECONOMIC SCIENCES (SES) **$86,660,000**
-$9,770,000 / -10.1%

SES Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$96.43**	**-**	**$86.66**	**-$9.77**	**-10.1%**
Research	**89.37**	**-**	**81.24**	**-8.13**	**-9.1%**
Education	**0.89**	**-**	**0.38**	**-0.51**	**-57.3%**
Infrastructure	**6.17**	**-**	**5.04**	**-1.13**	**-18.3%**
NNCI	0.40	-	-	-0.40	-100.0%
Research Resources	5.77	-	5.04	-0.73	-12.7%

About SES

SES supports foundational research and related programs that improve the delivery of essential goods and services across the country. These programs improve understanding of how individuals and organizations behave within a range of economic and social contexts; advance risk assessment and strategic planning in various areas of society; provide insights into social effects of disruptive technologies—providing the basic ideas that help individuals, communities, governments, and business adapt more effectively. In addition, SES-supported research helps develop more robust and trustworthy ways of conveying critical information to enhance understanding of complex systems that are the foundation of the Nation's security and preparedness imperatives. SES coordinates the Ethical and Responsible Research program, supporting, along with other NSF directorates, the Online Ethics Center for Engineering and Science. SES research helps to clarify how organizations of all kinds can be more effective in increasingly competitive marketplaces and how individuals can find new opportunities to participate in America's evolving workforce. This research has the potential to help to grow the economy, secure the homeland, improve the health and safety of American families, and increase the competitiveness of America's farms, offices, and factories.

SES supports widely used data infrastructure such as the Panel Study of Income Dynamics, the American National Election Studies, and the General Social Survey. These surveys are national resources for research and teaching and have become models for data collections in other fields.

In general, about 78 percent of the SES portfolio is available to support new research grants. The remaining 22 percent supports research grants made in prior years and the research infrastructure needed by this community.

NATIONAL CENTER FOR SCIENCE AND ENGINEERING STATISTICS (NCSES) **$52,110,000**
-$2,120,000 / -3.9%

NCSES Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual: Amount	Change over FY 2019 Actual: Percent
Total	**$54.23**	**-**	**$52.11**	**-$2.12**	**-3.9%**
Education	**0.10**	**-**	**-**	**-0.10**	**-100.0%**
Infrastructure	**54.13**	**-**	**52.11**	**-2.02**	**-3.7%**

About NCSES

NCSES is one of the federal government's thirteen principal statistical agencies with a mission to provide statistics and analysis regarding the S&E enterprise. NCSES provides policymakers, researchers, and the public high-quality data and analysis on R&D, innovation, the education of scientists and engineers, and the S&E workforce. NCSES also supports research; the education and training of researchers; statistical methodology and data quality improvement efforts; and information compilation and dissemination to meet the statistical and analytical needs of a diverse user community.

The agency was originally created within NSF in 1950 as the Division of Science Resources Statistics. In 2010, the agency's mandate was expanded and it was renamed as NCSES by Section 505 of the America COMPETES Reauthorization Act of 2010 (P.L. 111-358). The Act mandates that NCSES collect data on R&D trends, the science and engineering workforce, U.S. competitiveness, and the condition and progress of the Nation's STEM education. This includes the preparation of two congressionally mandated biennial reports—*Science and Engineering Indicators*; and *Women, Minorities, and Persons with Disabilities in Science and Engineering*.

The FY 2021 Request supports NCSES's core data collection and analytic activities, including nationally representative surveys of U.S. investment in R&D across all sectors of the economy, the education of scientists and engineers, and the science and engineering workforce. This also includes preparation of the aforementioned *Science and Engineering Indicators*; and *Women, Minorities, and Persons with Disabilities in Science and Engineering*. In FY 2021, NCSES will continue with initiatives related to

- studying the Skilled Technical Workforce (STW)—with emphasis on the STW's current and potential future relevance to industries of the future such as, but not limited to AI, the bioeconomy, and future manufacturing;
- using of administrative and organic data to inform efforts to increase government effectiveness and efficiency through increased data integration; and
- maintaining systems and data collection efforts for modern federal statistics.

SBE OFFICE OF MULTIDISCIPLINARY ACTIVITIES (SMA) $22,930,000
-$3,230,000 / -12.3%

SMA Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$26.16**	**-**	**$22.93**	**-$3.23**	**-12.3%**
Research	**18.28**	**-**	**17.31**	**-0.97**	**-5.3%**
Education	**6.42**	**-**	**5.62**	**-0.80**	**-12.5%**
Infrastructure	**1.46**	**-**	**-**	**-1.46**	**-100.0%**
Research Resources	1.46	-	-	-1.46	-100.0%

About SMA

SMA provides a focal point for the wide range of activities that cut across SBE and NSF disciplinary boundaries. SMA supports research that seeks to improve the effectiveness of the scientific workforce. It also supports Research Experiences for Undergraduates Sites, the Science of Science: Discovery, Communication, and Impact (SoS:DCI) program, and the SPRF program. SMA will play a major role in several crosscutting NSF investments in FY 2021: innovation, via I-Corps™; and interdisciplinary research and training, via activities such as the SPRF-Fundamental Research and Broadening Participation tracks. In addition, SMA's SoS:DCI program is designed to increase the public value of scientific activity. While all SBE divisions pursue interdisciplinary work, SMA assists with seeding multidisciplinary activities for the future, such as leveraged and targeted co-funding directed towards national, NSF, and directorate priorities.

In general, about 62 percent of the SMA portfolio is available to support new research grants. The remaining 38 percent supports research grants made in prior years.

OFFICE OF INTERNATIONAL SCIENCE AND ENGINEERING (OISE) **$44,010,000**
-$4,990,000 / -10.2%

OISE Funding
(Dollars in Millions)

FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
$49.00	**-**	**$44.01**	**-$4.99**	**-10.2%**

About OISE

OISE is the focal point for NSF's international science and engineering activities. OISE's mission is to promote an integrated, Foundation-wide international engagement strategy and manage internationally-focused programs that are innovative and catalytic. OISE focuses on international activities to identify research opportunities for U.S. researchers through access to international knowledge, infrastructure, and capabilities. OISE's FY 2021 Request supports this by focusing on three activities: (1) promoting the development of a globally engaged U.S. workforce, (2) facilitating and supporting international partnerships, and (3) providing opportunities for U.S. leadership to shape the global science and engineering agenda.

In FY 2021, OISE will continue its support for the Accelerating Research through International Networks (AccelNet) program. The goals of AccelNet are to accelerate the process of scientific discovery and prepare the next generation of U.S. researchers for multi-team international collaborations. AccelNet supports strategic linkages among U.S. research networks and complementary networks abroad (i.e., network of networks) to leverage research and educational resources to tackle grand scientific challenges that require significant coordinated international efforts. The program seeks to foster high-impact science and engineering by providing opportunities to create new collaborations and new combinations of resources and ideas among linked global networks. In FY 2021, AccelNet will continue to focus on NSF-priority investment areas. Each AccelNet award will build a network of networks across international and interdisciplinary boundaries. AccelNet will provide the funding to connect U.S. research networks with their international counterpart networks. These efforts will ensure the United States has access to the best ideas, people, and facilities, wherever they may be.

In FY 2021, OISE will continue to provide opportunities for STEM undergraduate and graduate students through the International Research Experiences for Students (IRES) program. IRES supports the development of a diverse, globally-engaged U.S. science and engineering workforce and the active engagement of U.S. students in international research in all disciplines funded by NSF. Given the increasingly global nature of science and engineering, the long-term goal of IRES is to enhance U.S. leadership by developing the next generation of STEM leaders. In FY 2021, IRES will continue to include three tracks:

- Track I focuses on the development of world-class research skills in international cohort experiences for U.S. undergraduate and graduate students.
- Track II is dedicated to targeted, intensive learning and training opportunities for U.S. graduate students that leverage international knowledge at the frontiers of research.
- Track III supports U.S. institutional partnerships to develop and evaluate innovative models for high-impact, large-scale international research and professional development experiences for U.S. graduate students, as individuals or groups.

IRES also plans to integrate insights from an external evaluation of Track I, due to OISE at the end of FY 2020, in the FY 2021 competition. An IRES student registration portal will facilitate tracking of long-term outcomes of the program.

In FY 2021, OISE will continue to execute MULTIPlying Impact Leveraging International Expertise in Research (MULTIPLIER) expeditions with emphasis placed on NSF priority topics and those identified in the annual Office of Management and Budget and Office of Science and Technology Policy memo on research and development budget priorities. MULTIPLIER expeditions focus on fields of science and engineering where researchers outside of the U.S. are making significant developments and have the potential to benefit American prosperity, security, health, and well-being. MULTIPLIER expands NSF's commitment to international outreach by:

- Identifying emerging scientific research areas worldwide through a collaborative analytical approach;
- Providing subject matter experts and international specialists to assess international capabilities and develop diplomatic connections that may benefit the United States;
- Organizing short-term missions for information gathering, ground truthing and network building; and
- Preparing analysis on country—and discipline—specific insights, as well as reports and presentations.

In FY 2021, OISE will relaunch the Partnerships in International Research and Education (PIRE) program, adopting an updated approach that emphasizes coordination with NSF research and education directorates. PIRE seeks to catalyze a higher level of international engagement in the U.S. science and engineering community to enable sustained research excellence. PIRE supports high quality research and education that cannot occur without international collaboration.

OISE will continue to co-fund with NSF directorates meritorious proposals that include international collaboration through its Global Venture Fund. OISE will provide support to assure that U.S. researchers contribute to, and benefit from, complementary efforts around the globe.

In FY 2021, OISE will contribute to the NNA and QL NSF Big Ideas.

- OISE will continue supporting NNA at a level of $1.0 million, which will support research that builds on and extends existing observing networks and scientific knowledge as well as logistics expertise to address the convergent scientific challenges in the changing Arctic. Interagency, state government, and international partnerships will be further developed to achieve pan-Arctic and Arctic-global perspectives.
- OISE will invest $1.0 million in QL. The QL Big Idea will continue to build upon and extend the existing knowledge of the quantum world, fostering breakthroughs in the fundamental understanding of quantum phenomena and enabling the exploitation of these phenomena to disrupt the Nation's science and engineering landscape. These advances will unleash the potential of the Nation's quantum-based scientific enterprise, economy, and security.

Funding Profile

OISE Funding Profile

	FY 2019 Actual Estimate	FY 2020 (TBD)	FY 2021 Estimate
Statistics for Competitive Awards:			
Number of Proposals	417	-	475
Number of New Awards	59	-	50
Funding Rate	14%	N/A	11%
Statistics for Research Grants:			
Number of Research Grant Proposals	413	-	450
Number of Research Grants	55	-	45
Funding Rate	13%	N/A	10%
Median Annualized Award Size	$101,293	-	$101,000
Average Annualized Award Size	$177,216	-	$250,000
Average Award Duration, in years	3.1	-	3.3

In FY 2021, OISE expects the number of research grant proposals to increase as a result of re-launch of the PIRE program to accompany the already-heavily subscribed IRES and AccelNet programs. In general, about 47 percent of the OISE portfolio is available to support new research grants, and 53 percent is available for continuing grants.

Program Monitoring and Evaluation

External Program Evaluations and Studies

- An evaluation of the IRES program began in September 2018 and will produce deliverables at various stages of the evaluation. The evaluation is expected to be completed in FY 2020. The evaluation will review educational and career trajectories of principal investigators and students and the extent of their international engagement as a result of participating in the program.
- In FY 2020, OISE will initiate an assessment of MULTIPLIER, which will focus on three years of activity to determine the effectiveness of the MULTIPLIERs as a permanent mechanism for international engagement.

Committees of Visitors (COV)

- In FY 2019, no COV of OISE programs was held a COV.
- In FY 2022, a COV will review OISE's programs and activities.

The Performance and Management chapter provides details regarding the periodic reviews of programs and portfolios of programs by external Committees of Visitors and directorate Advisory Committees. Please see this chapter for additional information.

People Involved in OISE Activities

Number of People Involved in OISE Activities

	FY 2019 Actual Estimate	FY 2020 (TBD)	FY 2021 Estimate
Senior Researchers	391	-	350
Other Professionals	49	-	40
Postdoctoral Associates	32	-	30
Graduate Students	145	-	130
Undergraduate Students	34	-	30
Total Number of People	**651**	**-**	**580**

OFFICE OF POLAR PROGRAMS (OPP) $419,780,000

-$68,900,000 / -14.1%

OPP Funding

(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Research	**$123.09**	**-**	**$101.32**	**-$21.77**	**-17.7%**
Long Term Ecological Research (LTER)	3.41	-	3.38	-0.03	-0.9%
Education	**2.14**	**-**	**0.72**	**-1.42**	**-66.4%**
Infrastructure	**363.45**	**-**	**317.74**	**-45.71**	**-12.6%**
Arctic Research Support and Logistics	50.15	-	40.50	-9.65	-19.2%
IceCube Neutrino Observatory (ICNO)	3.51	-	3.50	-0.01	-0.3%
U.S. Antarctic Facilities and Operations[1]	210.94	-	190.14	-20.80	-9.9%
U.S. Antarctic Logistical Support	81.30	-	71.00	-10.30	-12.7%
Geodetic Facility for the Advancement of Geoscience (GAGE)	1.10	-	0.70	-0.40	-36.5%
Seismological Facility for the Advancement of Geoscience (SAGE)	1.61	-	1.00	-0.61	-38.0%
Research Resources	7.95	-	4.04	-3.91	-49.2%
Polar Environment, Safety, and Health (PESH)	6.88	-	6.86	-0.02	-0.2%
Total	**$488.68**	**-**	**$419.78**	**-$68.90**	**-14.1%**

[1] FY 2019 Actual includes additional funding to replace the aging pier at Palmer Station and to replace or refurbish other equipment and facilities.

About OPP

OPP invests in polar scientific research and education as well as provides research support and logistics including infrastructure, such as permanent stations and temporary field camps, in the Antarctic and the Arctic. OPP's FY 2021 Request is influenced by three key priorities: (1) maintaining strong disciplinary programs that provide the basis for investments in cross-disciplinary system science programs; (2) supporting critical facilities that enable research in the Earth's polar regions; and (3) supporting the construction phase of the Antarctic Infrastructure Modernization for Science (AIMS) project which was awarded to Leidos Corporation in May 2019. These priorities reflect opportunities for fundamental scientific discovery uniquely accessible in polar regions, as well as studies to investigate the causes and future trajectory of environmental, biological, and human system changes now being observed in the polar regions that have possible global implications.

OPP is the primary U.S. supporter of fundamental research in the polar regions. In the Arctic, NSF helps coordinate research planning as directed by the Arctic Research Policy Act of 1984, and the NSF Director chairs the Interagency Arctic Research Policy Committee (IARPC) created for this purpose. In the Antarctic, per Presidential Memorandum 6646, NSF manages all U.S. activities as a single, integrated program, making Antarctic research possible for scientists supported by NSF and by other U.S. agencies. The latter include the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), the U.S. Geological Survey (USGS), the Smithsonian Institution, the Department of Energy, and the National Institute of Standards and Technology (NIST). The U.S. Antarctic Program (USAP) research activity supported by NSF also supports leadership by the U.S. Department of State in the governance of the continent and Southern Ocean under the aegis of the Antarctic Treaty System.

In addition to shared cross-directorate basic research objectives, OPP investments will be guided by recent sponsored studies to identify priority areas and ensure effective polar research programs:

- For the Arctic, IARPC's Arctic Research Plan: FY 2017-2021,[1] and the World Meteorological Organization's Year of Polar Prediction Implementation Plan[2] inform science investment priorities. Efforts to build an integrated research capacity to address the potential opportunities and challenges of Arctic change for the Nation's security and economics and well-being of Arctic residents will continue.
- For the Antarctic, the 2015 National Research Council report *A Strategic Vision for NSF Investments in Antarctic and Southern Ocean Research*[3] informs science investment priorities. Specifically, in 2018, OPP initiated support of a five-year deep-field program to study the Thwaites Glacier region that was the highest priority in that study. The Thwaites program is jointly supported, including shared logistics, with the National Environment Research Council of the U.K. The first field work will be accomplished in the 2019-20 austral summer season.

Major Investments

- In FY 2021, OPP research funding is $101.32 million. To accommodate its core research priorities, OPP will continue to leverage interagency and international partnerships.
- Arctic programs will continue to focus on integrating sustained observations, process studies, theory, and modeling of the natural and social systems to understand and improve predictions of the changing Arctic and its role in the Earth system. This has, in prior years and will in FY 2021, include investments in polar cyberinfrastructure, data analytics, and software. A major FY 2019 investment was made in the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC),[4] an international study of the formation and melt of sea-ice in the central Arctic Ocean with a year-round field presence that extends into FY 2020. NSF will continue to invest in this effort as the project transitions from field work to analysis of the data generated by the observations. Arctic programs will continue to invest in the Navigating the New Arctic NSF-wide Big Idea that will support research needed to inform the economy, security, and resilience of the Nation, the larger region, and the globe in the face of a rapidly changing Arctic.
- Antarctic science will maintain funding in priority areas as outlined in the 2015 National Academies report and the NSF's WoU and URoL Big Ideas. In particular, Antarctic programs will begin upgrades to the IceCube Neutrino Observatory (ICNO) at the South Pole. OPP will continue to support three LTER projects: two in the Antarctic and one in the Arctic at $3.38 million.
- Arctic research support and logistics are funded at $40.50 million while U.S. Antarctic Logistical Support will be funded at $71.0 million. This will support existing commitments for field work in the Arctic and the Antarctic.
- Education activities across OPP will be through Improving Undergraduate STEM Education (IUSE) and Research Experiences for Undergraduates (REU) Supplements.
- In FY 2021, Antarctic Facilities and Operations funding is $190.14 million. This will accommodate the science supported by McMurdo Station for the third year of two major multiyear field science projects: the International Thwaites Glacier Collaboration[5] and the Subglacial Antarctic Lakes Scientific Access project (SALSA).[6]
- FY 2021 will be the third year of the AIMS project's construction phase, which addresses major recommendations of the 2012 Blue Ribbon Panel study, *More and Better Science in Antarctica through*

[1] www.iarpccollaborations.org/uploads/cms/documents/iarpc_arctic_research_plan_2017-2021.pdf

[2] www.polarprediction.net/fileadmin/user_upload/www.polarprediction.net/Home/YOPP/YOPP_Documents/FINAL_WWRP_PPP_YOPP_Plan_28_July_2016_web-1.pdf

[3] www.nap.edu/catalog/21741/a-strategic-vision-for-nsf-investments-in-antarctic-and-southern-ocean-research

[4] www.mosaic-expedition.org/

[5] https://thwaitesglacier.org/

[6] https://salsa-antarctica.org/

Increased Logistical Effectiveness.[7] AIMS focuses on modernizing McMurdo Station, the major NSF Antarctic logistics hub, and thereby ensures continued cross-discipline access to the continent for the U.S. science community. OPP will support a major ramp-up in the construction tempo of the AIMS project. AIMS commenced in 2019 as a MREFC project to be completed within 10 years from its award.

OPP Funding for Facilities

OPP Funding for Major Multi-User Facilities

(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$217.17**	**-**	**$195.34**	**-$21.83**	**-10.1%**
IceCube Neutrino Observatory (ICNO)	3.51	-	3.50	-0.01	-0.3%
U.S. Antarctic Facilities and Operations[1]	210.94	-	190.14	-20.80	-9.9%
Geodetic Facility for the Advancement of Geoscience (GAGE)	1.10	-	0.70	-0.40	-36.5%
Seismological Facility for the Advancement of Geoscience (SAGE)	1.61	-	1.00	-0.61	-38.0%

[1] FY 2019 Actual includes additional funding to replace the aging pier at Palmer Station and to replace or refurbish other equipment and facilities.

For detailed information on individual facilities, please see the Facilities and the Major Research Equipment and Facilities Construction chapters.

Funding Profile

OPP Funding Profile

	FY 2019 Actual Estimate	FY 2020 (TBD)	FY 2021 Estimate
Statistics for Competitive Awards:			
Number of Proposals	459	-	500
Number of New Awards	171	-	150
Funding Rate	37%	N/A	30%
Statistics for Research Grants:			
Number of Research Grant Proposals	448	-	450
Number of Research Grants	162	-	130
Funding Rate	36%	N/A	29%
Median Annualized Award Size	$187,785	-	$187,800
Average Annualized Award Size	$292,827	-	$292,800
Average Award Duration, in years	2.7	-	2.6

In general, about 20 percent of the OPP portfolio is available for new research grants. In FY 2021, the number of research grant proposals is not expected to change significantly compared to the FY 2019 Actual and OPP expects to award about 130 research grants.

[7] www.nsf.gov/geo/opp/usap_special_review/usap_brp/rpt/index.jsp

Program Monitoring and Evaluation

Science and Technology Policy Institute (STPI) Reports

- STPI performed its annual Survey Analysis of the United States Antarctic Program Logistical Support Services for the 2018–19 Field Season report.

Committees of Visitors (COV) and Advisory Committee (AC)

- In 2020, COVs will review both the Antarctic and Arctic programs.
- The OPP AC meets twice annually, in the fall and spring. It recently published*: An Overview of Advisory Studies for the Office of Polar Programs,* 2019.[8]

The Performance and Management chapter provides details regarding the periodic reviews of programs and portfolios of programs by external Committees of Visitors and directorate Advisory Committees. Please see this chapter for additional information.

People Involved in OPP Activities

Number of People Involved in OPP Activities

	FY 2019 Actual Estimate	FY 2020 (TBD)	FY 2021 Estimate
Senior Researchers	786	-	600
Other Professionals	418	-	300
Postdoctoral Associates	120	-	100
Graduate Students	302	-	200
Undergraduate Students	271	-	200
Total Number of People	**1,897**	**-**	**1,400**

[8] www.nsf.gov/geo/opp/opp_advisory/OPP_AC_Report2019.pdf

INTEGRATIVE ACTIVITIES (IA) **$538,730,000**
-$8,590,000 / -1.6%

IA Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
NSF Convergence Accelerator[1]	$41.39	-	$70.00	$28.61	69.1%
EPSCoR[2]	175.67	-	163.67	-12.00	-6.8%
CAREER	0.36	-	-	-0.36	-100.0%
Evaluation and Assessment Capability	3.00	-	3.00	-	-
Facility Operations Transition	-	-	10.00	10.00	N/A
Graduate Research Fellowship Program	142.29	-	137.64	-4.65	-3.3%
Growing Convergence Research	15.80	-	15.20	-0.60	-3.8%
HBCU Excellence in Research	15.20	-	9.50	-5.70	-37.5%
Major Research Instrumentation	75.11	-	61.70	-13.41	-17.9%
Mid-scale Research Infrastructure	60.04	-	32.67	-27.37	-45.6%
NSF 2026	6.01	-	-	-6.01	-100.0%
Planning and Policy Support[1]	3.73	-	2.00	-1.73	-46.4%
Research Experiences for Undergraduates	0.14	-	-	-0.14	-100.0%
Research Investment Communications	3.47	-	3.30	-0.17	-4.9%
STC Class of 2021	-	-	25.00	25.00	N/A
STC Admin	0.38	-	0.50	0.12	31.6%
Science & Technology Policy Institute	4.74	-	4.55	-0.19	-4.0%
Total	**$547.32**	**-**	**$538.73**	**-$8.59**	**-1.6%**

[1] NSF Convergence Accelerator funding includes support for CA Planning and Development activities, which is part of NSF's total Planning and Policy Support (PPS) budget line within NSF's Organizational Excellence activities. Total IA funding for PPS in FY 2021 is $4.0 million.

[2] No less than $20.0 million in EPSCoR Co-funding will support Mid-scale RI Track 1 awards in EPSCoR jurisdictions.

The FY 2021 Budget Request for IA is $538.73 million. This request highlights NSF's continuing emphasis on building capacity in research and research training across the United States.

About IA

The IA budget is managed by the Office of Integrative Activities (OIA), which is composed of four organizational units: NSF Convergence Accelerator (CA), Established Program to Stimulate Competitive Research (EPSCoR), Evaluation and Assessment Capability (EAC), and Integrative Activities.

IA investments catalyze transformational advances in science and technology by incubating new ideas and communities, supporting innovation in research and in NSF's own processes, and promoting the integration of research and education. They enhance the competitiveness of the Nation's research through activities that build capacity for science and engineering (S&E) and broaden participation in research and research training. They expand NSF's capability to gather and use evidence about the progress and impacts of its programs, and they nurture new cross-cutting programs, especially as S&E evolves toward more transdisciplinary, convergence-style research and education.

IA provides NSF stewardship support of two Big Ideas, Growing Convergence Research (GCR) and Mid-scale Research Infrastructure (Mid-scale RI), as well as the CA. Collectively, these activities expand NSF's capabilities to support innovative, transdisciplinary team science, advanced research infrastructure, and use-inspired research.

IA provides funding for programs designed to enhance the capacity of jurisdictions, institutions, and individuals to conduct globally competitive research. IA's jurisdictional and institutional capacity-based programs include EPSCoR, NSF's Historically Black Colleges and Universities Excellence in Research (HBCU-EiR) program, and the Major Research Instrumentation (MRI) program. The Graduate Research Fellowship Program (GRFP) and the prestigious Alan T. Waterman honorary award are two programs that grow the capacity of the U.S. research enterprise by investing in and recognizing emerging talent. IA also supports a center-scale program, Science and Technology Centers: Integrative Partnerships (STC), that promotes discovery and innovation through collaborative research and knowledge transfer.

IA FY 2021 Activities

<u>NSF Convergence Accelerator</u>
- The CA enables NSF to move ideas from discovery into practice by identifying, nurturing, and funding use-inspired convergence research in areas aligned with Administration priorities. The CA will facilitate convergence activities in areas of national importance, especially by strengthening and expanding strategic, multi-sector partnerships and prioritizing the technologies that power Industries of the Future (IotF).

<u>Established Program to Stimulate Competitive Research</u>
- EPSCoR investments assist NSF in its statutory function "to strengthen research and education in the sciences and engineering, including independent research by individuals, throughout the United States, and to avoid undue concentration of such research and education."
- EPSCoR provides strategic programs and opportunities that stimulate sustainable improvements to EPSCoR jurisdictions' R&D capacity and capability. EPSCoR aims to stimulate research that enhances jurisdictional competitiveness in NSF disciplinary and multidisciplinary research programs, especially those that drive economic growth.

<u>Evaluation and Assessment Capability</u>
- EAC promotes and supports the rigorous generation and timely use of evidence across NSF. EAC invests in enhancing data access and quality, building methodological expertise, conducting research and evaluation studies, and developing analytic tools that make useful evidence available at key decision-making moments. These strategies help foster NSF's position as an innovator and leader in evaluating and assessing investments in S&E research, education, and infrastructure to support potentially transformative research ideas and build the S&E workforce.
- EAC collaborates with internal and external partners to conduct its work. Internally, EAC works with all NSF organizational units through a steering committee that provides advice and a working group that includes NSF staff engaged with EAC projects. Externally, EAC collaborates with partners in strategic initiatives; examples include (1) an ongoing collaboration with the National Institutes of Health on using machine learning to generate evidence, and (2) participation with OMB and an interagency council to develop guidance for program evaluation in fulfillment of the Foundations for Evidence-Based Policymaking Act of 2018 (Evidence Act) section 101(e).
- In FY 2021, EAC will continue to prioritize its response to OMB guidance on the implementation of the Evidence Act. This will include participation in meetings and councils (such as the Evaluation Officers Council) and preparation of deliverables specified in OMB's guidance, including NSF's evaluation policy, interim agency-wide learning agenda, and annual evaluation plan. Studies conducted to support this work include an agency-wide capacity assessment and several evaluations listed under "External Program Evaluations and Studies."

Facility Operation Transition

- Facility Operation Transition reflects NSF's strategic commitment to a smooth transition from MREFC to O&M funding of new major facilities, as well as achievement of a balanced portfolio between facilities and investigator research, both of which were emphasized in the NSB's Congressionally requested 2019 report entitled "Study of Operations and Maintenance Costs for NSF Facilities" (NSB-2018-17).[1] The Facility Operation Transition funding will be used to (1) partially support initial O&M of new facilities so that the full O&M costs can be gradually absorbed into the managing division or directorate, and (2) partially support divestment of lower-priority facilities, the full cost of which may significantly impact individual division or directorate funding.

Graduate Research Fellowship Program

- GRFP supports training tomorrow's leaders in the research community and contributes to building a diverse, highly skilled U.S. workforce. Funding for GRFP is split equally between IA and EHR. NSF's FY 2021 GRFP funding will support 1,600 new fellows. The program will continue to align awards with Administration priorities, including artificial intelligence, quantum information science, and other areas within the Administration's Industries of the Future initiative. Information on recent evaluations of GRFP may be found in the Graduate STEM Education narrative in the NSF-Wide Investments chapter.

Growing Convergence Research

- GCR, as an "enabling" Idea within NSF's Big Ideas, supports basic research that uses novel, transdisciplinary approaches to solve complex problems. The unifying characteristics of these undertakings are that: (1) they have the potential to make a significant impact, either on fundamental understanding in S&E or on the Nation's ability to meet pressing societal challenges, or both; and (2) they require the integration of knowledge, tools, and ways of thinking from multiple disciplines. GCR also aims to grow the next generation of convergence researchers. In FY 2021, GCR investments will support six to eight new exploratory research collaborations and the continuation of six to eight projects begun in FY 2019. For more information about GCR, see the narrative in the NSF-Wide Investments chapter.

Historically Black Colleges and Universities – Excellence in Research

- The HBCU-EiR program focuses on improving the research capacity and competitiveness of HBCUs by supporting new research opportunities at these institutions. IA will fund approximately 15 to 30 HBCU-EiR research grants managed by NSF's S&E directorates. A new solicitation will encourage new investigators and support projects with budgets similar to those typically supported by the research program(s) with which the proposals align. This may result in a change in the average award size relative to prior years.

Major Research Instrumentation

- MRI will continue to invest in shared-use S&E research instrumentation. Approximately 120 new awards will support instrument development and acquisition in all of NSF's S&E domains. MRI's investments also contribute to research-intensive learning environments that enhance the training of a diverse S&E workforce and facilitate partnerships between academia and the private sector.

Mid-scale Research Infrastructure

- The Mid-scale RI-1 activity funded through the IA budget within the R&RA account is one component of NSF's Mid-scale Research Infrastructure Big Idea. It aims to significantly advance the Nation's

[1] National Science Board, Study of Operations and Maintenance Costs for NSF Facilities (NSB-2018-17), May 2018, www.nsf.gov/pubs/2018/nsb201817/nsb201817.pdf.

capabilities for conducting potentially transformative research and maintaining U.S. leadership in global S&E. Mid-scale RI-1 investments support: (1) the implementation of research infrastructure projects between $6.0 million and $20.0 million; and (2) the design of future mid-scale or larger research infrastructure projects. In FY 2021, $32.67 million will be available for investment in Mid-scale RI-1 projects in any jurisdiction. Additionally, the EPSCoR program will invest no less than $20.0 million in Mid-scale RI-1 projects in EPSCoR jurisdictions. For more information about NSF's Mid-scale RI investments, see the NSF-Wide Investments chapter.

Planning and Policy Support (PPS)

- PPS includes funding for Proposal Management Efficiencies, which comprises activities such as the NSF biennial survey and studies of NSF's merit review process. PPS supports annual agency awards (the Vannevar Bush Award, Public Service Award, Alan T. Waterman Award, and National Medal of Science) and summer science internship programs that target STEM students from underrepresented groups. PPS also provides funding to the National Academies of Science, Engineering, and Medicine (the National Academies) for the Committee on Science, Engineering, Medicine, and Public Policy (CoSEMPuP)[2] and the Government-University-Industry Research Roundtable (GUIRR),[3] as well as studies, workshops, and letter reports spanning multiple research domains. PPS invests in catalytic activities - workshops, conferences, and long-term planning exercises, focused on emerging themes and agency innovations - as well as capacity-building activities for NSF's Big Ideas.

Research Investment Communications (RIC)

- RIC will continue its investment in a leading-edge communications effort that is essential for public awareness and support of S&E. RIC creates products and processes through traditional and social media platforms that make NSF's investments in STEM readily available and easily understandable to everyone. In FY 2021, RIC will continue to inform policy makers, the media, and the general public about the impact of NSF's investments on their daily lives and the Nation's future.

Science and Technology Centers: Integrative Partnerships Program

- The STC program supports innovative, potentially transformative, complex research and education projects that require large-scale, long-term awards. STCs engage the Nation's intellectual talent through partnerships across academia, industry, national laboratories, and government. These collaborations create synergies that enhance the training of the next generation of scientists, engineers, and educators. In FY 2021, five new STCs will begin as part of the STC Class of 2021 ($25.0 million), which replaces the sunsetting Class of 2010 cohort.
- STC Administration ($500,000) supports post-award management of STC awards, including site visits by review teams. Funding also supports the management of the STC Class of 2021 proposal competition that began in FY 2019 and concludes in FY 2021.

Science and Technology Policy Institutes (STPI)

- STPI is a Federally Funded Research and Development Center sponsored by NSF on behalf of the White House Office of Science and Technology Policy (OSTP). STPI provides analysis of significant domestic and international science and technology policies and developments for OSTP and other federal agencies.

[2] CoSEMPuP webpage (http://sites.nationalacademies.org/pga/cosepup/index.htm).
[3] GUIRR webpage (http://sites.nationalacademies.org/pga/guirr/).

Program Monitoring and Evaluation

<u>External Program Evaluations and Studies</u>

Planned evaluations and studies (FY 2020 – 2021)

- In support of NSF's response to the Evidence Act, EAC will conduct the following NSF-wide assessments:
  - *Capacity Assessment*. EAC will support a capacity assessment as required in Title 1 of the Evidence Act; and
  - *Investment strategy analysis*. EAC will lead the first stage of a comprehensive study of NSF's portfolio of investments across directorates. This study will provide a foundation for the development of an agency-wide learning agenda.
- *"No deadlines" pilot* (NSF-wide). Four NSF directorates are experimenting with solicitations without proposal submission deadlines to increase efficiency in operations—namely, BIO, CISE, ENG and GEO. EAC will coordinate work across these directorates and divisions to study the overall impact of the change.
- *Research Experiences for Undergraduates (REU)* (NSF-wide). The REU data system will be tested at scale in FY 2020. Expected in 2021, results will inform the selection of a data collection approach to support program monitoring, evaluation, and research.
- *Convergence Accelerator Evaluation* (OIA). CA provides an innovative funding mechanism to accelerate public benefit arising from investments in basic research. EAC will work with CA to set requirements for an evaluation (contracted in FY 2020 or FY 2021) to inform program improvements.

Ongoing evaluations and studies (unless otherwise stated, results are expected in FY 2020)

- *Intergovernmental Personnel Act (IPA)* (NSF-wide). In FY 2017, NSF began piloting a requirement that all institutions provide a minimum of ten percent cost share for every IPA agreement. EAC is conducting a study of this pilot in collaboration with OIRM.
- *NSF INCLUDES* (NSF-wide). This study builds on the developmental evaluation completed in FY 2019 and addresses questions prioritized in the initiative's learning agenda. Results are anticipated in FY 2021 and will be used to inform strategy and disseminate best practices, both for NSF INCLUDES and as a pilot for NSF's learning agenda.
- *Knowledge Management/Mobilization Architecture & Tool Development to Support the Use of Evidence-based Decision Making* (OIA). This study seeks to strengthen EAC's knowledge management and mobilization efforts by (1) integrating existing NSF information management systems, and (2) developing and testing new technology-based communications solutions.
- *NSF Data Analytics and Evaluation Support Services* (OIA). This study pilots two approaches to using data analytics for ongoing learning. Pilot 1 builds an analytics workflow to support hypothesis testing or scenario planning for assessing NSF programs using quantitative, administrative data. Pilot 2 uses machine learning to replicate human coding of qualitative data.
- *EPSCoR* (OIA). The evaluation of EPSCoR's portfolio of investments seeks to (1) develop a cohesive academic research competitiveness evaluation framework, and (2) determine the availability and quality of data to document jurisdictional progress over time.
- *Secure and Trustworthy Cyberspace* (CISE). This evaluation examines the program's impact on the field of cyber-security and on the career trajectories of principal investigators. Results will inform revisions to program activities and investments in monitoring, evaluation, and learning.

Completed evaluations and studies (unless otherwise stated, completed in FY 2019)

- *NSF INCLUDES* (NSF-wide). This developmental evaluation provided real-time feedback to support continuous learning and improvement during this Big Idea's inaugural phase. Results helped refine the program's theory of change, create new funding mechanisms, clarify the solicitation, strengthen proposal review processes (reviewer training and review criteria), and pursue more streamlined performance monitoring and outcome measurement.

- *NSF Innovation Corps Teams (I-Corps™)* (NSF-wide). This longitudinal evaluation focused on outcomes for participants and their academic institutions. I-Corps™ projects outperformed comparison projects on a range of commercialization outcomes. Program staff are considering recommendations for program improvements related to curriculum, communications, and data management.
- *Broadening Participation (BP) in Research and Related Activities* (OIA). This feasibility study showed that machine learning and text analytics can be used to identify underrepresented groups in STEM engaged in R&RA awards and suggests a viable approach for a future NSF-wide assessment of BP goals.
- *Centers for Chemical Innovation* (Chemistry). Study results are under review and are expected to (1) help strengthen program design and implementation, (2) identify program contributions, and (3) inform NSF about effective structures and operations for center-based research.

Science and Technology Policy Institute (STPI) Reports

- STPI is working on two reports for NSF that are anticipated to continue into FY 2021:
  - A conceptual framework for conducting themed evaluations; and
  - Administration and analysis of the U.S. Antarctic Program logistics support data collection instrument.

Workshops and Reports

- In FY 2020, several studies by the National Academies, co-funded with the National Institutes of Health and other agencies, continued:
  - The role of inducement prizes in spurring innovation. Three public meetings on the role of inducement prizes were held in the first half of 2019. Release of a final report is anticipated in 2020; and
  - The underrepresentation of women in science, engineering, and medicine. Several public meetings were held in 2019, including a symposium in March 2019 highlighting evidence-based interventions for addressing the underrepresentation of women. Release of a final report is anticipated by Spring 2020. In FY 2019, NSF provided additional funding to support an intensive, one-year outreach campaign to disseminate the key messages, best practices, and recommendations outlined in the final report.
- In 2019, the Committee on Equal Opportunity in Science and Engineering (CEOSE) transmitted to Congress its biennial report for 2017-2018, which emphasized investing in diverse community voices in research projects.[4] The next biennial report is anticipated in 2021.

Committees of Visitors (COV)[5]

- In FY 2019, none of the IA programs held a COV.
- In FY 2020, a COV will review the EPSCoR program.
- In FY 2021, a COV will review the MRI program.

The Performance and Management chapter provides details regarding the periodic reviews of programs and portfolios of programs by external Committees of Visitors and directorate Advisory Committees. Please see this chapter for additional information.

[4] Committee on Equal Opportunities in Science and Engineering, 2017-2018 Biennial Report to Congress: Investing in Diverse Community Voices. National Science Foundation, Alexandria VA, 2019, www.nsf.gov/od/oia/activities/ceose/reports/CEOSE_ReportToCongress_RP_FVmp_508.pdf.
[5] www.nsf.gov/od/oia/activities/cov/

ESTABLISHED PROGRAM TO STIMULATE COMPETITIVE RESEARCH (EPSCOR) **$163,670,000**
-$12,000,000 / -6.8%

EPSCoR Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
Total	**$175.67**	**-**	**$163.67**	**-$12.00**	**-6.8%**
Research Infrastructure Improvement	144.94	-	118.54	-26.40	-18.2%
Co-Funding[1]	30.61	-	45.03	14.42	47.1%
Outreach and Workshops	0.12	-	0.10	-0.02	-16.7%

[1] No less than $20.0 million in EPSCoR Co-funding will support Mid-scale RI Track 1 awards in EPSCoR

About EPSCoR

EPSCoR assists NSF in its statutory function "to strengthen research and education in science and engineering throughout the United States and to avoid undue concentration of such research and education." EPSCoR seeks to advance excellence in science and engineering research and education, enhancing the competitiveness of EPSCoR jurisdictions in the science and engineering domains supported by NSF.

In general, about 14 percent of the EPSCoR portfolio is available to support new research grants. The remaining 86 percent supports grants made in prior years.

EPSCoR uses three strategic investment tools: Research Infrastructure Improvement (RII) awards, Co-Funding, and Outreach/Workshops.

Research Infrastructure Improvement (RII)

- RII investments support development of physical, human, and cyber-based research infrastructure in EPSCoR jurisdictions, with an emphasis on collaborations among academic researchers, the private sector, and state and local governments, to effect sustainable improvements in research infrastructure. RII projects are designed to improve the research competitiveness of jurisdictions by strengthening their academic research infrastructure in areas of S&E supported by NSF that are critical to the jurisdiction's science and technology initiatives. RII projects increase the participation of underrepresented groups in STEM, enable broader regional and topical collaborations among jurisdictions, and facilitate the enhancement of discovery, learning, and economic development in EPSCoR jurisdictions. EPSCoR facilitates the engagement of its jurisdictions in S&E priority areas such as NSF's Big Ideas.

Co-Funding

- EPSCoR co-funding – with NSF directorates and offices – focuses on meritorious proposals from individual investigators, groups, and centers in EPSCoR jurisdictions that are submitted to the Foundation's research and education programs, including crosscutting initiatives. These proposals undergo merit review in the program to which they were submitted and are recommended for award, but cannot be funded without the combined, leveraged support of EPSCoR. In FY 2021, no less than $20.0 million will be invested in Mid-scale RI-1 projects in EPSCoR jurisdictions. For more information about the Mid-scale Research Infrastructure Big Idea, see the narrative in the NSF-Wide Investments chapter.

Outreach and Workshops

- The Outreach component of EPSCoR solicits requests for workshops, conferences, and other community-based activities. These are designed to explore opportunities in emerging areas of S&E and to share best practices in strategic planning, diversity, communication, and other capacity-building areas of importance in EPSCoR jurisdictions. EPSCoR also supports outreach travel that enables NSF staff from all directorates and offices to directly engage and inform the EPSCoR research community about NSF opportunities, priorities, programs, and policies.

Strategic Partnership and Evaluation Activities

- In FY 2021, NSF EPSCoR will continue to implement a cohesive academic research competitiveness evaluation framework, which will be completed in May 2020. This framework will enable the study of the processes and outcomes that contribute to academic research competitiveness. EPSCoR will continue to identify and collect high-quality data from jurisdictions and will work with jurisdictions to use the framework to identify opportunities for increasing their competitiveness in NSF research programs and for other federal and private S&E funding. EPSCoR will also use the evidence gained from this framework to guide continuous improvement in its overall program.

People Involved in EPSCoR Activities

Number of People Involved in EPSCoR Activities

	FY 2019 Actual Estimate	FY 2020 (TBD)	FY 2021 Estimate
Senior Researchers	384	-	360
Other Professionals	72	-	70
Postdoctoral Associates	39	-	40
Graduate Students	385	-	360
Undergraduate Students	397	-	370
K-12 Teachers	2,607	-	2,400
K-12 Students	42,132	-	39,200
Total Number of People	**46,016**	**-**	**42,800**

NSF CONVERGENCE ACCELERATOR (CA) **$70,000,000**
+$28,610,000 / 69.1%

CA Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$41.39**	**-**	**$70.00**	**$28.61**	**69.1%**
CA Research Tracks	41.39	-	68.00	26.61	64.3%
CA Planning & Development (total)	-	-	2.00	2.00	N/A

About CA

CA seeks to transform how NSF supports innovative science, reflecting its commitment to foundational research, while also encouraging rapid advances through partnerships between academic and non-academic stakeholders. CA makes timely investments that (1) initiate new capabilities to accelerate convergence research in areas of national importance, and (2) build capacity in multi-stakeholder convergence teams to address these critical challenges.

Convergence research is a means of solving complex research problems. The unifying characteristics of these problems are that: (1) they have the potential to make a significant impact, either on fundamental understanding in S&E or on the Nation's ability to meet pressing societal challenges, or both; and (2) they require the integration of knowledge, tools, and ways of thinking from multiple disciplines. Focusing on use-inspired, convergence research, with directed deliverables and using an approach that rewards innovation, risk-taking, and transition to use, CA has customized various models and techniques on acceleration and innovation activities that have proven successful in similar environments.

Convergence Accelerator Research
In FY 2021, CA will invest in HDR and FW-HTF related research tracks and new research tracks informed by community input through responses to a Request for Information and other external stakeholder input. The CA will support use-inspired research while encouraging rapid advances through partnerships that include, or will include, multiple stakeholders (e.g., industry, academic, not-for-profits, government entities).

CA research tracks comprise two phases of evolving technical topics within the CA.
- Phase 1: Each CA project begins with a nine-month planning effort, funded at up to $1 million, for further development of the initial proposal, identifying new team members, participating in an innovation curriculum, and developing initial prototypes. The innovation curriculum consists of training in human-centered design, team science activities, inter-team communications, and presentation coaching, all of which are essential components of the operations of the Accelerator. The training will help the teams better prepare for success in the next phase of support, focused on building prototypes, developing experimental designs, and other deliverables, as appropriate. At the end of Phase 1, teams will participate in a pitch competition along with a proposal evaluation.
- Phase 2: Each Phase 1 team selected to proceed to Phase 2 will be provided additional support of up to $5.0 million for 24 months. Teams are expected to provide specific research deliverables by the end of Phase 2.

In each of FY 2020 and FY 2021, an estimated 30 Phase 1 awards will be made in new CA tracks. Two or three new FY 2020 tracks will be selected in February 2020 based on the responses to the Request for

Information[6] and community workshops. Two or three new FY 2021 CA research tracks will be selected no later than December 2020. The new FY 2021 tracks will be based on analysis of community-based inputs and assessment of the progress of the existing tracks and will take into account Administration R&D priorities such as IotF. In addition, an estimated 10 Phase 2 awards will be made in FY 2020 and 10 Phase 2 awards in FY 2021.

CA Planning and Development

Investments in CA Planning and Development will enable opportunities in emerging S&E areas best suited for CA consideration, through workshops, conferences, and other community-based activities. This component also supports the sharing of best practices in innovation, diversity, team building, and communication.

[6] www.nsf.gov/pubs/2019/nsf19065/nsf19065.jsp?WT.mc_id=USNSF_179

UNITED STATES ARCTIC RESEARCH COMMISSION (USARC) **$1,600,000**
+$125,000 / 8.5%

USARC Funding
(Dollars in Millions)

FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
$1.48	**-**	**$1.60**	**$0.13**	**8.5%**

About USARC

USARC was created by the Arctic Research and Policy Act of 1984, (as amended, P. L. 101-609), to establish the national policy, priorities, and goals necessary to construct a federal program plan for basic and applied Arctic scientific research. USARC advises the Interagency Arctic Research Policy Committee in developing national Arctic research projects and a five-year plan to implement those projects. USARC also supports interaction with Arctic residents, international Arctic research programs and organizations, and local institutions, including regional and local governments, in order to obtain the broadest possible view of Arctic research needs. USARC is an independent federal agency, funded through NSF's appropriation, specifically as an activity in the Research and Related Activities account.

USARC is requesting $1.60 million, $125,000 above the FY 2019 Actual. In FY 2020, new leases will be established for both USARC offices (in Arlington, VA, and in Anchorage, AK) by the General Services Administration. The FY 2021 Request provides funds to advance Arctic research, and to recommend Arctic research policy that is consistent with the Administration's *FY 2021 Administration Research and Development Budget Priorities* (M-19-25).

The FY 2021 Request will support three FTE funded at USARC. In addition, the FY 2021 Request supports one full-time contractor and four part-time contractors. A total of seven compensated personnel are authorized per P.L. 101-609. The seven Commissioners may also receive up to 90 days of salary per year, at the Executive Schedule Level IV.

EDUCATION FOR HUMAN RESOURCES (EHR) **$930,930,000**
-$3,600,000 / -0.4%

EHR Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Division of Research on Learning in Formal and Informal Settings (DRL)	$228.27	-	$223.53	-$4.74	-2.1%
Division of Undergraduate Education (DUE)	264.82	-	236.59	-28.23	-10.7%
Division of Human Resource Development (HRD)	188.11	-	188.78	0.67	0.4%
Division of Graduate Education (DGE)	253.33	-	282.03	28.70	11.3%
Total	**$934.53**	**-**	**$930.93**	**-$3.60**	**-0.4%**

About EHR

EHR supports the Administration's priorities of building and leveraging a diverse, highly skilled U.S. STEM workforce and STEM-literate public by funding high quality research and development in STEM education, unique in the federal context, and also grounding its programs in basic research findings about STEM learning and teaching.

EHR recognizes the need to invest in foundational and future-oriented STEM educational research, using the results of research to inform STEM programs and practices, to ensure the prosperity of the nation through a well-educated STEM workforce. Like all research, results might be applied more immediately or well into the future. As such, in FY 2021, EHR will deepen efforts to build capacity for STEM education research and identify and tackle the challenges in STEM education needed to create the workforce for the Industries of the Future (IotF). Thus, EHR's research portfolio will address foundational (perennial) issues in STEM education by exploring persistent questions about the learning and teaching of STEM content, as well as future-oriented areas that result from changes in technology, the nation's demography, the economy, and new directions in STEM. These areas include how and what to teach students so that they are prepared to engage with Artificial Intelligence, Quantum Information Science, and Computing, and how to do so in a manner that reduces demographic disparities. EHR's partnership with Boeing is one model for leveraging public-private partnerships to develop the STEM workforce for IotF. In FY 2020, EHR and Boeing focused on how to develop the workforce in model-based engineering, mechatronics, and data science/sensor analytics through the use of flexible, personalized learning systems. In FY 2021, EHR will continue to study the implementation of personalized learning systems in developing the STEM workforce for IotF.

EHR allocations across divisions are designed to accomplish the collective work of the directorate, best described by three underlying themes: STEM learning and learning environments, broadening participation and institutional capacity, and STEM professional workforce development. These themes dovetail with the three aspirational goals of the Federal government's 5-year strategic plan*, Charting a Course for Success: America's Strategy for STEM Education*,[1] which are: (1) Build Strong Foundations for STEM Literacy; (2) Increase Diversity, Equity, and Inclusion in STEM, and (3) Prepare the STEM Workforce for the Future. EHR's programs all contribute to these strategic goals. In addition, EHR supports the implementation of the 5-year strategic plan by co-chairing the NSTC Subcommittee on Federal Coordination in STEM

[1] NSTC (2018). Charting a Course for Success: America's Strategy for STEM Education. www.whitehouse.gov/wp-content/uploads/2018/12/STEM-Education-Strategic-Plan-2018.pdf

Education (FC-STEM) and co-leading several FC-STEM Interagency Working Groups.

Progress in STEM depends on *discoverers*—innovators and future leaders in the nation's science and engineering (S&E) enterprise in both the public and private sectors. These discoverers, including those from K-12 and informal learning environments, are critical members of the future STEM and STEM-related workforce. Through its scholarship, fellowship, and traineeship programs, EHR supports the development of discoverers at the undergraduate and graduate levels. EHR programs support the STEM-specific workforce, including a data-skilled workforce and the broader workforce that rely on STEM skills, thus addressing the Nation's critical need for a diverse, highly skilled technical workforce.

The progress of S&E also depends on a public that can take full advantage of STEM-related employment opportunities, and that values and participates in STEM, both formally and informally. Importantly, the opportunities made possible by federal investments in STEM must be provided effectively to—and draw from—the full and diverse talent pool of the Nation. To this end, EHR continues to support the Historically Black Colleges and Universities Undergraduate Program (HBCU-UP), the Improving Undergraduate STEM Education (IUSE): Hispanic Service Institutions (HSI) Program, and the Tribal Colleges and Universities Program (TCUP) to facilitate the advancement of early career STEM professionals at Minority Serving Institutions (MSIs) and to enhance the academic experience of students studying STEM at MSIs.

As a natural extension of EHR's experience in broadening participation, EHR serves as the steward for NSF INCLUDES, one of NSF's Big Ideas. EHR continues to make advances in knowledge generation and dissemination through NSF INCLUDES to understand what interventions work and under what conditions to broaden participation in STEM. For more information about NSF INCLUDES, see the narrative in the NSF-Wide Investments chapter.

EHR supports NSF and Administration priorities through participation in Foundation-wide activities. Through existing programs, EHR invests in NSF's Big Ideas HDR, FW-HTF, and NNA. By incorporating the Big Ideas into NRT's priority themes, EHR invests in the development of researchers with the necessary skills to conduct convergence research. In FY 2021, EHR continues to support SaTC, and NITRD (education and workforce), all of which provide opportunities for research on the intersection of artificial intelligence and education.

EHR continues its strong emphasis on evidence-based decision making and its commitment to generating robust evidence to inform the development, management, and assessment of its programs and portfolios of investment. A multi-year learning agenda (evidence-building plan) for EHR's STEM human capital development programs will inform and guide future actions. EHR experts in evaluation will continue to collaborate with staff in NSF's Evaluation and Assessment Capability in developing NSF-wide learning agendas and with other federal agencies to share best practices, work toward the use of common metrics and instruments, strengthen evidence-building capacity for decision-making, and accomplish the transparency and accountability objectives set out in the federal five-year strategy for STEM education.

Major Investments

EHR Major Investments
(Dollars in Millions)

Area of Investment[1,2]	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Advanced Manufacturing[3]	-	-	$2.00	$2.00	N/A
Artificial Intelligence[3]	-	-	37.59	37.59	N/A
Bioeconomy	10.62	-	9.00	-1.62	-15.3%
GRFP	142.26	-	137.64	-4.62	-3.2%
IUSE	89.99	-	74.09	-15.90	-17.7%
NRT	33.04	-	61.87	28.83	87.3%
SaTC	55.33	-	52.13	-3.20	-5.8%
NSF's Big Ideas					
NSF INCLUDES Stewardship	*20.01*	-	*18.92*	*-1.09*	*-5.4%*

[1] Major investments may have funding overlap and thus should not be summed.

[2] This table reflects this directorate's support for selected areas of investment. In other directorate narratives, areas of investment displayed in this table may differ and thus should not be summed across narratives.

[3] EHR did not formally track these activities in FY 2019.

- Artificial Intelligence in Education and Workforce: EHR activities in this area include investments in NRT for AI focused traineeships, investments in the Artificial Intelligence Institutes as well as investments in AI across EHR programs.
- Bioeconomy: EHR invests in bioeconomy through research and workforce development programs. Graduate Research Fellowship Program (GRFP): An equal investment is provided through the Integrative Activities budget for a total GRFP investment of $275.28 million. For more information on the GRFP, see the Major Investments in STEM Graduate Education narrative within the NSF-Wide Investments chapter.
- Improving Undergraduate STEM Learning (IUSE): EHR will lead the NSF-wide IUSE activity. For more information, see the IUSE narrative within the NSF-Wide Investments chapter. The primary goals of the IUSE: HSI activity are to promote research on engaged student learning at HSIs, to incentivize institutional and community transformation, and to promote fundamental research about what it takes to diversify and increase participation in STEM effectively, including research that improves our understanding of how to build institutional capacity at HSIs. These activities will address the Nation's need to make the STEM workforce more inclusive.
- NSF Research Traineeship (NRT): The investment for FY 2021 NRT activities will advance transformative programs that combine interdisciplinary training with innovative professional development activities to educate the next generation of scientist to solve convergent research problems in areas of national need. In FY 2021, NRT will expand to include a special focus on traineeships in artificial intelligence and artificial intelligence engineering. For more information, see the Major Investments in STEM Graduate Education narrative within the NSF-Wide Investments chapter.
- SaTC ($52.13 million): EHR will support SaTC activities through the CyberCorps®: Scholarship for Service (SfS) program.
- NSF INCLUDES: EHR will support NSF INCLUDES Alliances. For more information, see the NSF INCLUDES narrative within the NSF-Wide Investments chapter.

For more information on programs that support EHR Major Investments, see the narratives for individual EHR divisions.

Appropriations Language

For necessary expenses in carrying out science, mathematics and engineering education and human resources programs and activities pursuant to the National Science Foundation Act of 1950 (42 U.S.C. 1861 et seq.), including services as authorized by section 3109 of title 5, United States Code, authorized travel, and rental of conference rooms in the District of Columbia,~~ $940,000,000~~ $930,930,000 to remain available until September 30,~~ 2021.~~ 2022.

Education and Human Resources
FY 2021 Summary Statement
(Dollars in Millions)

	Enacted/ Request	Unobligated Balance Available Start of Year	Unobligated Balance Available End of Year	Adjustments to Prior Year Accounts	Transfers	Obligations/ Estimates
FY 2019 Appropriation	$910.00	$14.27	-$5.66	$3.92	12.00	$934.53
FY 2020 Enacted	940.00	5.66				945.66
FY 2021 Request	930.93					930.93
$ Change from FY 2020 Enacted						-$14.73
% Change from FY 2020 Enacted						-1.6%

Totals exclude reimbursable amounts.

Explanation of Carryover

Within the Education and Human Resources (EHR) account, $5.66 million was carried over into FY 2020.

Excellence Awards in Science and Engineering
- Amount: $2.32 million
- Purpose: These funds will be used to recognize recipients of the Presidential Awards for Excellence in Mathematics and Science Teaching and recipients of the Presidential Awards for Excellence in Science, Mathematics and Engineering Mentoring.
- Obligation: Funds were obligated during FY 2020 Quarter 1

Robert Noyce Teacher Scholarship Program
- Amount: $3.34 million
- Purpose: Recovered no-year funds will be applied to Noyce future commitments.
- Obligation: Anticipated FY 2020 Quarter 2

Funding Profile

EHR Funding Profile

	FY 2019 Actual Estimate	FY 2020 (TBD)	FY 2021 Estimate
Statistics for Competitive Awards:			
Number of Proposals	3,782	-	4,400
Number of New Awards	843	-	850
Funding Rate	22%	N/A	19%
Statistics for Research Grants:			
Number of Research Grant Proposals	3,106	-	3,200
Number of Research Grants	511	-	550
Funding Rate	16%	N/A	17%
Median Annualized Award Size	$250,707	-	$260,000
Average Annualized Award Size	$340,370	-	$280,000
Average Award Duration, in years	3.1	-	2.9

EHR supports investment in core research in education and STEM learning as well as STEM education development and training.

Program Monitoring and Evaluation

External Program Evaluations and Studies

- In FY 2020, EHR will initiate the following evaluations.
  - In FY 2020, the Division of Undergraduate Education (DUE) will initiate several activities designed to provide evaluative evidence on and inform future evaluations of the Improving Undergraduate STEM Education: Education and Human Resources (IUSE: EHR) program. A Dear Colleague Letter will invite proposals for research (e.g., meta-syntheses) on results of IUSE: EHR investments in institutional and community transformation. Results from funded proposals, expected in FY 2022 and beyond, are expected to be used to inform plans for future solicitations and for accountability purposes. Additionally, DUE will convene a meeting of all IUSE funding programs in FY 2020 to inform plans for future external program evaluations and studies in FY 2021 and beyond.
- EHR has two evaluations underway, each of which is summarized below:
  - The ADVANCE: Organizational Change for Gender Equity in STEM Academic Professions (ADVANCE) program is currently being assessed. The evaluation is being conducted by Windrose Vision. Final results from this study are expected in FY 2022.
  - The Advanced Technological Education (ATE) program is currently being assessed. The evaluation is being conducted by Insight Policy Research. Final results from this study are expected in FY 2020.

Committees of Visitors (COV)

- The DGE COV convened October 2018 and reviewed division operations and the core programmatic portfolio for the four-year period spanning FY 2014 through FY 2017. The COV stated that DGE's merit review process was working very well, and that the panel summaries were substantive. DGE's unique cross-agency mission to serve all of the disciplines was centrally important to the overall mission of meeting the needs of graduate education. The COV was impressed at the excellent scholarship demonstrated in the review process by the program officers. Major recommendations of the COV were to improve coaching and tools for reviewers to ensure equally consistent reviews, collecting more robust demographic and scientific information on reviewers, and more focus on evaluation activities. DGE is addressing the COV recommendations through its future planning activities, internal process changes, and programmatic updates.

- In November 2018, the DUE COV reviewed division operations and core programs for FY 2014 or FY 2015 through FY 2018 (depending on the funding program). The DUE COV concluded that DUE had implemented NSF's merit review criteria with high quality and effectiveness. They were impressed by DUE's ability to manage a high volume of work while maintaining high merit review standards. They noted that panel summaries could be improved to better describe the rationale for the panel decision and suggested potential improvements to reviewer training, outreach, and efficiency. DUE is prioritizing the recommendations based on potential impact and will address these recommendations through changes in merit review processes, technical enhancements, and revision of funding program solicitations.
- In October 2019, the COV reviewed DRL. The COV is expected to present their report to the EHR Advisory Committee at its Spring 2020 meeting.
- In 2020, a COV is anticipated to review HRD.

The Performance and Management chapter provides details regarding the periodic reviews of programs and portfolios of programs by external Committees of Visitors and directorate Advisory Committees. Please see this chapter for additional information.

People Involved in EHR Activities

Number of People Involved in EHR Activities

	FY 2019 Actual Estimate	FY 2020 (TBD)	FY 2021 Estimate
Senior Researchers	3,233	-	5,700
Other Professionals	1,302	-	2,000
Postdoctoral Associates	175	-	300
Graduate Students	11,300	-	11,300
Undergraduate Students	16,600	-	16,200
K-12 Teachers	37,700	-	37,700
K-12 Students	85,200	-	85,000
Total Number of People	**155,510**	**-**	**158,200**

DIVISION OF RESEARCH ON LEARNING IN FORMAL AND INFORMAL SETTINGS (DRL) **$223,530,000**
-$4,740,000 / -2.1%

DRL Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
Total	**$228.27**	**-**	**$223.53**	**-$4.74**	**-2.1%**
Learning and Learning Environments	**25.70**	**-**	**70.28**	**44.58**	**173.5%**
Computer Science for All (CSforAll)[1]	-	-	9.46	9.46	N/A
EHR Core Research (ECR): STEM Learning	25.70	-	60.82	35.12	136.7%
Broadening Participation & Institutional Capacity	**150.69**	**-**	**145.66**	**-5.03**	**-3.3%**
Advancing Informal STEM Learning (AISL)	62.48	-	55.77	-6.71	-10.7%
Discovery Research PreK-12 (DRK-12)	88.21	-	89.89	1.68	1.9%
STEM Professional Workforce	**51.88**	**-**	**7.59**	**-44.29**	**-85.4%**
Artificial Intelligence Research Institutes	-	-	7.59	7.59	N/A
Science, Technology, Engineering, Mathematics + Computing (STEM+C) Partnerships[1]	51.88	-	-	-51.88	-100.0%

[1] In FY 2019, CSforAll was supported as a component of STEM+C. The FY 2019 Actual is shown for comparison purposes only. FY 2021 funding for STEM+C moves to implement CSforAll as a freestanding program and to expand EHR's computer science education portfolio through existing programs.

About DRL

DRL invests in foundational research to advance understanding about teaching and learning in STEM—including computer science as part of STEM. Advances in STEM learning ultimately support individuals who pursue STEM careers, as well as the Nation's broader workforce that will increasingly require STEM knowledge. The DRL portfolio includes the design, implementation, and study of learning environments, models, and digital platforms intended to enable STEM learning for all students—particularly those who have been underrepresented in STEM—through both formal and informal activities across the STEM ecosystem. DRL's programs inform and support lifelong access to high-quality STEM learning opportunities that will prepare learners for jobs of the future.

FY 2021 Summary

Learning and Learning Environments

- CSforAll, which focuses on improving computer science instruction at the preK-12 level, became a free-standing program in FY 2020. In FY 2021, CSforAll will be supported at $9.46 million in EHR, with an additional $9.51 million in support from CISE. Previously, CSforAll was supported as a component of the STEM+C Partnerships program.
- ECR funds enable significant progress on important questions about STEM learning and teaching. ECR supports research addressing persistent issues in the learning and teaching of STEM content as well as frontier topics that envision STEM learning environments of the future. In FY 2021, ECR will expand the portfolio of research on frontier topics in the education and training of a workforce for the IotF, push the boundaries of technology use in learning, and examine how learning will change because of advances in technology and developments in IotF. Researchers will need to develop new methodologies to tackle new questions. In FY 2021 EHR will continue efforts through the ECR Building Capacity in STEM Education Research initiative to develop capacity for future-oriented STEM education research.

Broadening Participation and Institutional Capacity

- AISL resources will support design, adaptation, implementation, and research on innovative modes of lifelong learning in informal environments. Emphases will include broadening participation in STEM, workforce development, adult and family learning of STEM, and public participation in scientific research, do it yourself technology, and cyberlearning.
- DRK-12 focuses on research and development of resources, models, and tools to help U.S. students pre-K through 12 learn STEM, including computer science. U.S. students require a strong early start and continuing education in mathematics and other STEM disciplines in order to compete for jobs in the global economy. Resources will support improving STEM achievement for preK-12 students in key innovative and emerging science areas. DRK-12 supports research and development of innovative learning environments across diverse educational settings including technology-supported learning environments.

STEM Professional Workforce

- In FY 2021, EHR will support research institutes on AI in relation to education and the workforce. The goal of these institutes is to improve learning and education, by incorporating AI into educational technology and anticipating how future workplaces will be changed by AI. There will be a particular focus on the changing roles of human teachers/educators, mentors and collaborators, and the changing nature of educational systems and workforce needs.

DIVISION OF UNDERGRADUATE EDUCATION (DUE) **$236,590,000**
-$28,230,000 / -10.7%

DUE Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$264.82**	**-**	**$236.59**	**-$28.23**	**-10.7%**
Learning and Learning Environments	**123.12**	**-**	**121.15**	**-1.97**	**-1.6%**
EHR Core Research (ECR): STEM Learning Environments	13.13	-	37.60	24.47	186.4%
IUSE: Hispanic Serving Institutions (HSI) Program	20.00	-	9.46	-10.54	-52.7%
Improving Undergraduate STEM Education (IUSE)	89.99	-	74.09	-15.90	-17.7%
STEM Professional Workforce	**141.70**	**-**	**115.44**	**-26.26**	**-18.5%**
Advanced Technological Education (ATE)	66.51	-	70.97	4.46	6.7%
Robert Noyce Teacher Scholarship Program (Noyce) - Annual Funding	64.50	-	44.47	-20.03	-31.1%
Robert Noyce Teacher Scholarship Program (Noyce) - No Year Funding	10.69	-	-	-10.69	-100.0%

About DUE

DUE supports excellence in undergraduate STEM education for all students. It achieves this goal by supporting projects that will strengthen STEM education at two- and four-year colleges and universities. These projects include efforts to design, develop, and implement high-quality educational experiences, as well as scientific research to understand the effectiveness of those experiences. DUE investments promote educational innovations across the full range of public and private U.S. institutions of higher education. The resulting improvements in STEM education increase student learning, leading to greater retention and degree attainment by undergraduates. STEM graduates have more employment opportunities and career options, and greater lifetime earning potential.[2] For example, innovative educational programs at community colleges enable students to enter careers in advanced technologies such as additive manufacturing, biotechnology, precision agriculture, nano-optics, and cybersecurity. DUE support also enables STEM majors to enter the K-12 teaching workforce in high-need school districts. In these ways, DUE investments broaden participation in the future STEM workforce and help the nation meet STEM workforce needs.

FY 2021 Summary

<u>Learning and Learning Environments</u>

- ECR funds enable significant progress on important questions about STEM learning and teaching. ECR supports research addressing persistent issues in the learning and teaching of STEM content as well as frontier topics that envision STEM learning environments of the future. In FY 2021, ECR will expand the portfolio of research on frontier topics in the education and training of a workforce for the IotF, push the boundaries of technology use in learning, and examine how learning will change because of advances in technology and developments in IotF. Researchers will need to develop new methodologies to tackle new questions In FY 2021 EHR will continue efforts through the ECR Building Capacity in STEM Education Research initiative to develop capacity for future-oriented STEM education research.

[2] https://ncses.nsf.gov/pubs/nsb20198/s-e-labor-market-conditions#earnings

- IUSE funding will support: increased use of evidence-based educational practices; advancements in the knowledge base concerning undergraduate research, including course-based research; and development or identification of indicators, metrics, and assessments to measure readiness for and progress toward institutional and national improvements in undergraduate STEM education. For more information see the IUSE narrative in the NSF-Wide Investments chapter.
- DUE's HSI budget of $9.46 million and HRD's HSI budget of $4.73 million will enable a total FY 2021 investment of $14.19 million. These funds will continue to support the improvement of undergraduate education at HSIs and build the capacity for STEM education and STEM education research at HSIs that have previously received little or no funding from NSF.

<u>STEM Professional Workforce</u>

- ATE funding will support research on and development of effective preparation of the skilled technical workforce, including technicians in advanced technological industries such as advanced manufacturing.
- Noyce funding will invest in teacher preparation and support Noyce fellows during completion of a teaching obligation in high-need school districts.
- ATE and Noyce will continue to emphasize the preparation of a diverse STEM workforce and will incorporate a focus on inclusion, in partnership with the NSF INCLUDES initiative.

DIVISION OF HUMAN RESOURCE DEVELOPMENT (HRD) $188,780,000
+$660,000 / 0.4%

HRD Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
Total	**$188.12**	**-**	**$188.78**	**$0.66**	**0.4%**
Learning and Learning Environments	**59.54**	**-**	**67.87**	**8.33**	**14.0%**
ADVANCE[1]	[18.00]	-	17.03	N/A	N/A
Alliances for Graduate Education and the Professoriate (AGEP)	7.99	-	7.13	-0.86	-10.8%
Historically Black Colleges and Universities Undergraduate Program (HBCU-UP)	35.01	-	31.22	-3.79	-10.8%
Tribal Colleges and Universities Program (TCUP)	15.01	-	12.49	-2.52	-16.8%
Broadening Participation & Institutional Capacity	**98.95**	**-**	**95.72**	**-3.23**	**-3.3%**
EHR Core Research (ECR): Broadening Participation and Institutional Capacity in STEM	12.92	-	28.54	15.62	120.9%
IUSE: Hispanic Serving Institutions (HSI) Program	20.01	-	4.73	-15.28	-76.4%
Big Idea: NSF INCLUDES[2]	20.01	-	18.92	-1.09	-5.4%
Louis Stokes Alliances for Minority Participation (LSAMP)	46.01	-	43.53	-2.48	-5.4%
STEM Professional Workforce	**29.63**	**-**	**25.19**	**-4.44**	**-15.0%**
Centers for Research Excellence in Science and Technology (CREST)	24.00	-	21.41	-2.59	-10.8%
Excellence Awards in Science and Engineering (EASE)	5.63	-	3.78	-1.85	-32.9%

[1] Total FY 2019 Actual funding for ADVANCE is $18.0 million with $16.47 million contributed from the R&RA account. In FY 2021, all funding for ADVANCE resides in the EHR account.

[2] Total FY 2019 Actual funding for NSF INCLUDES is $20.20 million with $200,000 contributed from the R&RA account. In FY 2021, all funding for NSF INCLUDES resides in the EHR account.

About HRD

HRD serves as a focal point for NSF's agency-wide commitment to enhancing the quality and excellence of STEM education and research through broadening participation in STEM of historically underrepresented groups—minorities, women, and persons with disabilities. HRD's mission is to create and grow a vibrant and diverse U.S. STEM workforce by supporting the inclusion and participation of underrepresented individuals in STEM and the institutions that serve them. Priority is placed on investments in innovative and transformative strategies that serve as models for achieving the full participation of these populations and for providing opportunities for educators, researchers, and institutions who serve them. Programs within HRD have a strong focus on partnerships and collaborations in support of institutional transformation and capacity building that lead to increased STEM participation of underrepresented groups.

FY 2021 Summary

Learning and Learning Environments

- ADVANCE will be funded entirely in EHR. ADVANCE will continue to evaluate the sustainability of its strategies and support adaptation of successful practices for achieving institutional change.
- AGEP funds will continue to support innovative STEM faculty career pathway models for advancing

doctoral students, postdoctoral scholars and faculty who are historically underrepresented minorities (URMs). The AGEP program will continue efforts to conduct a portfolio analysis, complete awardee site reviews and share best practices, collaborative partnerships findings and networking through the annual AGEP research conference.

- HBCU-UP funds will support research for HBCU STEM faculty, enhance the academic experience of students, increase numbers of students completing STEM degrees, and support institutional transformation efforts.
- TCUP funding will support the design, implementation, and assessment of comprehensive institutional improvements in STEM instruction and research capacity at TCUP institutions. TCUP will support eligible institutions through the TCUP Enterprise Advancement Centers to partner with tribal communities to enhance their ability to respond to community needs.

Broadening Participation and Institutional Capacity

- ECR funds enable significant progress on important questions about STEM learning and teaching. ECR supports research addressing persistent issues in the learning and teaching of STEM content as well as frontier topics that envision STEM learning environments of the future. In FY 2021, ECR will expand the portfolio of research on frontier topics in the education and training of a workforce for the IotF, push the boundaries of technology use in learning, and examine how learning will change because of advances in technology and developments in IotF. Researchers will need to develop new methodologies to tackle new questions In FY 2021 EHR will continue efforts through the ECR Building Capacity in STEM Education Research initiative to develop capacity for future-oriented STEM education research.
- HRD's HSI budget of $4.73 million combines with DUE's $9.46 million contribution for a total FY 2021 level of $14.19 million, which will continue to support the improvement of undergraduate education at HSIs and build capacity for STEM education and research at HSIs that have previously received little or no funding from NSF.
- NSF INCLUDES program will continue to fund broadening participation projects and related research through NSF INCLUDES Alliances and the existing NSF broadening participation portfolio such as pilot projects, planning grants, supplements, and starter networks (e.g., research coordination networks) that serve as on-ramps to the NSF INCLUDES Alliances and the NSF INCLUDES National Network. For more information about NSF INCLUDES, see the NSF-Wide Investments chapter.
- LSAMP funding will continue to support an increased focus on broadening participation in STEM research and evaluation to expand knowledge about effective strategies for student recruitment, retention, and persistence in STEM programs. Additionally, LSAMP will emphasize support for evidence-based interventions that are proven to increase STEM baccalaureate degree production, particularly mentoring and early experiential research experiences nationally and abroad and continue support for STEM post-baccalaureate activities.

STEM Professional Workforce

- Centers of Research Excellence in Science and Technology (CREST) funding will enable new CREST centers and support additional Postdoctoral Research Fellows, fostering increased collaborations across the centers and building research capacity at minority serving institutions.
- Excellence Awards in Science and Engineering (EASE) will collaborate with the Noyce program to continue supporting the professional development of pre K-12 STEM teachers through the STEM Teacher Leadership Network. EASE will also initiate research into the impact of PAEMST on awardees.

DIVISION OF GRADUATE EDUCATION (DGE) $282,030,000
+$28,700,000 / 11.3%

DGE Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$253.32**	**-**	**$282.03**	**$28.71**	**11.3%**
Learning and Learning Environments	**6.68**	**-**	**-**	**-6.68**	**-100.0%**
Project and Program Evaluation (PPE)	6.68	-	-	-6.68	-100.0%
STEM Professional Workforce	**246.64**	**-**	**282.03**	**35.39**	**14.3%**
CyberCorps®: Scholarship for Service (SFS)	55.33	-	52.13	-3.20	-5.8%
EHR Core Research (ECR): STEM Professional Workforce Preparation	16.01	-	30.39	14.38	89.8%
Graduate Research Fellowship Program (GRFP)	142.26	-	137.64	-4.62	-3.2%
NSF Research Traineeship (NRT)[1]	33.04	-	61.87	28.83	87.3%

[1] Total FY 2019 Actual funding for NRT is $54.09 million with $21.05 million contributed from the R&RA account. In FY 2021, all funding for NRT resides in the EHR account.

About DGE

DGE provides leadership for cross-Foundation investments that support U.S. graduate students in STEM, and for improvement and innovation in graduate education to prepare tomorrow's STEM leaders. The division achieves this through direct investment in individuals; funding projects that spearhead the development and implementation of bold, new, and potentially transformative models for graduate education training in high priority interdisciplinary or convergent research areas; and through basic research on STEM graduate education. This research supports innovations in graduate education by exploring new ways for graduate students in research-based master's and doctoral degree programs to develop the skills, knowledge, and competencies needed to pursue a range of STEM careers in the 21st century. Special emphasis is given to training students in areas of national priority. DGE also leads EHR research on the development of the STEM professional workforce. The resulting body of research expands the knowledge base that informs successful models, practices and approaches for the preparation of a STEM professional workforce ready to advance the frontiers of science and engineering.

FY 2021 Summary

<u>STEM Professional Workforce</u>

- ECR funds enable significant progress on important questions about STEM learning and teaching. ECR supports research addressing persistent issues in the learning and teaching of STEM content as well as frontier topics that envision STEM learning environments of the future. In FY 2021, ECR will expand the portfolio of research on frontier topics in the education and training of a workforce for the IotF, push the boundaries of technology use in learning, and examine how learning will change because of advances in technology and developments in IotF. Researchers will need to develop new methodologies to tackle new questions In FY 2021 EHR will continue efforts through the ECR Building Capacity in STEM Education Research initiative to develop capacity for future-oriented STEM education research.
- SFS funding will improve the capacity of institutions to provide students with the latest curricular and assessment approaches and experiences available ensuring they are well prepared with cybersecurity skills and knowledge. SFS support will also allow institutions to conduct research to build understanding of the most effective preparation for a variety of cybersecurity professions. In addition,

SFS will invest in the cybersecurity education and workforce development component of NSF's Secure and Trustworthy Cyberspace: Education (SaTC:EDU) investment area. Emphasis will be given to K-12 cybersecurity education, students from community colleges, veterans, and other underrepresented groups.

- NSF Graduate Research Fellowships Program (GRFP) funding in EHR, together with matching funds in the IA budget, provide a total FY 2021 funding level of $275.28 million to support 1,600 new fellowships with a cost of education allowance of $12,000 and a stipend of $34,000 per fellow. The GRFP program will continue to align awards with Administration priorities, including artificial intelligence, quantum information science. In addition, DGE will continue efforts to improve professional development opportunities for program participants.
- NRT's Innovations in Graduate Education (IGE) program, will focus on model design, innovation, and research in graduate student training and professional development. The NRT traineeships will advance transformative programs that combine interdisciplinary training with innovative professional development activities to educate the next generation of scientist to solve convergent research problems in areas of national need. In FY 2021, NRT will expand to include a special focus on traineeships in artificial intelligence and artificial intelligence engineering. Additionally, the monitoring and evaluation program for NRT will be initiated.
- For more information about GRFP and NRT, see the Major Investments in STEM Graduate Education narrative within the NSF-Wide Investments chapter.

H-1B NONIMMIGRANT PETITIONER FEES **$157,000,000**

In FY 2021, H-1B Nonimmigrant Petitioner Fees are projected to be $157.0 million.

H-1B Nonimmigrant Petitioner Fees Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 Estimate	FY 2021 Request	FY 2021 Request Change Over FY 2020 Estimate Amount	Percent
H-1B Nonimmigrant Petitioner Fees Funding	$149.00	$157.00	$157.00	-	-

Beginning in FY 1999, Title IV of the American Competitiveness and Workforce Improvement Act (ACWIA) of 1998 (P.L. 105-277) established an H-1B Nonimmigrant Petitioner Account in the general fund of the U.S. Treasury for fees collected for each petition for alien nonimmigrant status. That law required that a prescribed percentage of funds in the account be made available to NSF for scholarships to low-income STEM students; grants for mathematics, engineering, or science enrichment courses; and systemic reform activities. In FY 2005, Public Law 108-447 reauthorized H-1B funding. NSF was provided with 40 percent of the total H-1B receipts collected. Thirty percent of H-1B receipts (75 percent of the receipts that NSF receives) are to be used for a low-income scholarship program, Scholarships in Science, Technology, Engineering, and Mathematics (S-STEM). Ten percent of receipts (25 percent of the receipts that NSF receives) are designated for support of private-public partnerships in K-12 education through Innovative Technology Experiences for Students and Teachers (ITEST).

The FY 2021 Request includes a legislative proposal to double the ACWIA fee for the H-1B visa program (to $3,000 per worker for large employers and $1,500 for small employers) to prepare American workers for jobs that are currently being filled by foreign workers, especially in STEM fields. Under the proposal, NSF's allocation for the ITEST program (10 percent) would remain the same, while its allocation for S-STEM would decrease from 30 percent to 15 percent, a level that would maintain absolute funding levels under current estimates.

Scholarships in Science, Technology, Engineering, and Mathematics (S-STEM)

The S-STEM program began in 1999 under P.L. 105-277. Originally, the program was named Computer Science, Engineering, and Mathematics Scholarships (CSEMS) and supported grants for scholarships to academically talented, low-income students with demonstrated financial need pursuing associate, baccalaureate, or graduate degrees in computer science, computer technology, engineering, engineering technology, or mathematics. Grantee institutions awarded scholarships of up to $2,500 per year for two years to eligible students. The CSEMS activity continued under the American Competitiveness in the 21st Century Act (P.L. 106-313) with a prescribed percentage of H-1B receipts (22 percent) which totaled approximately 59.5 percent of the total H-1B funding for NSF. P.L. 106-313 also amended P.L. 105-277 by increasing the maximum scholarship duration to four years and the annual stipend to $3,125.

Under the Consolidated Appropriations Act, 2005 (P.L. 108-447), the prescribed percentage of H-1B receipts available for the low-income scholarship program was increased to 30 percent (approximately 75 percent of the total H-1B funding for NSF). Eligibility for the scholarships was expanded from the original fields of computer science, engineering, and mathematics to include "other technology and science programs designated by the Director." The maximum annual scholarship award amount was raised from $3,125 to $10,000. Language also was added allowing NSF to use up to 50 percent of funds "for undergraduate programs for curriculum development, professional and workforce development, and to advance technological education." As a result, the program was renamed in 2006 from CSEMS to S-STEM.

- Low-income Scholarship Program: S-STEM. The S-STEM program provides institutions with funds for student scholarships to encourage and enable academically talented low-income U.S. students with unmet financial need to complete an associate, baccalaureate, or graduate degree in fields of science, technology, engineering, or mathematics. Earning these degrees enables the graduates to enter the STEM workforce or STEM graduate school. The program emphasizes the importance of recruiting students to STEM disciplines, mentoring and supporting students through degree completion, and partnering with employers to facilitate student career placement in the STEM workforce.

  Since its inception, the low-income scholarship program has received more than 7,000 proposals from all types of colleges and universities and has made more than 2,000 awards. In addition to scholarships, S-STEM awards also provide funding for student support activities such as faculty mentoring, academic support, curriculum development, leadership development, and internships. These high-impact activities are known to be effective for recruiting and retaining students in high-technology fields through graduation and into employment. In FY 2020, in addition to the long-standing scholarship support, all S-STEM projects will continue to conduct research on interventions that affect associate or baccalaureate STEM degree attainment by academically talented, low-income U.S. students with unmet financial need. S-STEM projects report much higher retention and graduation rates among their scholarship students than among other STEM majors. As a result, research on S-STEM projects can help the nation understand effective practices to support STEM degree attainment at scale. Approximately 90 awards are anticipated in FY 2020, with a continued emphasis on increasing involvement of community colleges, especially Hispanic-serving institutions. S-STEM activities in FY 2020 will leverage efforts in IUSE: EHR, LSAMP, and the IUSE: HSI Program to enhance persistence of students. S-STEM will continue to be a partner in the NSF INCLUDES initiative. S-STEM programming and research also will align with NRT, with the goal of understanding and enhancing effective learning environments and pathways for students on the continuum from two-year to four-year to master's and doctoral degrees.

Private-Public Partnerships in K-12

The American Competitiveness in the 21st Century Act (P.L. 106-313) amended P.L. 105-277 and changed the way petitioner fees were to be expended. P.L. 106-313 directed the remaining 40.5 percent of the total H-1B funding for NSF (15 percent of H-1B receipts) toward K-12 activities involving private-public partnerships in a range of areas such as materials development, student externships, and mathematics and science teacher professional development. The ITEST program was developed as a partnership activity in K-12 to increase opportunities for students and teachers to learn about, experience, and use information technologies within the context of STEM, including information technology (IT) courses. In FY 2005, P.L. 108-447 reduced the prescribed percentage of H-1B receipts available for private-public partnerships in K-12 to 10 percent (approximately 25 percent of the total H-1B funding for NSF).

- Private-Public Partnerships in K-12: ITEST. The ITEST program invests in K-12 activities that address the ongoing and growing need for STEM professionals and information technology workers in the U.S. and seeks solutions to help ensure the breadth and depth of the U.S. STEM workforce. ITEST funds activities for students and teachers that emphasize mathematics, science, and engineering and computer science careers, and emphasizes the importance of evaluation and research to understand the impact of such activities. The program supports the development, implementation, testing, and scale-up of models, STEM robotics projects, and research studies to improve the STEM workforce and build a student's capacity to participate in the STEM workforce. The solicitation places emphasis on capturing and establishing a reliable knowledge base about the dispositions toward and knowledge about STEM workforce skills in U.S. students.

Since its inception, the ITEST program has received more than 3,800 grant proposals and made more than 450 awards (including co-funded projects) that allow K-12 students and teachers to work closely with scientists, engineers, and other STEM professionals on extended research projects that promote awareness of STEM careers and interest in pursuing education pathways to those careers. Funded projects draw on a wide mix of local resources, including universities, industry, museums, science and technology centers, and school districts to identify the characteristics that attract a wide and diverse range of young people to STEM careers, especially those students historically underrepresented in those careers. ITEST will make approximately 25-30 awards in FY 2021.

H-1B Financial Activities from FY 2010 - FY 2019
(Dollars in Millions)

	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019
Receipts	**$91.22**	**$106.11**	**$128.99**	**$120.94**	**$132.49**	**$143.00**	**$138.80**	**$141.07**	**$155.99**	**$156.72**
Unobligated Balance start of year	**$52.62**	**$50.15**	**$60.93**	**$99.31**	**$108.31**	**$111.39**	**$116.02**	**$74.63**	**$96.86**	**$64.68**
Appropriation Previously unavailable (Sequestered)					**$5.10**	**$9.54**	**$7.30**	**$6.80**	**$9.73**	**$10.30**
Appropriation Currently unavailable (Sequestered)					**-$9.54**	**-$7.30**	**-$6.80**	**-$9.73**	**-$10.30**	**-$9.72**
Obligations incurred:										
Scholarships in Science, Technology, Engineering, and Mathematics	75.96	77.67	72.57	83.98	92.18	109.34	140.54	84.38	156.40	114.76
Private-Public Partnership in K-12[1]	20.85	18.62	21.59	31.51	37.23	29.83	44.35	35.11	35.86	34.24
Total Obligations	**$96.81**	**$96.29**	**$94.16**	**$115.49**	**$129.41**	**$139.17**	**$184.89**	**$119.49**	**$192.26**	**$149.00**
Unallocated Recoveries	2.20	3.12	0.96	3.55	-	4.95	1.60	3.58	4.66	4.49
Unobligated Balance end of year	**$49.24**	**$63.09**	**$96.72**	**$108.31**	**$111.39**	**$122.41**	**$72.03**	**$96.86**	**$64.68**	**$77.47**

[1] P.L. 108-447 directs that 10 percent of the H-1B Petitioner funds go toward K-12 activities involving private-public partnerships in a range of areas such as materials development, student externships, math and science teacher professional development, etc.

Explanation of Carryover

Within the H-1B account, $77.47 million was carried over into FY 2020.

Innovation Technology Experiences for Students

- Amount: $32.19 million
- Purpose: Since NSF receives the largest payments of H-1B visa fees in August and September, there was insufficient time to obligate the receipts on awards before the end of the fiscal year.
- Obligation: Anticipated FY 2020 Quarter 2

Scholarships in Science, Technology, Engineering, and Mathematics

- Amount: $45.28 million
- Purpose: Since NSF receives the largest payments of H-1B visa fees in August and September, there was insufficient time to obligate the receipts on awards before the end of the fiscal year.
- Obligation: Anticipated FY 2020 Quarter 2

MAJOR RESEARCH EQUIPMENT AND FACILITIES CONSTRUCTION

MAJOR RESEARCH EQUIPMENT AND FACILITIES CONSTRUCTION (MREFC) **$229,750,000**
-$13,480,000 / -5.5%

Major Research Equipment and Facilities Construction Funding

(Dollars in Millions)

FY 2019 Actual	FY 2020 Estimate	FY 2021 Request	Change over FY 2020 Estimate Amount	Percent
$285.27	$243.23	$229.75	-$13.48	-5.5%

Overview

The Major Research Equipment and Facilities Construction account supports the acquisition, construction, and commissioning of major and larger mid-scale research infrastructure that provide unique capabilities at the frontiers of science and engineering. Initial development, design, and post-construction operations and maintenance are funded through the R&RA account.

MREFC Account Funding, by Project

(Dollars in Millions)

	FY 2019 Actual	FY 2020 Estimate	FY 2021 Request	FY 2022 Estimate	FY 2023 Estimate	FY 2024 Estimate	FY 2025 Estimate	FY 2026 Estimate
AIMS	$103.70	$97.89	$90.00	$90.00	$28.81	-	-	-
DKIST	19.59	-	-	-	-	-	-	-
HL-LHC Upgrade	-	33.00	33.00	36.00	33.00	18.00	-	-
Vera C. Rubin Observatory	53.48	46.34	40.75	5.36	-	-	-	-
Mid-scale Research Infrastructure[1]	-	65.00	65.00	65.00	65.00	65.00	65.00	65.00
NEON	0.07	-	-	-	-	-	-	-
RCRV	108.12	-	-	-	-	-	-	-
Dedicated Construction Oversight[2]	*0.32*	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	**$285.27**	**$243.23**	**$229.75**	**$197.36**	**$127.81**	**$84.00**	**$66.00**	**$66.00**

[1] Mid-scale Research Infrastructure funding in the FY 2019 Actual is reflected in the R&RA account within Integrative Activities to support mid-scale infrastructure activities with an implementation cost between $6 million and $20 million or a design cost between $600,000 and $20 million. Mid-scale projects in this table have a total project cost between $20 million and $100 million. Outyear funding numbers for Mid-scale Research Infrastructure are assumed based on maintaining the program at a steady level in the future.

[2] Dedicated Construction Oversight in FY 2019 was funded from prior year recoveries.

Modern and effective research infrastructure is critical to maintaining U.S. international leadership in science and engineering. The future success of entire fields of research depends upon access to new generations of powerful research tools. Increasingly, these tools are large and complex and have a significant information technology or cyber-infrastructure component. To be considered for MREFC funding, NSF requires that a major multi-user research facility project represent an exceptional opportunity to enable research and education. The project should be transformative in nature, with the potential to shift the paradigm in scientific understanding. The major facility projects included in this budget request meet these criteria based on NSF and National Science Board review and approval. The mid-scale research infrastructure projects funded through this budget line are evaluated separately as described in the section below.

In FY 2021, NSF requests $229.75 million for mid-scale research infrastructure and to continue construction on three ongoing major research facility projects; the Antarctic Infrastructure Modernization for Science (AIMS), the High Luminosity-Large Hadron Collider (HL-LHC) Upgrade, and the Vera C. Rubin Observatory (formerly the Large Synoptic Survey Telescope-LSST). For more information on each major facility project see the individual narratives later in this chapter.

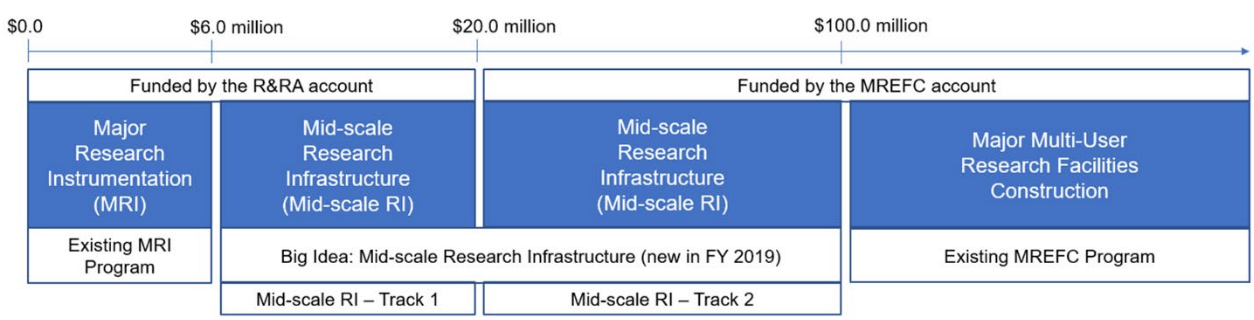
Major Facilities

Since FY 2009, major research facility projects funded through the MREFC account have been subject to NSF's "no cost overrun" policy. As a result, NSF processes and procedures must assure the development of realistic and well-supported total project cost estimates such that approved budgets for the award recipient are sufficient to accomplish the scientific objectives. The current policy as published in NSF's Major Facilities Guide (MFG) requires that: (1) the total project cost estimate when exiting the preliminary design phase includes adequate contingency to cover foreseeable risks manageable by the recipient; (2) any cost increases not covered by contingency be accommodated first by reductions in scope with any significant scope reductions reviewed by the agency prior to implementation; and (3) if the project is approved to continue and further scope reductions become too detrimental to science, then the first 10 percent of any cost increase must be covered by the sponsoring directorate through R&RA funding. NSF holds the risk to total project cost for events that are beyond the recipient's control.

Mid-scale Research Infrastructure

The American Innovation and Competitiveness Act (AICA) of 2017 required the agency to develop a strategy for supporting research infrastructure with a total project cost above the upper limit for the Major Research Instrumentation (MRI) program, which is $6.0 million including cost sharing, and below the lower threshold for the MREFC account, which was then at $70.0 million. NSF has evaluated community demand through the issuance of a Request for Information (NSF 18-013)[1] that resulted in the submission of approximately $10 billion in ideas for projects in the NSF cost range of $20 - $100 million. After evaluating that community input, existing mechanisms, and implementation options, NSF has included a dedicated funding line within the MREFC account for research infrastructure projects in the $20 - $100 million range.[2] This funding line supports upgrades to major facilities as well as stand-alone projects. Projects between $6.0 million and $20.0 million in total project cost are being addressed by individual directorates and by a new NSF-wide program drawing its heritage from the NSF-wide MRI program.

NSF Portfolio of Central Instrumentation and Infrastructure Implementation Programs



The graphic above shows NSF's centralized instrumentation and infrastructure programs. Information presented in this chapter focuses on the MREFC account. All Mid-scale Research Infrastructure (RI) –

[1] www.nsf.gov/pubs/2018/nsf18013/nsf18013.jsp

[2] The first NSF solicitation for large mid-scale projects covered the $20 million to $70 million range; NSF has extended that range up to $100 million to achieve consistency with AICA definitions regarding the threshold for major facility projects.

Track 2 investments will be managed as a single portfolio, with individual projects selected from submissions to a dedicated program solicitation and NSF's merit review process. The NSF-established thresholds for Mid-scale RI – Track 2 projects and major facilities construction projects have been updated from initial presentations to provide for greater consistency with AICA definitions. Information on Mid-scale RI programs (Tracks 1 and 2), as part of the Mid-scale Big Idea, can be found in the Mid-scale narrative in the NSF-wide priorities chapter. Information on the MRI program can be found in the IA narrative in the R&RA chapter.

Dedicated Construction Oversight

All projects funded through the MREFC account undergo periodic cost, schedule, and risk reviews as required by the MFG and the terms and conditions of the cooperative agreements. NSF policies and routine reporting are designed to ensure timely and reliable tracking of progress including the use of Earned Value Management, project spending, and use of contingency, and that program managers and recipients each have sufficient oversight and management authority (respectively) to meet project objectives.

NSF has greatly strengthened its oversight of major facility projects in recent years, with a number of those enhancements now codified in AICA. One significant enhancement is holding a portion of budget contingency (up to 100 percent) and only allocating contingency funds for obligation to the project based on demonstrated need. This oversight mechanism will generally result in some MREFC carryover each year. However, future obligation of this carryover is anticipated to manage project risks. Enhanced oversight of the construction stage now also includes mandatory incurred cost audits and independent cost estimates, as well as other audits and reviews based on NSF's annual major facility portfolio risk assessment. These efforts are conducted by NSF and are generally not attributable to a specific project at the time of budget formulation, nor are they part of the total project cost developed and managed by the recipient. To properly support and transparently account for these efforts, actual costs and future estimates for Dedicated Construction Oversight are shown separately from each project in the MREFC account table. From FY 2017 through FY 2019, these activities were supported with funds recovered from projects completed in previous years. Beginning in FY 2020, dedicated funding was requested for these activities in the MREFC account.

Oversight of the mid-scale research infrastructure projects is more flexible and tailored to the technical nature of the project. All mid-scale research infrastructure projects funded through the MREFC account will be required to provide a detailed Project Execution Plan for review. The MFG, Section 5, notes that the detailed oversight requirements, and application of major facility oversight practices, will depend on characteristics such as the technical scope, type and mix of work performed, and assessment of the technical and programmatic risks.[3]

Appropriations Language

For necessary expenses for the acquisition, construction, commissioning, and upgrading of major research equipment, facilities, and other such capital assets pursuant to the National Science Foundation Act of 1950 (42 U.S.C. 1861 et seq.), including authorized travel, ~~$243,230,000~~$229,750,000, to remain available until expended.

[3] AICA currently requires the same level of oversight for all projects funded through the MREFC account. NSF is currently seeking a slight modification of AICA language to enable large mid-scale projects to have the more tailored oversight discussed in the MFG.

Major Research Equipment and Facilities Construction
FY 2021 Summary Statement
(Dollars in Millions)

	Enacted/ Request	Unobligated Balance Available Start of Year	Unobligated Balance Available End of Year	Adjustments to Prior Year Accounts	Transfers	Obligations Actual/ Estimates
FY 2019 Appropriation	$295.74	$28.43	-$38.95	$0.05	-	$285.27
FY 2020 Enacted	243.23	38.95				282.18
FY 2021 Request	229.75					229.75
$ Change from FY 2020 Enacted						-$52.43
% Change from FY 2020 Enacted						-18.6%

Explanation of Carryover

Within the Major Research Equipment and Facilities Construction (MREFC) account, $38.95 million was carried over into FY 2020.

Regional Class Research Vessels
- Amount: $35.97 million
- Purpose: Budget contingency funding not obligated in FY 2019.
- Obligation: Anticipated FY 2020 Quarter 3

Vera C. Rubin Observatory
- Amount: $82,943
- Purpose: Budget contingency funding not obligated in FY 2019.
- Obligation: Anticipated FY 2020 Quarter 3

National Ecological Observatory Network
- Amount: $1.35 million
- Purpose: NSF-held management reserve funding not obligated in FY 2019.
- Obligation: Anticipated FY 2020 Quarter 3

Dedicated Construction Oversight
- Amount: $64,155
- Purpose: Budget contingency funding not obligated in FY 2019.
- Obligation: Anticipated FY 2020 Quarter 4

The remaining MREFC carryover of $1.48 million resulted from downward adjustments recovered at the close of FY 2019.

ANTARCTIC INFRASTRUCTURE MODERNIZATION FOR SCIENCE (AIMS) $90,000,000

The Antarctic Infrastructure Modernization for Science construction project was initiated in FY 2019 with an investment of $103.70 million, followed by $97.89 million in FY 2020. The FY 2021 Request amount is $90.0 million, the third year in a multi-year funding profile with a Total Project Cost of $410.40 million.

Appropriated and Requested MREFC Funds
for the Antarctic Infrastructure Modernization for Science Project

(Dollars in Millions)

FY 2019	FY 2020	FY 2021 Request	FY 2022 Estimate	FY 2023 Estimate	FY 2024 Estimate	Total Project Cost
$103.70	$97.89	$90.00	$90.00	$28.81	-	$410.40

The AIMS project will replace several major structures at McMurdo Station, Antarctica, one of three permanent stations that comprise the U.S. presence in Antarctica, to meet anticipated science support requirements for the next 35 to 50 years while reducing operations costs. The project will help ensure enduring U.S. leadership and influence in this strategic region. It will also support critical scientific research and capabilities such as nuclear test detection, earthquake monitoring, and real-time weather data collection for global forecasting.

McMurdo Station's main purpose is to support both near- and deep-field science in Antarctica, including activities at Amundsen-Scott South Pole Station. AIMS will enable faster, more streamlined logistics and science support by co-locating or consolidating field science support, warehousing, skilled trades work, and personnel and administrative support into more operationally and energy efficient facilities. AIMS will also replace outdated lodging facilities, and provide more effective centers for vehicle and equipment operations and emergency operations, as well as upgrade utilities to support these facilities.

Previously appropriated funds have been used to procure equipment and construction material that will be transported to McMurdo Station in early FY 2020 and FY 2021, in preparation for the beginning of major AIMS site construction. Site preparation work started in FY 2019 and will continue in FY 2020 along with backbone utilities installation. FY 2021 funds will be used to begin construction of the Vehicle and Equipment Operations Center (VEOC), the new lodging facility, and the Central Services building. Site preparation and materials procurement will be done for the water tank and the emergency operations center. The AIMS project is currently anticipated to take up to 10 years to complete.

Baseline History

In 2011, the Office of Science and Technology Policy and NSF convened a Blue Ribbon Panel (BRP) to evaluate the U.S. Antarctic Program (USAP) logistical enterprise. The BRP was asked to conduct a review of NSF facilities and operations supporting science in Antarctica and to ensure that the facilities can support the scientific opportunities articulated by an earlier 2011 National Research Council report entitled *Future Science Opportunities in Antarctica and the Southern Ocean.*[1] The BRP report[2] made numerous recommendations regarding maintaining and enhancing the U.S.'s world-class science program in Antarctica.

[1] www.nap.edu/catalog/13169/future-science-opportunities-in-antarctica-and-the-southern-ocean
[2] www.nsf.gov/geo/opp/usap_special_review/usap_brp/rpt/index.jsp

NSF responded to the BRP report by immediately addressing issues of safety, implementing operational efficiencies that resulted in a rapid return on investment, and developing long-term plans for each of the three year-round U.S. stations: Palmer, Amundsen-Scott South Pole, and McMurdo. The AIMS project is a pivotal component of the McMurdo Station Master Plan with a specific focus on the primary core functions of this critical logistics hub.

The AIMS project seeks to enhance operational support for science by improving operations efficiency, containing operating costs, and enhancing safety. The following major scope elements are targeted to achieve these goals:

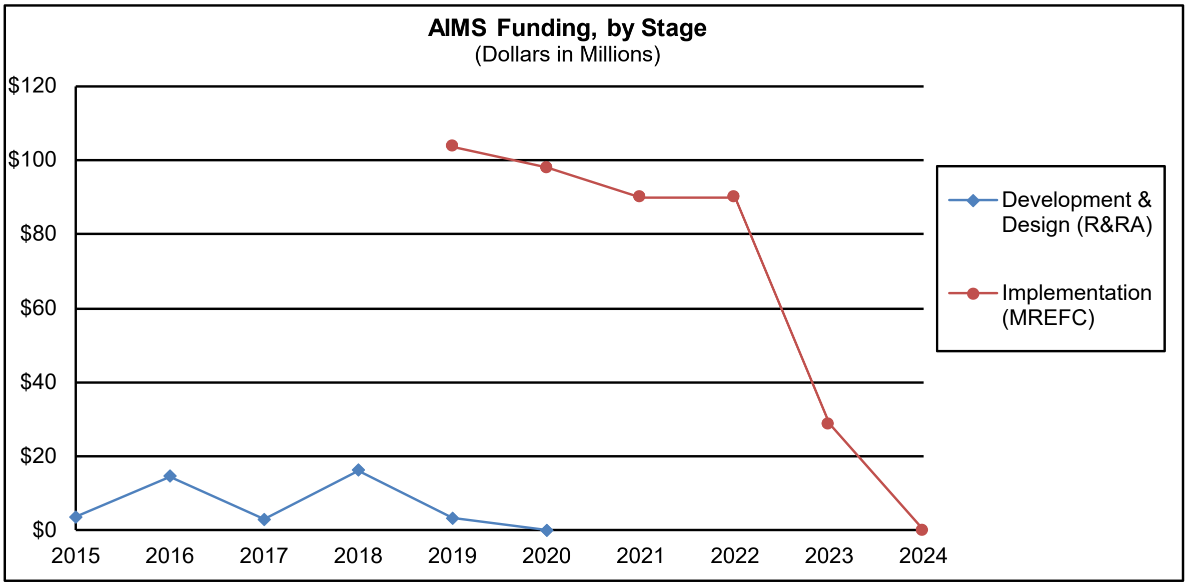
- Construction of a Centralized Services building that replaces and modernizes multiple existing facilities on station including centralized warehousing.
- Construction of an Emergency Operations Center to replace the existing fire station, medical facilities, and fitness and skills development facilities.
- Construction of a consolidated Field Science Support Facility.
- Construction of an Industrial Trades Shop to consolidate existing facilities across the station.
- Construction of a VEOC that facilitates maintenance and repair of both heavy and light equipment ranging from traverse tractors, cranes, loaders, and earth moving equipment to trucks, vans, snowmobiles, and field generators.
- Construction of one new lodging facility to ensure adequate bed space to support near-term needs, including population surges from an influx of construction workers. Importantly, this facility is comprised primarily of single-occupancy rooms recommended by the BRP to promote safety and health. Shared rooms exacerbate sleep disturbance that can arise from widely varying work and travel schedules for the station workforce as well as scientists, and promote the spread of contagious illnesses such as colds and flu.
- Upgrade of utilities distribution networks for fire protection water, domestic water, heating, power, communications, and sanitary sewer.

The Final Design Review was held in October 2018 and the NSB authorized NSF to award a contract for AIMS in February of 2019. The NSB-approved not-to-exceed TPC is $410.40 million.

Total Funding Requirements for AIMS

(Dollars in Millions)

	Cumulative Prior Years	FY 2019 Actual	FY 2020 Request	FY 2021 Request	ESTIMATES FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
R&RA:									
Development & Design	$37.31	-	-	-	-	-	-		
Subtotal, R&RA	$37.31	-	-	-	-	-	-	-	-
MREFC:									
Implementation	-	103.70	97.89	90.00	90.00	28.81	-	-	-
Subtotal, MREFC	-	$103.70	$97.89	$90.00	$90.00	$28.81	-	-	-
TOTAL REQUIREMENTS	**$37.31**	**$103.70**	**$97.89**	**$90.00**	**$90.00**	**$28.81**	**-**	**-**	**-**



Note: Outyear (FY 2021 through FY 2024) Implementation funding reflects current estimates.

Management and Oversight

AIMS is being accomplished under the Federal Acquisition Regulations (FAR) via an existing contract to Leidos Innovations Corporation as the current Antarctic Support Contractor. OPP works in collaboration with the Division of Acquisition and Cooperative Support (DACS) to use existing contract mechanisms (e.g., monthly program reviews, earned value reporting, award fee evaluation) to ensure rigorous management and oversight of this work. Appropriate NSF major facility oversight requirements apply, including engagement with the Large Facilities Office (LFO) and use of an Independent Cost Estimate.

Reviews

The Conceptual Design Review (CDR) and Preliminary Design Review (PDR) were passed successfully in FY 2015 and FY 2017, respectively, resulting in an NSB resolution (NSB-2017-20) authorizing NSF to include AIMS in a future budget request.

The Final Design Review (FDR) was conducted in October 2018. The external panel found that the project execution plan was well-developed for the FDR and recommended that the project proceed to the construction stage. They also recommended that NSF attempt to retain all the major science-support capabilities in the original scope, in spite of a cost increase since PDR related to commodity prices and market conditions, in order to realize the long-term benefits to the USAP. An Independent Cost Estimate was also carried out to support NSF's cost analysis in conjunction with the FDR process.

In addition to daily communications with Leidos' AIMS project management, NSF conducts a monthly project review. This review covers the monthly project management report produced by Leidos. Also planned are annual Construction Reviews by NSF management, with the first one to take place in May, 2020.

Project Status

Leidos continues to advance the designs with formal intermittent and scheduled design reviews of the different AIMS construction components outlined above, and is completing procurement of long-lead items required to support construction activities.

Cost and Schedule

FY 2021 funds will be used to do site preparation work, procure construction materials, and to begin on-site construction. Construction projects to be initiated will include the core utilities, outside cable plant, and Emergency Operations Center. During FY 2021 construction of the VEOC, lodging facility, and Central Services building will continue. Construction is phased to allow for minimal impact on science support during construction, as well as ensure continuity of operations in the event that subsequent funding is disrupted. Although the actual execution of the entire AIMS project is expected to take up to 10 years, the proposed appropriation profile is shorter in order to reduce procurement risks.

Risks

The two main ongoing risks to the project are the market price uncertainty for labor and materials and the uncertainty in the supply chain—getting appropriately skilled workers and materials from the U.S. to McMurdo Station when needed. NSF and Leidos have implemented a rigorous risk management approach which includes the identification of risks and mitigating actions. NSF holds the risk of cost and schedule increases that are out of control of the contractor, including events such as unpredictably severe weather, icebreaker availability, and macroeconomic changes.

Future Operations Costs

Implementing AIMS will provide a material reduction in the annual cost to maintain and operate McMurdo Station, including an estimated $1.80 million savings in fuel and $4.20 million savings in labor and other direct costs in comparison with FY 2018 operating costs. By consolidating the station footprint and using modern energy efficient designs, AIMS will save an estimated 500,000 gallons of fuel per year. Consolidated warehousing and co-located work centers are estimated to reduce the support labor requirement by 80 workers. The new layout will enable improved quality of support and increase the throughput of field science projects.

DANIEL K. INOUYE SOLAR TELESCOPE (DKIST) $0

No funding is requested in FY 2021 for construction of NSF's Daniel K. Inouye Solar Telescope. FY 2019 represented the final year in an 11-year funding profile within an NSB approved not-to-exceed total project cost of $344.13 million. Completion of construction atop Haleakalā on Maui, Hawai'i is planned for no later than June 2020. This narrative provides an update on the project's status.

Appropriated and Requested MREFC Funds for the Daniel K. Inouye Solar Telescope
(Dollars in Millions)

	Prior Years	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021 Request[1]	Total Project Cost
MREFC Approp.	$122.00	$20.00	$20.00	$20.00	$16.13	-	-	$198.13
ARRA MREFC Appropriation	146.00	-	-	-	-	-	-	146.00
Total	**$268.00**	**$20.00**	**$20.00**	**$20.00**	**$16.13**	**-**	**-**	**$344.13**

[1] FY 2019 was the final year for MREFC funding for DKIST construction. The project is currently on track to complete construction in 2020 within the Total Project Cost cap.

When completed, DKIST will be the world's most powerful solar observatory, poised to answer fundamental questions in solar physics by providing transformative improvements over current ground-based facilities. DKIST will enable the study of magnetic phenomena in the solar photosphere, chromosphere, and corona. Determining the role of magnetic fields in the outer regions of the Sun is crucial to understanding the solar dynamo, solar variability, and solar activity including flares and coronal mass ejections. Solar activity can affect civil life on Earth through phenomena generally described as space weather and may impact the terrestrial climate. The relevance of DKIST's science drivers was reaffirmed by the National Academies of Sciences, Engineering, and Medicine 2010 Astronomy and Astrophysics decadal survey: *New Worlds, New Horizons in Astronomy and Astrophysics*[1] as well as the 2012 Solar and Space Physics decadal survey: *Solar and Space Physics: A Science for a Technological Society*.[2] DKIST will play an important role in enhancing the "fundamental understanding of space weather and its drivers," an objective called out in the *National Space Weather Strategy* and associated *National Space Weather Action Plan* both of which were released by the National Science and Technology Council in October 2015. An update to the National Space Weather Strategy has been developed through the Space Weather Operations, Research, and Mitigation Working Group of the National Science and Technology Council and was informed by community input. This update, entitled *National Space Weather Strategy and Action Plan,* was released in March 2019.[3]


The DKIST telescope enclosure and Support and Operations building at the site on Haleakalā, Maui, HI. *Credit: David Boboltz, NSF.*

[1] www.nap.edu/catalog/12951/new-worlds-new-horizons-in-astronomy-and-astrophysics
[2] www.nap.edu/catalog/13060/solar-and-space-physics-a-science-for-a-technological-society
[3] www.whitehouse.gov/wp-content/uploads/2019/03/National-Space-Weather-Strategy-and-Action-Plan-2019.pdf

Baseline History

Beginning in 2001, NSF provided funds to the National Solar Observatory (NSO) for an eight-year development and design program for DKIST and its initial complement of instruments through the Division of Astronomical Sciences (AST) in MPS and through the Division of Atmospheric and Geospace Sciences in GEO. The current design, cost, schedule, and risk were scrutinized in an NSF-conducted Preliminary Design Review in October-November 2006.

The original total project cost to NSF, $297.93 million, was set after a Final Design Review (FDR) in May 2009, which determined that the project was fully prepared to begin construction. The NSB approved an award for this amount at the NSF Director's discretion, contingent upon completion of compliance with relevant environmental and cultural/historic statutes. In FY 2009, $153.0 million was appropriated to initiate construction. Funding was provided through a combination of the MREFC account ($7.0 million) and the American Recovery and Reinvestment Act (ARRA) account ($146.0 million). Given the timing of the receipt of budget authority and the complexity of project contracting, the entire $153.0 million was carried over from FY 2009 and obligated in FY 2010.

The environmental compliance requirements were completed on November 20, 2009, and the NSF Director signed the Record of Decision authorizing construction in December 2009. The Hawaiʻi Board on Land and Natural Resources (BLNR) approved the project's application for a Conservation District Use Permit (CDUP) in December 2010. A contested case challenge to the 2010 CDUP issuance delayed site construction until the BLNR ruled in favor of the DKIST project and issued a new CDUP in November 2012. Full access to the site atop Haleakalā followed shortly thereafter. A ground-breaking ceremony kicking off site construction was held December 1, 2012.

The unexpected length of the delay associated with the environmental compliance process led to a reassessment of the project schedule and total project cost in 2012. An external panel of experts reviewed the revised baseline and recommended increasing the total project cost by approximately $46.20 million. The NSB subsequently considered and authorized a revised total project cost of $344.13 million at its August 2013 meeting.

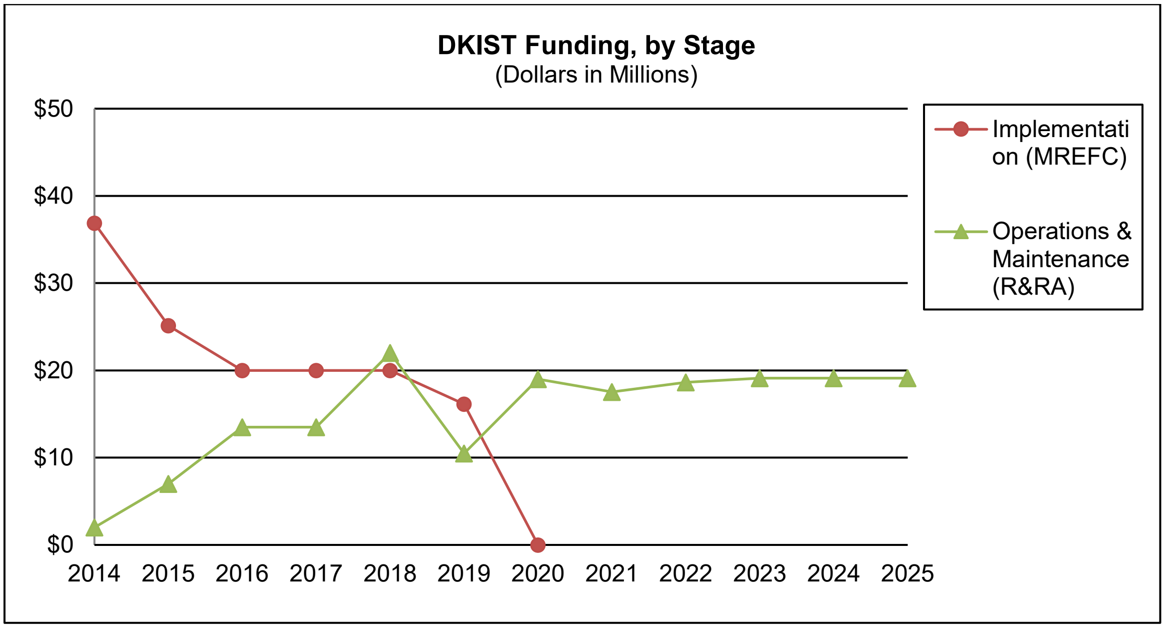
Total Funding Requirements for DKIST

(Dollars in Millions)

	Prior Years	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	ESTIMATES[1] FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
R&RA:									
Development & Design	$20.41	-	-	-	-	-	-	-	-
Operations & Maintenance[2]		10.50	-	17.54	18.08	18.62	19.13	19.13	19.13
ARRA	3.10	-	-	-	-	-	-	-	-
Subtotal, R&RA	$23.51	$10.50	-	$17.54	$18.08	$18.62	$19.13	$19.13	$19.13
MREFC:									
Implementation	182.00	16.13	-	-	-	-	-	-	-
ARRA	146.00	-	-	-	-	-	-	-	-
Subtotal, MREFC	$328.00	$16.13	-	-	-	-	-	-	-
TOTAL REQUIREMENTS	**$351.51**	**$26.63**	**-**	**$17.54**	**$18.08**	**$18.62**	**$19.13**	**$19.13**	**$19.13**

[1] FY 2019 includes $2.0 million to another awardee for cultural mitigation activities as agreed to during the compliance process. Excluded is $8.0 million of 2019 O&M costs obligated in FY 2018.

[2] Outyear O&M funding estimates are for planning purposes only. The current cooperative agreement ends September 2024.



The DKIST project is a collaboration of scientists and engineers at more than 20 U.S. and international organizations. Other partners include the Air Force Office of Scientific Research and international groups in Germany, the United Kingdom, and Italy. Some partnership activities include:

- The U.S. Air Force (USAF) replaced the aluminizing chamber at their Advanced Electro-Optical System telescope on Maui and sized it to accommodate the DKIST primary mirror. An Interagency Agreement for use of the Mirror Coating Facility (MCF) was signed by NSF and the U.S. Air Force in FY 2017. This eliminates the need to build a dedicated aluminizing chamber for DKIST.
- Leibniz-Institut für Sonnenphysik (KIS; Freiburg, Germany) is constructing a narrow-band instrument named the Visible Tunable Filter (VTF) as an in-kind contribution.
- Queens University Belfast (Northern Ireland) is leading a consortium of institutions from the United Kingdom that will supply high-speed visible cameras to feed the DKIST instruments.

Discussions of other possible contributions for second-generation instruments, algorithm development, coordinated observations, and student exchange are ongoing.

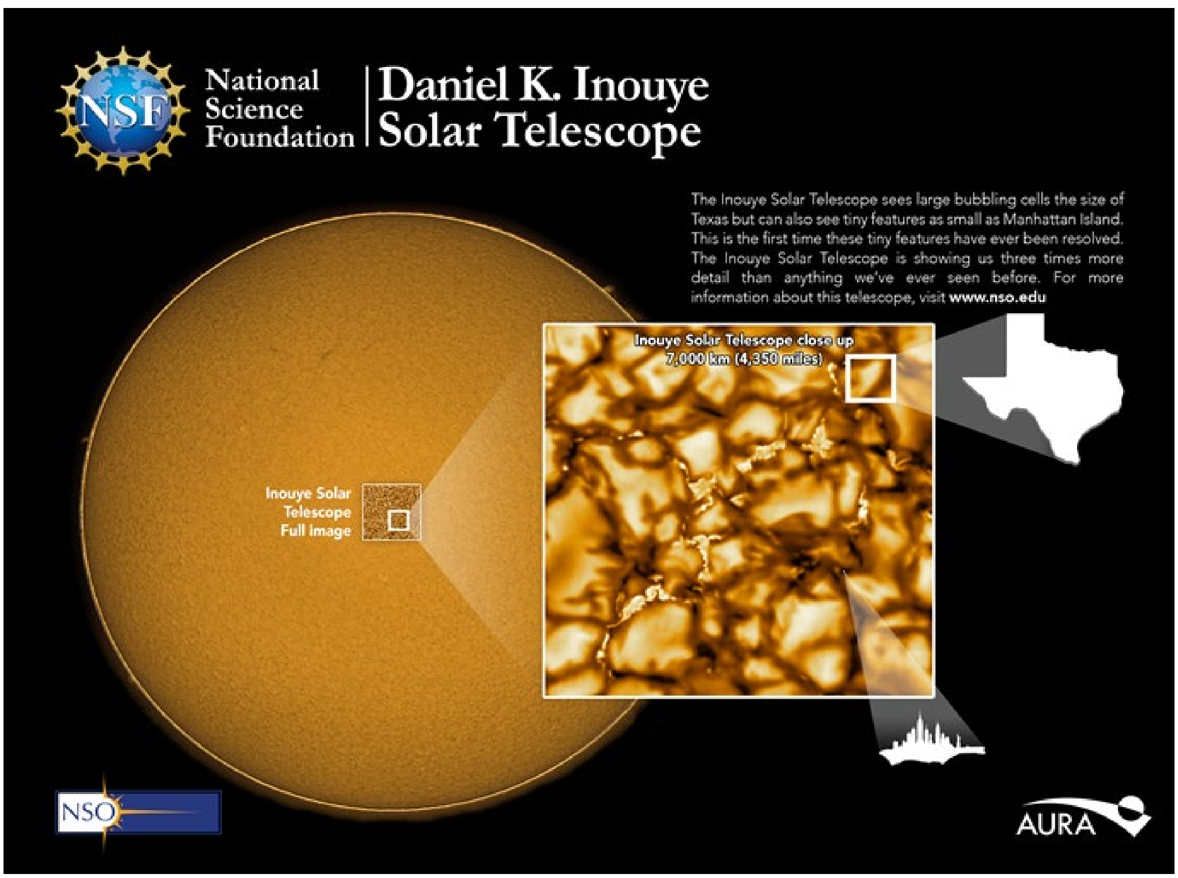
Management and Oversight

- NSF Structure: NSF oversight is handled by a program officer in AST working cooperatively with staff from MPS, the Office of Budget, Finance, and Award Management (BFA), the Office of the General Counsel (OGC), and the Office of Legislative and Public Affairs. Within BFA, the Large Facilities Office (LFO) provides advice to program staff and assists with agency oversight and assurance. Representatives from the above NSF offices comprise the DKIST Integrated Project Team, which meets on a quarterly basis to discuss outstanding project issues.
- External Structure: NSO conducts the construction project. NSF funds NSO operations and maintenance (O&M) and DKIST design and construction via separate cooperative support agreements (CSAs) beneath an overarching cooperative agreement (CA) with the managing organization, the Association of Universities for Research in Astronomy, Inc. (AURA). The DKIST CSA for construction expires June 30, 2020. In 2015, the NSO CA and O&M CSA were renewed through the end of FY 2024. This period covers the DKIST construction phase and the achievement of sustainable operations of the completed facility. The DKIST director is a senior NSO scientist who was a leader in

the development of the science case and an expert in the field of solar adaptive optics, a critical technology for DKIST. The project manager has experience in large telescope development, having served as lead telescope engineer for the Gemini Telescopes project. Several councils and working groups give input from the solar and space physics communities.

Reviews

- Management, Cost, and Schedule reviews: DKIST scope, schedule, budget estimate, and risk-adjusted total project cost were scrutinized and validated at the Preliminary Design and Final Design Reviews.
- Programmatic Review: A comprehensive external programmatic review of the DKIST MREFC construction project took place April 8-10, 2019 in Boulder, CO. In addition to an assessment of the project's status against the Project Execution Plan, the review focused on establishing the criteria for project close-out and acceptance. The panel's final report was submitted to NSF and the results reviewed by NSF and transmitted to the project. NSF continues to work with the project to address any outstanding recommendations.
- Earned Value Management (EVM) System Surveillance: In conjunction with the programmatic review described above, a one-day surveillance of the project's EVM system was conducted on April 10-11, 2019. This surveillance provided an updated assessment of the project's previously validated EVM system. The final assessment report was submitted to NSF and transmitted to the project. NSF continues to work with the project to address any outstanding recommendations.



NSF's DKIST images the sun in more detail than ever seen before. The telescope can image a region of the sun 38,000km wide. Close up, these images show large cell-like structures hundreds of kilometers across and, for the first time, the smallest features ever seen on the solar surface, some as small as 30km. *Credit: NSO/NSF/AURA.*

Project Status

The DKIST project continues to make progress on construction at the summit of Haleakalā on Maui, HI, while remaining in compliance with all local, state, and federal environmental and cultural requirements. The project continues to consult with various stakeholders on a regular basis including the Hawaiʻi Department of Land and Natural Resources, the Hawaiʻi Department of Fish and Wildlife, the U.S. Fish and Wildlife Service, the Federal Aviation Administration, the National Park Service, and Native Hawaiʻian cultural practitioners.

Construction highlights

- In early FY 2019, DKIST achieved its first images of star light and completed its first pointing model using a temporary Nighttime Acquisition Telescope mounted at the telescope prime focus.
- In FY 2019, the project continued to implement the critical integration, testing, and commissioning (IT&C) phase of construction.
- Fabrication of the first of the DKIST instruments, the visible broadband imager (VBI), was completed and the VBI installed in the DKIST coudé laboratory on the summit in FY 2019.
- In early FY 2020, the Wave Front Correction (WFC) system was installed and tested on the summit of Haleakala. The WFC is the heart of the DKIST adaptive optics system that corrects for distortions due to the Earth's atmosphere.
- In FY 2020 the project achieved another Level 1 milestone, i.e., first light on the Sun through the entire optical path including the WFC. As part of this first-light initiative, the VBI instrument recorded the highest resolution images of the Sun ever made.

In FY 2020 the project will continue to work through the final stages of IT&C and the integration of the remaining first-light instruments. By Q4 of FY 2020, it is expected that DKIST will have achieved its final Level 1 milestone—Start of Operations.

Cost and Schedule

The original baseline not-to-exceed, risk-adjusted cost was established following FDR. As noted above, a revised project baseline review was held in October 2012; NSB approved the new baseline in August 2013. Total project cost of $344.13 million is derived from ARRA ($146.0 million) and annual appropriations in the MREFC account ($198.13 million). A Monte Carlo analysis of the risk-adjusted project end date at the time of the project re-baseline indicated June 2020 at an 80 percent confidence level for successful completion. The project is currently on track for a FY 2020 end date within the authorized funding level of $344.13 million.

Risks

Project management control, interface control, and change controls are in place. The project also maintains a risk register that is reviewed and updated monthly.

Technical: Most of the remaining technical risks are relatively low because of the long development and design phase. The CSA between NSF and AURA identifies four facility-class instruments to be delivered by the DKIST project at the end of the MREFC construction phase. The Project is on track to deliver those four instruments. The VTF is a fifth instrument and is an in-kind contribution from the German KIS being designed and developed through a Memorandum of Understanding between AURA and KIS; therefore, the risks for this instrument remain with the German institute. KIS is currently on track to deliver the VTF instrument to DKIST prior to the start of operations.

Environmental and Cultural Compliance: AST, NSF's OGC, and the DKIST project have carefully worked through the applicable statutes, and a cultural monitor has been retained during construction. All required permits are in place and semi-annual consultations with a Native Hawaiʻian working group continue. Following the November 2012 issuance of the CDUP as mentioned in the Baseline History section above, several challenges to both the CDUP and the University of Hawaiʻi's Haleakalā Observatory (HO) management plan made their way through the State court system. In October 2016, the Hawaiʻi Supreme Court ruled against the appellant in both cases, upholding both the project's CDUP and the HO management plan. On March 27, 2019, NSF received approval from the State of Hawaiʻi Division of Forestry and Wildlife for early termination of its environmental obligations as outlined in the Habitat Conservation Plan (HCP) and Incidental Take License (ITL). Remaining environmental and cultural compliance risks are very low.

Environmental Health and Safety: NSO has a well-developed safety program engendered in the DKIST project. The DKIST project has developed a site safety plan and conducts annual external safety reviews. In addition, safety updates are provided to NSF by the project on a monthly basis and DKIST project safety is one of the topics covered in the annual external program reviews.

Operations Costs

DKIST operations are funded through R&RA. In FY 2021, the projected budget is $17.54 million for DKIST operations. FY 2020 was the final year of the 10-year award for cultural mitigation activities.

HIGH LUMINOSITY-LARGE HADRON COLLIDER UPGRADE (HL-LHC) **$33,000,000**

The FY 2021 Request for the HL-LHC Upgrade is $33.0 million. This funding will support ongoing component upgrades of the A Toroidal LHC ApparatuS (ATLAS) and Compact Muon Solenoid (CMS) detectors to operate at the High Luminosity-Large Hadron Collider (HL-LHC). This is the second year of a five-year construction program that is expected to begin in FY 2020. See the Baseline History section below for more details on the approval timeline.

Appropriated and Requested MREFC Funds for the High Lumosity-Large Hadron Collider Upgrade
(Dollars in Millions)

FY 2020	FY 2021 Request	FY 2022 Estimate	FY 2023 Estimate	FY 2024 Estimate	FY 2025 Estimate	Preliminary Total Project Cost[1]
$33.00	$33.00	$36.00	$33.00	$18.00	-	$153.00

[1] Final number is pending NSB authorization, expected February 4, 2020.

The Large Hadron Collider (LHC) is the world's largest and highest-energy particle accelerator. Located near Geneva, Switzerland and operated by the European Organization for Nuclear Research (CERN), the LHC can accelerate and collide counter-propagating bunches of protons at a total energy of 14 tera-electron volts. Physicists study the debris from these collisions to learn about the elementary particles and fundamental forces that shape the universe. ATLAS and CMS are two general purpose detectors used by researchers to observe these collisions and analyze their characteristics. Detailed discussion of the current operations of LHC funded by NSF may be found in the Facilities Chapter.

Baseline History

Since 2011, U.S. funding for ATLAS and CMS O&M has included investments in advanced research and development (R&D) for investigations into detector modifications. These modifications will enable them to function at much higher collision rates following an upgrade to the LHC to increase its luminosity. The ATLAS and CMS groups, comprised of researchers from all participating countries, each developed a scoping document[1] that described its scientific goals and the technical path forward for operation in the challenging HL-LHC environment.

In 2014, the Particle Physics Project Prioritization Panel (P5), a subcommittee of the High Energy Physics Advisory Panel that advises NSF and the U.S. Department of Energy (DOE), recommended U.S. participation in the detector upgrades. In fall 2014, MPS charged a subcommittee of the MPS Advisory Committee (MPS AC) to advise on an appropriate response. The subcommittee, with MPS AC endorsement, recommended NSF provide construction funding at the MREFC level to enable meaningful participation by NSF-supported scientists in the HL-LHC research program.

In November 2015, the NSF Director approved entry of the HL-LHC Upgrade to the ATLAS and CMS detectors into the Conceptual Design phase. The principal objectives of this activity were to define a quantitative statement of science requirements, develop a flow-down of the science requirements to a set of technical requirements, define the major technical components, and provide NSF with a top-down estimate of the associated cost, schedule, and risk. Conceptual Design Reviews (CDR) in March-April 2016

[1] ATLAS: www.cds.cern.ch/record/1502664?ln=en; CMS: http://cds.cern.ch/record/2020886

established the major functional elements of each detector designated for NSF support and determined that these elements would enable the principal science objectives within the estimated $150.0 million funding envelope defined by NSF in consultation with the MPS AC.

In August 2016, the NSF Director approved entry into the Preliminary Design phase. The principal goals of this phase were to develop a detailed technical description of the scope to be fabricated, the risk-adjusted total project cost (TPC) for each detector based on bottom-up cost estimates, the corresponding resource-loaded schedules, year-by-year budget profiles for construction, and plans for managing risk. NSF directed that the initial estimated TPC not exceed $150.0 million, or $75.0 million for each detector. NSF conducted Preliminary Design Reviews (PDR) of CMS and ATLAS in December 2017 and January 2018 respectively, which established that both projects met the PDR requirements. The review panels expressed confidence that the MREFC scope for each detector upgrade could be accomplished within its individual preliminary $75.0 million MREFC budget target. NSF subsequently carried out a comprehensive cost analysis that supported the basis of estimate for the requested construction budgets.

In July 2018, NSB authorized the NSF Director to include construction of the High Luminosity upgrades to the ATLAS and CMS detectors in a future Budget Request.

Final Design Reviews (FDRs) held in September 2019 validated the construction-readiness of the upgrade plans. The FDRs established that the potential impacts of remaining pre-construction design and development are adequately bounded within the risk-adjusted budget of each collaboration. In this review process, the CMS budget was adjusted upward by $3.0 million to cover possible increased costs related to critical components. The NSF director will seek NSB's authorization to begin construction in FY 2020, with a five-year MREFC award totaling $153.0 million.

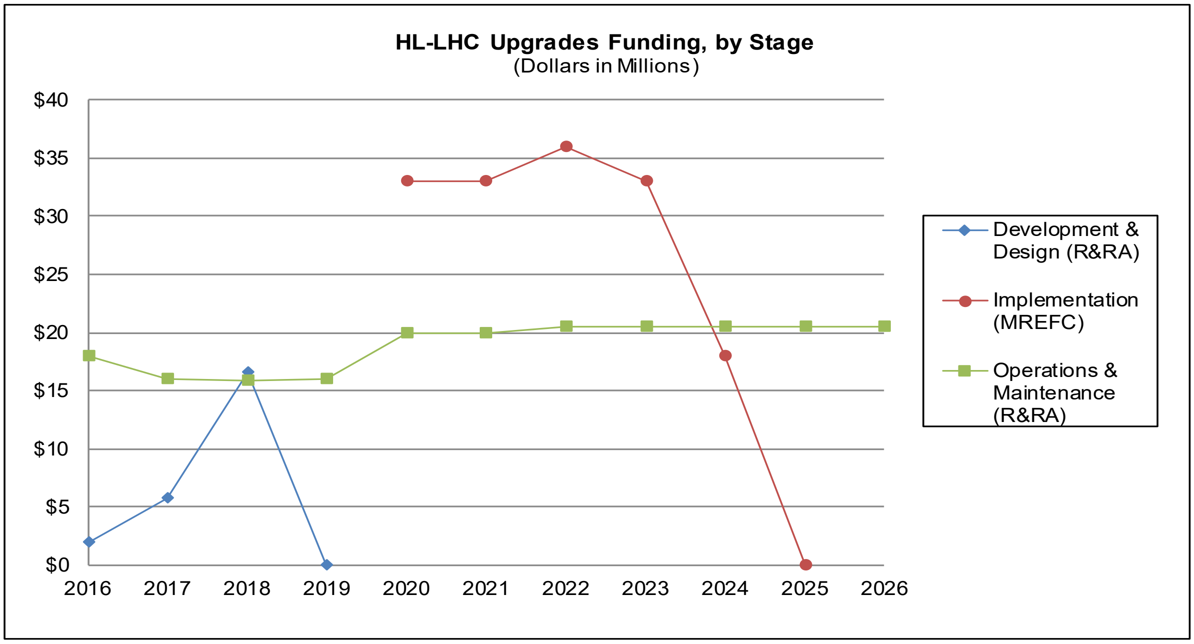
Total Funding Requirements for HL-LHC Upgrade

(Dollars in Millions)

	Cumulative Prior Years	FY 2019 Actual	FY 2020 Request	FY 2021 Request	ESTIMATES[1] FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
R&RA:									
Development & Design	$24.31	-	-	-	-	-	-	-	-
Operations & Maintenance[2]		16.00	20.00	20.00	20.50	20.50	20.50	20.50	20.50
Subtotal, R&RA	$24.31	$16.00	$20.00	$20.00	$20.50	$20.50	$20.50	$20.50	$20.50
MREFC:									
Implementation	-	-	33.00	33.00	36.00	33.00	18.00	-	-
Subtotal, MREFC	-	-	$33.00	$33.00	$36.00	$33.00	$18.00	-	-
TOTAL REQUIREMENTS	**$24.31**	**$16.00**	**$53.00**	**$53.00**	**$56.50**	**$53.50**	**$38.50**	**$20.50**	**$20.50**

[1] Outyear funding estimates are for planning purposes only. The current cooperative agreements end in December 2021 (CMS) and January 2022 (ATLAS).

[2] O&M funding represents operations support for the current LHC facility and is forecast to remain constant at a level of $20.50 million during the HL-LHC upgrade. Installation, integration, and system testing of the upgraded detectors will be coordinated by CERN during 2025-2027. NSF's share of installation and commissioning costs is estimated at $5.0 million per detector, which will be funded from the FY 2025-2027 O&M budgets.



HL-LHC Science Plan

Initial operation of the LHC, and the ATLAS and CMS detectors, enabled the discovery of the Higgs boson in 2012, leading to the 2013 Nobel Prize in Physics. The Higgs mechanism explains how fundamental particles acquire mass. This represents the last major piece in the Standard Model of Particle Physics, which describes all fundamental particles and their interactions. Despite this historic accomplishment, the ATLAS and CMS experiments have only scratched the surface of the ultimate physics potential of the LHC.

There are many open fundamental questions in particle physics. Three key science questions that the HL-LHC program will address are:

- What are the properties of the Higgs boson?
- Are there new particles and interactions beyond those predicted by the Standard Model?
- What is the nature of Dark Matter?

To answer these questions, researchers must compare theoretical predictions with observations of various rare processes, such as those involving the Higgs boson, that could be sensitive indicators of new physical phenomena. Discovering meaningful departures from theoretical predictions will require high precision measurements and the collection of a data sample more than two orders of magnitude larger than the one used for the Higgs discovery in 2012. To accomplish this, CERN plans to upgrade the accelerator, which will be renamed the High Luminosity-LHC, to deliver the high intensity proton beams required. In parallel, NSF proposes to fund the construction of critical components of the ATLAS and CMS detectors that will allow them to record and analyze the torrent of data to be produced. The accelerator enhancements and the detector upgrades are expected to be installed and commissioned from 2025 through mid-2027.

More than 45 funding agencies worldwide are contributing various components of the upgraded detectors; NSF and DOE each anticipate significant contributions, and together fund the U.S. HL-LHC program that is responsive to the P5 recommendation. NSF investments in the upgrades will enable university-based U.S. scientists and students to participate in the HL-LHC experimental program. NSF is working closely with DOE to coordinate development and design activities and to jointly oversee each detector's operation. HL-LHC will commence ten years of operation in mid-2027 to produce more than ten times the data collected by LHC operation through 2024.

Management and Oversight

NSF Structure: NSF oversight is handled by a program officer in PHY. Cross-foundation coordination is provided by an integrated project team that includes staff from MPS, BFA, EHR, OISE, the Office of the Director, the Office of the General Counsel, and the Office of Legislative and Public Affairs. Within BFA, the Large Facilities Office and the Division of Acquisition and Cooperative Support provide advice to program staff and assist with agency oversight and assurance. The MPS Facilities team and NSF's Chief Officer for Research Facilities also provides high-level guidance and oversight support for the project. The NSF program officer works closely with PHY colleagues overseeing the Experimental Particle Physics research program at NSF, and with counterparts in the DOE Office of High Energy Physics. Interagency coordination is accomplished through a Joint Oversight Group (JOG), which meets semi-annually. The framework for joint DOE/NSF oversight of the U.S. led portion of the international ATLAS and CMS collaborations has a successful history spanning two decades. It is based on an initial interagency memorandum of understanding (MOU) implemented in December 1999 and superseded in March 2018 to encompass HL-LHC activities.

External Structure: NSF-funded principal investigators at Columbia and Cornell will be responsible for accomplishing the NSF-designated scope. NSF- and DOE-funded activities, which together form the U.S. collaboration for ATLAS and CMS, are coordinated through the JOG as described above. The U.S. collaborations coordinate with the international ATLAS and CMS project leadership to accomplish the entire upgrade program. The NSF construction scope for ATLAS and CMS was selected, at the outset of Conceptual Design, to be minimally coupled to other construction activities of DOE or international partners so that NSF's construction can be executed as two relatively independent projects within the overall scope of upgrade activities. NSF currently receives monthly financial and technical status reports on pre-construction planning activities. Revisions to the scope, budget, and schedule baselines will be reported to NSF, and revisions exceeding thresholds defined in the cooperative agreements for construction will require prior NSF approval.

Interaction with CERN: In May 2015, DOE, NSF, and CERN executed a cooperation agreement concerning scientific and technical cooperation in nuclear and particle physics. The cooperation agreement establishes the framework under which DOE, NSF, and their awardees, as well as DOE national laboratories, participate in the particle physics programs in the international ATLAS and CMS detector collaborations (under the auspices of CERN) in the era of the HL-LHC. Subject to availability of appropriated funds, NSF's total contributions to the HL-LHC Upgrade program will be specified and incorporated under separate implementing arrangements in the form of addenda to the 2015 cooperation agreement. The CERN LHC Resources Review Boards (separate boards for ATLAS and CMS) are composed of representatives from each participating funding agency. The Boards monitor and oversee resource-related matters as defined by the framework for participation in each experiment. NSF is a full member of these LHC Resources Review Boards. The Boards meet semi-annually to approve all LHC upgrade planning at the international level.

Reviews

- CDR: March 2016 (ATLAS); March and April 2016 (CMS).
- PDR: January 2018 (ATLAS); December 2017 (CMS).
- Review of the O&M Plans of ATLAS and CMS for CY 2017-2021 (whose scope includes development and design activities for the detector upgrades): July 2016 (ATLAS); July 2016 (CMS).
- CERN international committee reviews: Major subsystems of the combined international effort were scientifically and technically reviewed by the CERN LHC Committee (LHCC), an international

committee of technical experts, followed by a cost and schedule review by the CERN Upgrade Cost Group, an international committee of technical and financial experts, which reported to the LHCC (July 2017-April 2018).

- FDR: September 2019 (ATLAS and CMS).
- Full Life-cycle Cost Reviews: NSF held reviews of the cost impacts of the MREFC upgrades on the LHC operations program in October 2019.

Project Status

The ATLAS and CMS FDRs established that each detector collaboration had completed all NSF-mandated pre-construction preparation needed to enable construction to commence in April 2020. The FDR panels considered each of the construction readiness criteria in NSF's Major Facilities Guide and advised NSF on whether they had been satisfied. The FDR panels also evaluated the sufficiency of each collaboration's response to the recommendations from prior reviews and offered suggestions to NSF on areas to follow closely during construction. NSF and the NSB are conducting additional assessments to assure readiness for an April 2020 construction start. NSF's Large Facilities Office is leading an Independent Cost Estimate of each project as part of the overall cost assessment process carried out by BFA. These will be completed and satisfactorily reconciled prior to awarding construction funds in FY 2020.

Cost and Schedule

The planned April 2020 construction start date is dictated by the need to complete fabrication and delivery to CERN to meet the international integration schedule for CY 2025-2027. A significant delay could result in the transfer of critical NSF-funded scope to other international partners for accomplishment, resulting in lost leadership opportunities for U.S. scientists. NSF's contributions to the ATLAS and CMS upgrades represent about six percent of the international detector upgrade program.

The MREFC project will be completed when the NSF-funded apparatus is delivered and passes verification of delivery in good condition at CERN. Installation, integration, and system testing will be coordinated by CERN during CY 2025-2027. NSF's share of installation and commissioning costs is estimated at about $5.0 million per detector, which will be funded from the FY 2025-FY 2027 O&M budgets. The annual O&M cost is forecast to remain constant during and following the HL-LHC Upgrade installation.

Risks

Technical Risk: Technical designs are sufficiently mature to credibly support estimates of the costs to complete development and industrialization, and of construction. Remaining technical decisions during the Final Design stage have credibly bounded cost and schedule impacts. There are multiple alternatives for dealing with the remaining design uncertainties.

Deployment Risk: The MREFC project concludes with delivery and verification of subcomponent operability at CERN. CERN has overall responsibility for assembly, integration, and commissioning of the upgraded detectors, integrating the contributions from more than 40 different countries. While a slip in the CERN schedule will delay scientific research, the total project cost of the NSF-funded construction projects is not anticipated to increase. A significant delay may increase demands on NSF's O&M beyond 2027.

Management Risk: The FDRs established that the ATLAS and CMS management teams are well-qualified and well prepared to undertake the proposed construction activities, with appropriate organizational structures and delegations of responsibility. The review committees reported each team's development of cost and schedule estimates was based on sound assumptions and methods that are consistent with best practices defined by the Government Accountability Office in the Cost Estimating and Schedule

Assessment guides. The FDR panels also expressed confidence that each upgrade can be accomplished within its estimated TPC, after adjusting the CMS estimate upward by $3.0 million to cover possible increased costs related to critical components. The ATLAS and CMS Project Execution Plans include detailed risk management considerations and mitigation strategies. The risk impacts of remaining development uncertainties, prior to the start of construction, are reasonably bounded within the proposed cost, scope, and schedule estimates.

Partnership Risk: The NSF scope for the detector upgrades relies on the successful and timely completion of development testing by international partners of some key components, such as radiation-tolerant custom electronic circuits. A second partnership risk is that the detector fabrication activities within the NSF scope rely in part on DOE and NSF research grants to universities. Faculty, post-docs, and graduate students will participate in the management, testing, characterization, and software development of detector components fabricated by engineers and technicians. While the engineering and technical labor is funded through the MREFC awards, the faculty, post-docs, and graduate students are supported by research grants from DOE and NSF to universities and colleges. Risks and contingency budgets were refined through the FDR process to assure NSF that partnership risks are confidently addressed.

Disposal Costs: CERN's policy is to dispose of all detector components when they are no longer used in the detectors. NSF will be responsible only for covering its share of the demolition costs to remove each detector from its underground operating location and transport it to the surface for disposal by CERN. At the Full Life-Cycle Cost Reviews each detector estimated these costs at approximately $1-2 million (not escalated).

Future Operations Costs

An additional agreement between NSF, DOE, and CERN ("Experiments Protocol II"), signed in December 2015, documents the responsibilities of U.S. participants to provide normal maintenance and operation of detector subsystems and components provided by NSF and DOE. Future MOUs with CERN will describe the distribution of tasks and other responsibilities for all participating institutions, including those supported by NSF, as well as the organizational, managerial, and financial guidelines to be followed by each detector collaboration. NSF anticipates providing approximately three percent of the total operation cost of the ATLAS and CMS detectors during HL-LHC operation (as it does today). This proportion is based on the number of NSF-supported scientists in each collaboration. NSF's external reviews of the impacts of the HL upgrades on future operating costs indicated that these operating cost projections are reasonable and are based on realistic assumptions.

A well-orchestrated global effort is underway, progressing in parallel with the HL-LHC detector upgrades, to meet the challenges of computing in the HL era. ATLAS and CMS are coordinating their efforts within this framework to seek common solutions. This improved coordination extends to the U.S. funding agencies, other funding agencies, and CERN. NSF conducted external reviews (the Full Life-Cycle Cost Reviews mentioned earlier) of the impacts of future computing needs on the operations program. The reviewers expressed confidence that the multiple software research programs now underway to address these challenges are likely to provide affordable solutions. Many of the R&D tasks underway are promising, and only a subset needs to be successful to meet the needs of the HL operating program.

MID-SCALE RESEARCH INFRASTRUCTURE TRACK 2 (MID-SCALE RI-2) $65,000,000

The Mid-scale Research Infrastructure program is an NSF-wide effort to meet the research community's needs for modern research infrastructure to support priority science and engineering research. The overall Mid-scale RI program is described in the NSF-wide Investments chapter of this Budget Request. Here, we describe Track 2 (Mid-scale RI-2) of this "enabling" Big Idea, covering projects with individual implementation costs between $20.0 million and $100.0 million,[1] with funding requested from the MREFC account.

Appropriated and Requested MREFC Funds for the Mid-Scale Research Infrastructure Track 2 Program

(Dollars in Millions)

FY 2020	FY 2021 Request	FY 2022 Estimate	FY 2023 Estimate	FY 2024 Estimate
$65.00	$65.00	$65.00	$65.00	$65.00

Baseline History

The scientific importance of mid-scale research infrastructure is reflected in the 2017 American Innovation and Competitiveness Act (AICA), which directed NSF to "evaluate the existing and future needs, across all disciplines supported by the Foundation, for mid-scale projects." NSF issued a Request for Information in late 2017 that resulted in nearly 200 ideas for research infrastructure with project costs in the $20.0 million to $100.0 million range, amounting to a prospective demand for approximately $10 billion in funding. Mid-scale RI-2 funding is intended to respond directly to that demand.

In the 2018 appropriation for NSF, report language from the House of Representatives directed "the National Science Board (NSB), in collaboration with the National Academies of Science, Engineering, and Medicine (NASEM), to consider steps to bridge the gap between the NSF's Major Research Instrumentation Program (MRI) and the agency's Major Research Equipment and Facility Construction (MREFC) account and to develop appropriate processes to address this matter through the MREFC account within a restricted funding environment." An NSF-wide strategy for mid-scale projects, also directed by AICA, was deferred until the NSB completed their report in response to the Congressional direction. In that report (NSB-18-40),[2] the first two of the four recommendations of NSB were the following:

- NSF should affirm and sustain the mid-scale Big Idea with a long-term *agency-level* commitment to mid-scale research infrastructure.
- NSF should investigate the feasibility of using the MREFC account as one possible funding mechanism.

NSF responded to these recommendations and the AICA mandate to develop a strategy with the detailed Mid-scale RI program that is described in the NSF-Wide Investments chapter of this Budget Request. As part of that strategy, funding for the mid-scale projects with implementation costs above $20.0 million was requested in the MREFC account as Track 2 of an NSF-wide mid-scale program, and funding was appropriated in that account in FY 2020. NSF issued its first solicitation for Mid-scale RI-2, NSF 19-542,[3]

[1] The first NSF-wide Mid-scale RI-2 solicitation called for implementation proposals with total project costs in the range from $20.0 million to $70.0 million. The long-term intent is for Mid-scale RI-2 to cover a range extending up to $100.0 million, to be maximally consistent with the definition of major multi-user research facility projects in the American Innovation and Competitiveness Act.

[2] www.nsf.gov/nsb/publications/2018/NSB-2018-40-Midscale-Research-Infrastructure-Report-to-Congress-Oct2018.pdf

[3] www.nsf.gov/pubs/2019/nsf19542/nsf19542.htm

in December 2018, requesting proposals with total implementation costs in the range between $20.0 million and $70.0 million.

Since Mid-scale RI-2 is intended to be a portfolio of implementation awards that may range across all NSF communities, it does not have a single set of a-priori scientific goals. In the initial solicitation, NSF stated that "the Mid-scale Research Infrastructure Program is aimed at transforming scientific and engineering research fields as well as science, technology, engineering and mathematics (STEM) education research fields by making available new capabilities, while simultaneously training early-career researchers in the development, design, and construction of cutting-edge infrastructure." The solicitation specifically called for proposals "that comprise any combination of equipment, instrumentation, computational hardware and software, and the necessary commissioning and human capital in support of implementation of the same." Past examples of mid-scale-size awards in individual directorates have included items such as mid-size telescopes or telescope systems, replacement of the Palmer Pier in Antarctica, advanced supercomputing systems, and higher-sensitivity instrumentation at LIGO.

Total Funding Requirements for Mid-scale RI-2[1]

(Dollars in Millions)

	Prior Years	FY 2019 Actual	FY 2020 Estimate	FY 2021 Request	ESTIMATES				
					FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
R&RA:									
Development & Design	-	-	-	-	-	-	-		
Subtotal, R&RA	-	-	-	-	-	-	-	-	-
MREFC:									
Implementation	-	-	$65.00	65.00	65.00	65.00	65.00	65.00	65.00
Subtotal, MREFC	-	-	$65.00	$65.00	$65.00	$65.00	65.00	65.00	65.00
TOTAL REQUIREMENTS	**-**	**-**	**$65.00**	**$65.00**	**$65.00**	**$65.00**	**$65.00**	**$65.00**	**$65.00**

[1]Operations costs to be borne by the lead disciplinary directorates are not included in this table but are discussed below in the section on Future Operations Costs.

Management and Oversight

Mid-scale RI-2 proposals have been solicited from all disciplines covered by NSF, as noted above. In anticipation of the funding of such proposals, the NSF Major Facilities Guide (NSF 19-068)[4] was updated with an extensive discussion of management and oversight processes for Mid-scale RI, found in Section 5 of that Guide. Because of the varied nature of potential Mid-scale RI-2 awards, the Major Facilities Guide states the following:

> "Mid-scale project oversight requirements are to be tailored based on each project's unique characteristics such as the technical scope, the type and mix of work performed (e.g. standard procurement by the Recipient, software development, or civil construction), and an assessment of the associated technical and programmatic risks. However, NSF is committed to the principle that this flexibility does not preclude the requirement for appropriate rigor on the part of NSF or the Recipient. Appropriate use of NSF major facility oversight practices will be determined on a case-by-case basis."

[4] www.nsf.gov/pubs/2019/nsf19068/nsf19068.pdf

In order to enable appropriate oversight, all Mid-scale RI-2 proposals were required to submit an extensive Project Execution Plan that will help NSF determine the appropriate oversight for each project once awards are made.

Reviews

The Mid-scale RI-2 proposals do not go through the Conceptual/Preliminary/Final Design stages of major facility projects, enabling a more agile process for these substantial, but smaller, projects. However, the Mid-scale RI-2 program only considers projects at a high state of readiness for implementation that have reached that mature stage through previous developmental investments. The solicitation was designed to include a two-step, pre-proposal/full-proposal process in order to limit the burden on the research community of both preparing and reviewing full proposals. Lead NSF directorates were identified for the review of each pre-proposal and proposal, based on the proposal submissions and assessments by NSF. Pre-proposals were externally reviewed according to the standard NSF merit review criteria and six solicitation-specific review criteria, with a subset invited to submit full proposals. Those full proposals were again externally reviewed, with a subset of these full proposals invited to a Reverse Site Visit (again with an external panel) for detailed assessment of the Project Execution Plans.

Based on the extensive input from external merit review, the most meritorious proposals were identified by the lead directorates and submitted to the Mid-scale RI-2 Working Group. That working group prepared sample portfolios of those proposals at different levels of total funding, and forwarded them to the Office of the Director. The Director will recommend a portfolio of awards to the National Science Board at its May 2020 meeting, which will consider the portfolio and then authorize any awards. All proposals reaching this final stage of portfolio selection demonstrate highly meritorious science. The final portfolio recommendation also will include consideration of the project readiness as evaluated by the Reverse Site Visits, breadth of science disciplines to be awarded, diversity in awardees and awardee institutions, and contributions to student training and workforce development. During the recommendation process, NSF's Office of Budget, Finance, and Award Management will also carry out rigorous cost analyses of the projects that are candidates for award, consistent with AICA requirements for MREFC-funded projects, and in order to assure best value for the taxpayer dollar. It is anticipated that the first awards will be started with the funds appropriated by Congress in FY 2020.

Project Status

The final steps in the portfolio selection and award process are in progress and anticipated for completion late in FY 2020. Depending on the status of the Project Execution Plans and the NSF cost analyses, some awards may not be made until FY 2021.

Cost and Schedule

FY 2020 funds will be used to make the first Mid-scale RI-2 awards, most of which are anticipated to last for five years. A sample budget portfolio for multiple solicitation rounds is shown in the table below.

Sample Budget Profile for Mid-Scale RI-2 Porfolio
(Dollars in Millions)

	FY 2020 Estimate	FY 2021 Request	FY 2022 Estimate	FY 2023 Estimate	FY 2024 Estimate	FY 2025 Estimate
Solicitation 1	$65.00	$65.00	$30.00	$30.00	$30.00	-
Solicitation 2	-	-	35.00	35.00	35.00	30.00
Solicitation 3	-	-	-	-	-	35.00
Total	**$65.00**	**$65.00**	**$65.00**	**$65.00**	**$65.00**	**$65.00**

Risks

Technical risks and risk management for the individual projects have been included as part of the Project Execution Plans and evaluated rigorously by an external panel of experts. The final portfolio recommendation will also rely significantly on an evaluation of agency risks. These will include, for example, a constraint that not all of the projects should be very high or very low risk, assessment of any potential partnership risks, the risk that events out of the control of an awardee might significantly impact an individual project, or the risk of overcommitting future budgets such that the next solicitation might be significantly delayed.

Future Operations Costs

The Mid-scale RI-2 solicitation specifically prohibited inclusion of operations costs in the individual project budgets, but proposers were required to present operations and utilization plans as well as estimates of full lifecycle costs. For each individual proposal considered for inclusion in the award portfolio, the lead directorate was required to estimate and commit to any additional operations costs in order to reap the scientific benefits of an award. At a hypothetical level of $220.0 million in awards from the first solicitation, and anticipating maximum operations costs of 10 percent of the capital costs per year, the total operations cost impact from the first round of Mid-scale RI-2 awards would ramp up to a steady state of no more than $22.0 million per year by about FY 2025. If any awarded proposals in the portfolio are upgrades to existing facilities or instrumentation, the anticipated increment to annual operations costs could be considerably less.

REGIONAL CLASS RESEARCH VESSELS (RCRV) $0

The RCRV Project is being constructed in a three-year funding profile within an NSB approved not-to-exceed total project cost of $353.97 million. In FY 2017, P.L. 115-31 appropriated $121.88 million to facilitate the planning and construction of three vessels. In FY 2018 P.L. 115-141 appropriated $105.0 million to continue construction of three vessels. In FY 2019, P.L. 116-6 appropriated $127.09 million, sufficient funding to complete construction of three vessels. This narrative provides a history and project status.

Appropriated and Requested MREFC Funds for the Regional Class Research Vessel Project
(Dollars in Millions)

FY 2017	FY 2018	FY 2019	FY 2020	FY 2021 Request	Total Project Cost
$121.88	$105.00	$127.09	-	-	$353.97

The 2015 National Academies of Sciences, Engineering, and Medicine (the National Academies) report, *Sea Change: 2015-2025 Decadal Survey of Ocean Sciences*,[1] described eight high-priority science questions that will be supported by RCRV in U.S. coastal waters:

1. What are the rates, mechanisms, impacts, and geographic variability of sea level change?
2. How are the coastal and estuarine ocean and their ecosystems influenced by the global hydrologic cycle, land use, and upwelling from the deep ocean?
3. How have ocean biogeochemical and physical processes contributed to today's climate and its variability, and how will this system change over the next century?
4. What is the role of biodiversity in the resilience of marine ecosystems and how will it be affected by natural and anthropogenic changes?
5. How different will marine food webs be at mid-century? In the next 100 years?
6. What are the processes that control the formation and evolution of ocean basins?
7. How can risk be better characterized and the ability to forecast geohazards like mega-earthquakes, tsunamis, undersea landslides, and volcanic eruptions be improved?
8. What is the geophysical, chemical, and biological character of the subseafloor environment and how does it affect global elemental cycles and understanding of the origin and evolution of life?

Baseline History

The RCRV project is a major component in the plan for modernizing the U.S. Academic Research Fleet.[2] In 2001, a report from the Federal Oceanographic Facilities Committee documented the need for Regional Class vessels. In 2004, NSF and the Naval Sea Systems Command (NAVSEA) entered into an interagency agreement that resulted in two candidate designs for Regional Class ships. In 2007, the Federal Oceanographic Fleet Status Report identified the need for NSF-built Regional Class vessels to meet future science demand. In 2009, another National Academies report, Science at Sea, described the desirable characteristics of a modern Regional Class vessel. These characteristics and other science community factors were considered by the review panel when the preferred NAVSEA design was later down-selected. In 2012, NSF issued a solicitation for the refreshed design and potential construction of RCRV. Oregon State University (OSU) was selected and received the award in 2013. Input from external review panels,

[1] The National Academies. Sea Change: 2015-2025 Decadal Survey of Ocean Sciences, 2015. www.nap.edu/read/21655/chapter/1

[2] National Ocean Council. Federal Oceanographic Fleet Status Report, 2013. https://obamawhitehouse.archives.gov/sites/default/files/federal_oceanographic_fleet_status_report.pdf

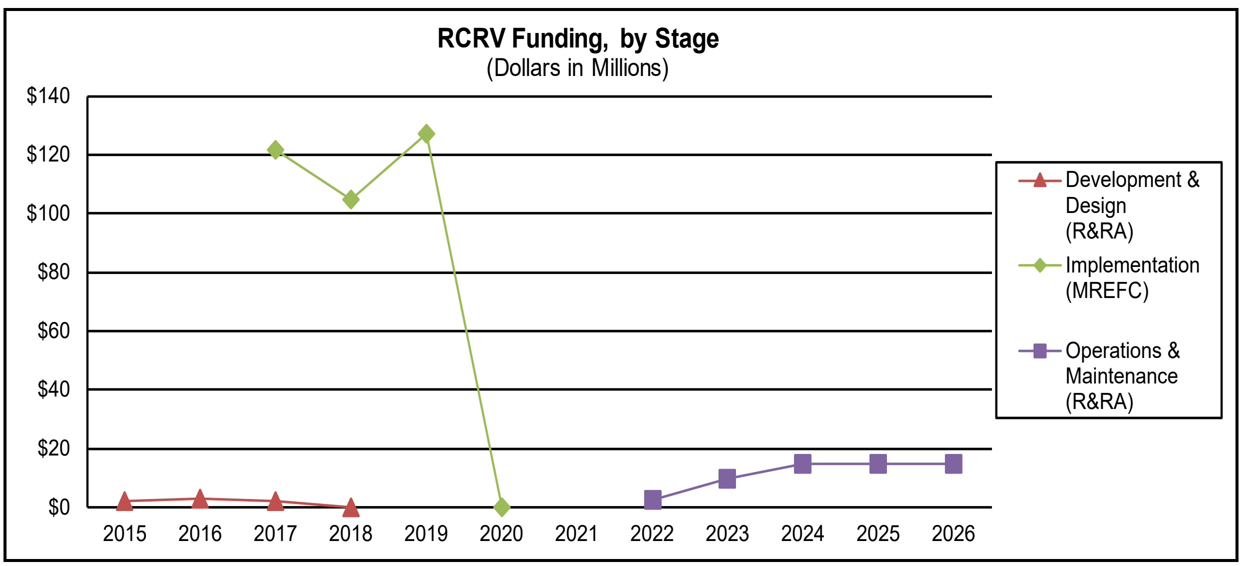
the University-National Oceanographic Laboratory System, and the National Academies *Sea Change* report, was received during the period 2013 to 2015 and informed the final decision to pursue construction. In 2015, the National Science Board authorized inclusion of funds to initiate construction for the RCRV project in future budget requests at the NSF Director's discretion. The Final Design Review was conducted in December 2016 and the panel recommended to NSF that the project was ready to advance to the construction stage. OSU awarded a contract for construction to Gulf Island Shipyards, Houma, LA. NSF plans to fund the operations of the RCRVs within the overall projected budget for the ARF, leveraging savings from fleet rightsizing through the retirement of older and less capable vessels.

Total Funding Requirements for RCRV

(Dollars in Millions)

	Prior Years	FY 2019 Actual	FY 2020 Estimate	FY 2021 Request	ESTIMATES FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
R&RA:									
Development & Design	$11.39	-	-	-	-	-	-	-	-
Operations & Maintenance	-	-	-	-	2.45	9.80	14.70	14.70	14.70
Subtotal, R&RA	$11.39	-	-	-	$2.45	$9.80	$14.70	$14.70	$14.70
MREFC:									
Implementation[1]	226.88	127.09	-	-	-	-	-	-	-
Subtotal, MREFC	$226.88	$127.09	-	-	-	-	-	-	-
TOTAL REQUIREMENTS	**$238.27**	**$127.09**	**-**	**-**	**$2.45**	**$9.80**	**$14.70**	**$14.70**	**$14.70**

[1] Includes $35.97 million carried forward into FY 2020.



Management and Oversight

- NSF Structure: The RCRV project is overseen by the Division of Ocean Sciences (OCE) as part of the Ship Acquisition and Upgrade Program. OCE provides overall interdisciplinary science community guidance and oversight, while the administrative location of the RCRV project in the Integrative Programs Section promotes science facilities support expertise and coordination. Within NSF, RCRV project oversight is managed by a dedicated program officer with support from a secondary program officer who has experience with other OCE facilities. Cross-Foundation coordination is provided by an

Integrated Project Team (IPT). The IPT includes staff from the BFA Large Facilities Office, BFA Division of Acquisition and Cooperative Support, BFA Division of Institution and Award Support, Office of the Director, Office of the General Counsel, Office of the Assistant Director for Geosciences, and Office of Legislative and Public Affairs.

- External Structure: The RCRV project is funded through a series of cooperative agreements with OSU to manage the design refresh (conceptual, preliminary, and final designs), construction, testing and trials, and eventual operation of the first RCRV for the scientific community. The principal investigator for the award is the project manager (PM), who reports directly to the OSU Dean of the College of Earth, Ocean, and Atmospheric Sciences. The PM interacts directly with the NSF Program Officer and manages the RCRV administrative staff. The project scientist is a co-principal investigator on the award. The PM manages the core RCRV team including the risk manager, earned value management and schedule specialists, contracting officer, and OSU shipyard representative (SR). The SR in turn manages the naval architect and engineering contract and oversees the OSU shipyard staff and marine science technical advisors. The RCRV Science Oversight Committee (SOC), with regional representation, multidisciplinary expertise, and independent science representatives conducting research in mission areas supported by stakeholder federal agencies (e.g., NSF, Office of Naval Research, and National Oceanic and Atmospheric Administration) will be active through all project phases. The SOC provides guidance to the OSU RCRV project team through the PM and/or the NSF program officer.

Reviews

- Proposal Review: In 2012, NSF issued Solicitation 12-558, Construction of Regional Class Research Vessels, which resulted in the selection of OSU as the lead institution for construction and ship operations.
- RCRV proceeded through the standard NSF processes that included a Conceptual Design Review (December 2013), Preliminary Design Review (August 2014) and Final Design Review (December 2016). The Final Design Review (FDR) ensured that anticipated project costs remained realistic and that no unforeseen events had arisen prior to the start of construction during FY 2017. The FDR Panel recommended that the project advance to the Construction Stage.
- Annual Progress Review: The first construction stage review was conducted in August 2018. Progress towards Design Verification and Transfer and OSU's management of the shipyard contract was evaluated. The panel expressed confidence that the OSU Team is well qualified, has extensive relevant experience in ship acquisition, has established a positive, professional working relationship with Gulf Island Shipyards, and is entirely capable of delivering up to three RCRVs, within budget and on schedule, that will meet mission requirements. Quarterly Management Reviews are conducted at the shipyard. An Annual Project Review with an External Panel is planned for February 2020 at Gulf Island Shipyards.

Project Status

OSU is managing the construction and transition to operations through a cooperative agreement with NSF, which encompasses the entire project, including tests and trials. The project is divided into four distinct phases, each to be funded through separate cooperative support agreements, with award of each phase contingent upon successful completion of the prior phase. These phases are:

Phase I: Project Refresh (Years one to three)
Phase II: Shipyard Selection (Year four)
Phase III: Construction (Years five through eight)
Phase IV: Transition to Operations (Years eight and nine)

The project completed Phase II in CY 2017, during which bids for construction of RCRV were solicited and evaluated from U.S. shipyards.

The project is now in Phase III construction. Keel-laying for the first RCRV, named R/V *Taani,* was completed in November 2018 and for the second RCRV, named R/V *Resolution*, in May 2019. A keel-laying for the third RCRV, named R/V *Gilbert R. Mason*, is planned for Spring 2020. The RCRV project includes up to one year of sea trials and science equipment testing/trials for each vessel after delivery from the shipyard to ensure readiness to safely and efficiently conduct science operations before entry into the U.S. Academic Research Fleet. This will mark the beginning of Phase IV Transition to Operations. R/V *Taani*, the first ship in the Class, is currently scheduled to be delivered in Fall 2021 and will likely begin operations in mid-late 2022. The project is planning a six-month stagger between vessel deliveries, with the projection that R/V *Resolution* will enter the ARF in early 2023 and R/V *Gilbert R. Mason* will enter in mid-late 2023.

Cost and Schedule

The length of the project is projected to be nine years, including nine months of schedule contingency. Funding for the construction of RCRV from FY 2017 through FY 2019 supports the shipyard contract structure.

Total estimated funding to OSU for RCRV through FY 2020 is $11.39 million in R&RA funds for development and design and $328.0 million in MREFC funds for construction.

A standard NSF oversight practice is to hold a portion of budget contingency and only allocating to the program, for obligation to the project, based on demonstrated need. This oversight mechanism will generally result in some MREFC carry over each year; however, future obligation is anticipated to manage project risks. An additional $25.97 million in MREFC funding is held by NSF for contingency.

Risks

<u>Technical</u>: The following technical risks are among the principal risks identified on OSU's project risk register. Planned mitigation strategies are included here with each identified risk. (1) Various situations may occur that could delay or add cost to OSU's management portion of the project. These include delayed appointments of key personnel, contracting issues, lack of management capacity due to optimistic planning, or misunderstanding of requirements. Contingency funds are included to increase OSU management capacity if needed. (2) Sonar sensors, science load handling systems, and other vessel sub-systems may not perform as required. Contingency funds are included to ensure performance capabilities are met, given that many warranties are not likely to be performance-based or are otherwise limited contractually with the shipyard. (3) Growth in weight and vertical center of gravity has required design changes, namely lengthening by six feet, to ensure vessel seaworthiness. This is a typical risk for ship construction (and research vessels in particular) that requires active management by OSU and the shipyard, as well as oversight by NSF, such that the ship can operate safely and effectively. This risk is reduced by the re-design but will not be entirely eliminated until the as-built ship is evaluated. Approximately $21.96 million in contingency has been allocated to-date as a result of realizing known risks.

A science-prioritized, time-phased de-scoping plan is in place (per NSF Large Facilities Manual, NSF17-066) to minimize impacts to science capabilities in case contingency funds are insufficient to cover realized risks.

Future Operations Costs

Annual ship operations costs are well understood after several decades of experience with vessels of all types in the U.S. Academic Research Fleet. OSU included an estimate for the first year of operations beginning in 2022 using reasonable assumptions for escalations through 2021. They also assumed a robust but reasonable operating schedule of 200 days per year. OSU estimates each RCRV will cost $7.0 million to operate in its first full year, resulting in a rate of approximately $35,000 per day, including technician support. This is comparable to the operation of current similar vessels after applying the appropriate cost escalation factors for size and complexity. NSF supports approximately 70 percent of the use of the U.S. Academic Research Fleet, which suggests RCRV is likely to cost NSF approximately $2.45 million in FY 2022 for six months of operations of the R/V *Taani*. The ultimate annual cost of approximately $14.70 million for operating three RCRVs will be balanced by cost savings from reducing scope elsewhere in the U.S. Academic Research Fleet. Solicitations for operations of additional vessels beyond the first RCRV (R/V *Taani*) operated by OSU were released in January 2018 and July 2019. The East Coast Oceanographic Consortium, whose members include the University of Rhode Island, the Woods Hole Oceanographic Institution, and the University of New Hampshire School of Marine Science and Ocean Engineering, along with 13 associate members, was selected to operate the second RCRV (R/V *Resolution*). The Gulf-Caribbean Oceanographic Consortium, whose members include the University of Southern Mississippi, the Louisiana University Marine Consortium, and 15 associate members, was selected to operate the third RCRV (R/V *Gilbert R. Mason)*.

VERA C. RUBIN OBSERVATORY $40,750,000

The FY 2021 Request for the Vera C. Rubin Observatory is $40.75 million. This is the eighth year of support for a nine-year construction project that began in August 2014. The NSB authorized award is $473.0 million for NS's contribution.

Appropriated and Requested MREFC Funds for the Vera C. Rubin Observatory

(Dollars in Millions)

FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020 Request	FY 2021 Request	FY 2022 Estimate	FY 2023 Estimate	Total Project Cost
$27.50	$79.64	$99.67	$67.12	$57.80	$48.82	$46.34	$40.75	$5.36	-	$473.00

Prior to the FY 2021 Request, this project had been called the Large Synoptic Survey Telescope. Following the passage of the Vera C. Rubin Observatory Designation Act (P.L. 116-97), the facility is now named the Vera C. Rubin Observatory. The facility's new name honors Dr. Rubin, an American astronomer who made a concerted effort to improve diversity in astronomy and whose pioneering studies of galactic rotation rates provided important evidence for the wide-spread existence of dark matter, one of the key science areas for the project. The Vera C. Rubin Observatory will be comprised of an 8.4-meter wide-field optical telescope in Chile with a 3.2 giga-pixel camera and an advanced data management system, which together are designed to carry out a deep survey of nearly half of the sky. The Rubin Observatory's initial 10-year survey has a cadence enabling repeat observation of each survey field approximately twice weekly. The requirements for the Vera C. Rubin Observatory and the survey were set by considering four key science areas:

- the physics of dark energy and dark matter;
- a census of small bodies in the Solar System, including potentially hazardous Near-Earth Objects (NEOs);
- the structure and contents of the Milky Way Galaxy; and
- the nature of transient astronomical objects on time scales ranging from seconds to years.

By satisfying the requirements defined by these key investigations, the Vera C. Rubin Observatory's initial survey will result in a comprehensive data set that will enable hundreds of fundamental astrophysical studies by the entire research community on these and other topics. Thus, the Vera C. Rubin Observatory has the potential to advance every field of astronomical study, from the inner Solar System to the large-scale structure of the Universe.

Baseline History

The Vera C. Rubin Observatory is a joint NSF and Department of Energy (DOE) project to build an instrument that was ranked as the top large ground-based astronomy project recommended by the National Academies of Sciences, Engineering, and Medicine 2010 Astronomy and Astrophysics decadal survey: *New Worlds, New Horizons in Astronomy and Astrophysics*.[1]

Prior to NSF's construction award, NSF, DOE, and private (non-federal) partners invested over $130.0 million in Vera C. Rubin Observatory-related work. About 70 percent supported design and development and about 30 percent, from the non-federal funding, supported casting and polishing of the innovative combined primary-tertiary mirror (M1M3), initial site preparation, and prototype detector creation and evaluation, all of which significantly reduced construction risk.

[1] www.nap.edu/catalog/12951/new-worlds-new-horizons-in-astronomy-and-astrophysics

NSF and DOE conducted a series of reviews in 2011 and 2012 to determine the project baseline, including the NSF Preliminary Design Review and a subsequent cost estimation review. Plans were kept up-to-date to synchronize the DOE and NSF funding profiles as reviews continued, leading to NSF's Final Design Review (FDR) in December 2013. NSF then carried out a detailed cost analysis prior to completing its approval process and making an award in the last quarter of FY 2014.

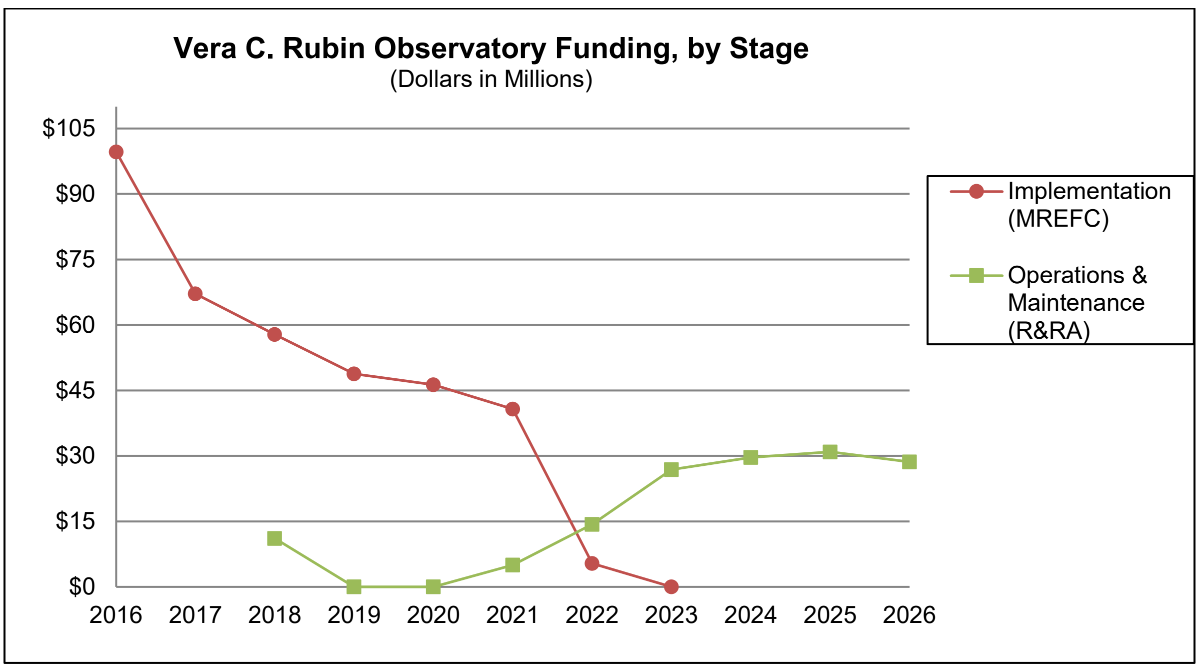
Total Funding Requirements for the Vera C. Rubin Observatory
(Dollars in Millions)

	Cumulative Prior Years	FY 2019 Actual	FY 2020 Request	FY 2021 Request	**ESTIMATES**[1] FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
R&RA:									
Development & Design	$57.13	-	-	-	-	-	-	-	-
Operations & Maintenance[2]		-	-	5.00	14.32	26.85	29.64	30.93	28.62
Subtotal, R&RA	$57.13	-	-	$5.00	$14.32	$26.85	$29.64	$30.93	$28.62
MREFC:									
Implementation[3]	331.73	48.82	46.34	40.75	5.36	-	-	-	-
Subtotal, MREFC	$331.73	$48.82	$46.34	$40.75	$5.36	-	-	-	-
TOTAL	**$388.86**	**$48.82**	**$46.34**	**$45.75**	**$19.68**	**$26.85**	**$29.64**	**$30.93**	**$28.62**

[1] Outyear funding estimates are for planning purposes only and represent preliminary estimates. A new cooperative agreement for O&M of the Vera C. Rubin Observatory for FY 2022-FY 2026 is anticipated in FY 2021

[2] O&M funding represents NSF support only and amounts to about 50 percent of the total operations cost. Support from DOE and non-federal contributors provides the balance.

[3] Includes $82,943 carried forward into FY 2020.



Vera C. Rubin Observatory Science Plan

The site on Cerro Pachón, Chile, was selected for the Vera C. Rubin Observatory because of the excellent sky transparency and image quality, dark skies, small fraction of cloudy nights, and the geological characteristics that enable the rapid telescope motions required to carry out Vera C. Rubin Observatory's ten-year survey. The Rubin Observatory will collect about 20 terabytes of multi-color imaging data every night[2] for 10 years, producing a long-lived data set of unprecedented utility. It will produce the widest-field sky image ever and issue alerts for changing and transient objects within 60 seconds of their discovery. Repeated deep imaging of every part of the accessible sky will turn up explosive events such as cataclysmic variable stars, supernovae, and the optical counterparts of X-ray flashes, as well as finding moving objects and better characterizing those already known. Estimates of the Vera C. Rubin Observatory's ability to locate NEOs[3] and Potentially Hazardous Asteroids (PHAs)[3] have been refined by Observatory project members,[4] as well as by external studies, including an independent Jet Propulsion Laboratory study[5] supported by NASA's Planetary Defense Coordination Office. Assuming other existing NEO efforts continue, at the end of the Vera C. Rubin Observatory's 10-year prime mission, the catalogue for objects larger than about 140 meters across should be about 75 percent complete for NEOs (about 80 percent for PHAs). Without the Vera C. Rubin Observatory, the completeness would be about 60 percent for NEOs (about 65 percent for PHAs).

The Vera C. Rubin Observatory's data will be widely accessible, and discovery opportunities will be available to K-12 students as easily as to professional astronomers. An innovative citizen science program will involve people of all ages in Rubin Observatory discoveries. About half the cost during operations is for data management, including the development of user-friendly interfaces tailored for the different anticipated communities. The survey strategy makes the same data set usable for the astronomy community as well as for educators and the general public.

Management and Oversight

NSF Structure: NSF oversight is handled by a program officer in the MPS Division of Astronomical Sciences (AST) working cooperatively with NSF staff through the Integrated Project Team with members from MPS, OISE, BFA, the Office of General Counsel, the Office of Legislative and Public Affairs, and the Office of the Director. Within BFA, the Large Facilities Office provides advice to program staff and assists with agency oversight and assurance. The MPS Facilities team and NSF's Chief Officer for Research Facilities also provide high-level guidance and oversight support for the project. The NSF program officer works closely with counterparts in the DOE Office of High Energy Physics, who have oversight responsibility for the construction of the camera. Interagency coordination is accomplished through weekly meetings of a Joint Oversight Group and was formalized through a Memorandum of Understanding signed in July 2012.

External Structure: The responsible awardee for the Vera C. Rubin Observatory construction is the Association of Universities for Research in Astronomy, Inc. (AURA), a non-profit science management corporation. The Vera C. Rubin Observatory Project Office is an AURA-managed center for construction, and AURA established a separate management council that oversees this Project Office. The Observatory's project director and project manager are experienced in large facility construction and operation and are appointed by AURA, with the approval of NSF and DOE. AURA is also the responsible awardee for the

[2] See Ivezić et al. (2019), *The Astrophysical Journal,* 873, 111.
[3] NEOs are objects that come within 1.3 astronomical units (au, the distance from Earth to Sun) of the Sun, which means they come near Earth's orbit. PHAs are defined as objects that come within a distance of 0.05 au (roughly 4,650,000 miles) of Earth and are larger than roughly 140 meters in diameter.
[4] www.doi.org/10.1016/j.icarus.2017.11.033
[5] www.arxiv.org/abs/1705.06209

Vera C. Rubin Observatory pre-operations ramp-up activity that began in October 2018. AURA is responsible for coordinating construction activities and pre-operations activities that are executed side-by-side.

Reviews

Technical Reviews: Stage-gate reviews were conducted throughout the Design Stage, culminating in NSF's FDR in December 2013, with DOE involvement. All major subsystems have undergone regular system-level reviews organized by the Vera C. Rubin Observatory Project Office during Design and Construction.

Management, Cost, and Schedule Reviews: Cost, schedule, and risk are also scrutinized by the technical reviews. During construction, NSF and DOE hold regular joint progress reviews. The most recent reviews are summarized below

- The fifth joint agency progress review occurred in August 2019 and was successful.
- An Earned Value Management System (EVMS) surveillance review coincided with the 2019 annual progress review and is used to evaluate the project's alignment with Government Accountability Office (GAO) good practices on schedule. This review determined that the Vera C. Rubin Observatory EVMS continues to meet both the intent of the American National Standards Institute/Electronic Industries Alliance standard, EIA-748-C, Earned Value Management Systems (EVMS) guidelines and NSF requirements for EVMS, and there were no findings or corrective actions.
- In December 2017, NSF and DOE held a joint review of the project's proposal for operations of the full ten-year survey, plus an additional four years of pre-operations ramp up activity and two years of post-survey activity. The review was successful, and NSF and DOE began initial funding of early pre-operations activity in FY 2019 (with NSF providing $11.10 million in FY 2018 for the period FY 2019–FY 2021). An additional $5.0 million is requested for FY 2021 to cover NSF's increased costs associated with the revised co-funding model with DOE, as described in the Future Operations Costs section below.

Project Status

NSF's construction award was issued in August 2014. As of November 2019, the project's MREFC scope is 76 percent complete. The primary telescope building, mirror cell lift, and mirror coating plant construction have been completed. The M1M3 mirror and cell are completed and have been safely transported to the summit. The secondary mirror (M2) has been successfully coated at the summit facility, and staff have begun moving into the recently completed base facility. Dome installation remains underway despite significant delays. Weather and vendor challenges caused those delays; however, the project has begun planning other activities to minimize the impact of delays on the integrated project schedule. The telescope mount assembly successfully completed factory testing in November 2018, and all parts are now on the summit with installation underway. The Auxiliary Telescope, used for calibration purposes, achieved first light on July 24 with commissioning continuing. NSF- and DOE-supported activities remain tightly coordinated, both at the project level and among agency program officers.

Cost and Schedule

The FDR panel found the NSF Total Project Cost of $473.0 million to be reasonable and recommended that the project improve their planning of potential descoping options. NSF carried out further cost review prior to making the award. The Vera C. Rubin Observatory Project performed a Monte Carlo simulation analysis on its resource-loaded integrated project schedule, as detailed in its project management control system process, and determined a probability of over 90 percent for completing the project for $473.0 million and by the planned survey start date of October 1, 2022. This result was finalized in April 2015 and incorporated into the associated cooperative support agreement. In addition to NSF's contribution, DOE's baseline for the camera was fixed at $168.0 million. Construction also includes approximately $39 million from non-federal sources, all of which have been expended.

In FY 2019, GAO performed an analysis, published in GAO-19-227, which found that the project schedule did not meet all of GAO's best practices and that the schedule was comprehensive and controlled, but that it was only "partially well-constructed" and "partially credible." NSF and the Vera C. Rubin Observatory project have worked to respond to the GAO findings and recommendations, and GAO has now reported (letter to NSF) that they consider the Vera C. Rubin Observatory project schedule to be well-constructed and credible.

As of November 2019, the project had allocated 70 percent of the total budget contingency to the baseline, and $25.10 million remains. One recent change was for a 2.5-month schedule shift of the baseline project completion date due to vendor delays, reducing schedule contingency to about 3.5 months. NSF and DOE are working closely with the project to monitor and consider remaining descoping and deferral options, to maintain sufficient cost and schedule contingency for proper project management.

Risks

Technical: Much of the technical risk was retired during development and design. Since full construction began, no new major risks have been identified. Realized risks have been mitigated by use of cost and schedule contingency or re-planning by the Vera C. Rubin Observatory Project Office. The Data Management (DM) effort was previously identified as a risk and subsequently re-planned following panel recommendations from the July 2017 DM review, including the release of cost and schedule contingency. Careful planning to stage DM deliverables in coordination with commissioning sequencing will mitigate the remaining risks associated with DM. Commissioning plans overall have pathfinders to mitigate technical risks as the entire system is assembled and integrated over the next two years.

Environmental and Cultural Compliance: Environmental and cultural impact mitigation continues as planned with no unforeseen issues.

Site: The possible site risk due to local geological anomalies, noted in previous requests, was realized during excavation. Since this risk was localized and anticipated, it was successfully handled. Site disruptions from geological events and extreme weather remain as possible risks with appropriate mitigation plans.

Environmental Health and Safety: The Vera C. Rubin Observatory project has a full-time head of safety with experience in AURA operations, which has a long history of an excellent safety record in Chile. Both the summit and base sites have on-site safety supervisors employed by the Observatory to monitor contractor and project activities. All safety plans are fully compliant with applicable standards from U.S., Chilean, and participating institutions, and are updated regularly. External reviews have given the project high marks for its safety culture.

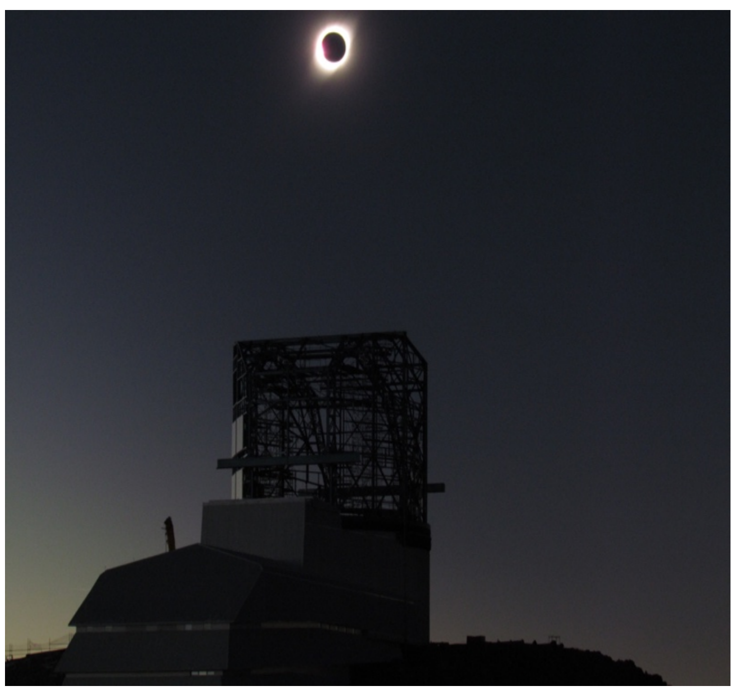
Partnership Risk: Significant attention has been paid to partnership risk, and that risk has been mitigated by careful coordination and unified project structures. The Vera C. Rubin Observatory project director oversees the entire project. A single project manager, agreed to by both NSF and DOE, manages the complete work breakdown structure elements. Budgetary management details are clearly set out between the project director, the project manager, the project's Change Control Board, AURA's management council for Vera C. Rubin Observatory construction, and the agencies' program officers, grants officers, and financial managers.

Future Operations Costs

NSF plans to provide approximately half of Vera C. Rubin Observatory operations funding, with support currently expected from within the NSF R&RA account. DOE is partnering with NSF on observatory operations and planning activities are in progress. Operations costs are planning estimates based on the most recently available data. The overall 10-year operations cost estimate to NSF remains unchanged at $310.0 million (then-year U.S. dollars). The final full operations costs will be determined through a review, approval, and award process that began with the project's submission of a formal proposal for the Vera C. Rubin Observatory operations, including pre- and post-survey activities, in August 2017 with external panel review in December 2017.

Operations of the Vera C. Rubin Observatory will be fully integrated into NSF's National Optical-Infrared Astronomy Research Laboratory (the Lab), which launched at the start of FY 2020. The Lab also encompasses the Mid-Scale Observatories and Community Science & Data Center, which formerly comprised the National Optical Astronomy Observatory, and the Gemini Observatory. For more details, refer to the corresponding section of the Facilities chapter.

Although it was originally anticipated that international parties would make financial contributions to the Vera C. Rubin Observatory operations, in FY 2019 NSF and DOE jointly modified the original operations funding model into a new model that seeks in-kind contributions from international participants rather than monetary contributions. Nominally, in-kind contributions are expected to benefit U.S. and Chilean scientists and/or offset NSF and DOE operations costs. The specific nature of these in-kind contributions is currently being formulated and negotiated. NSB is expected to review a request to authorize an operations award in FY 2021, which is anticipated to fund operations beginning in FY 2022.



The Vera C. Rubin Observatory during the July 2, 2019 total solar eclipse. *Credit: G. Poczulp. Rubin Observatory/AURA/NSF.*

ORGANIZATIONAL EXCELLENCE **$525,060,000**
+$27,570,000 / 5.5%

Organizational Excellence Funding Summary
(Dollars in Millions)

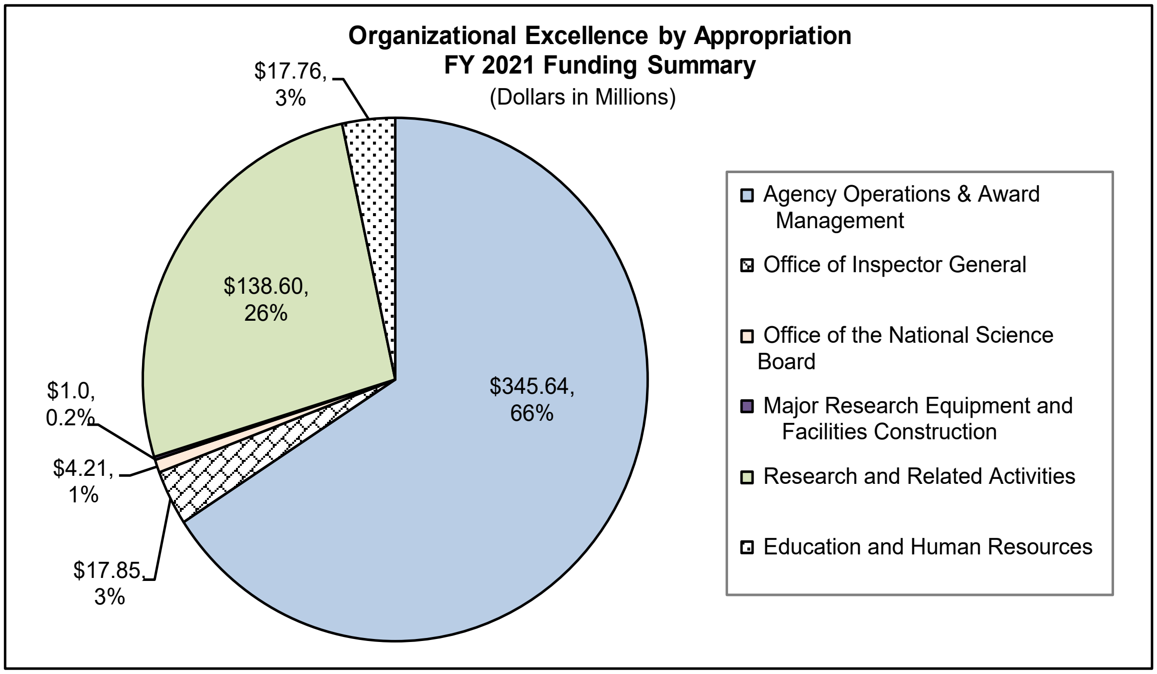
FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
$497.49	-	$525.06	$27.57	5.5%

NSF's FY 2021 funding for Organizational Excellence is $525.06 million, about seven percent of the total NSF FY 2021 Request. NSF's management objectives have the goal of achieving organizational excellence through a continuous emphasis on efficiency and efficacy, as noted in NSF's Strategic Plan for 2018-2022[1] under Strategic Goal 3, Enhance NSF's Performance of its Mission. The portfolio of activities included in Organizational Excellence addresses the agency's operations and administrative functions, which underpin NSF's programmatic activities. These activities are critical to the accomplishment of the agency's other two strategic goals, Expand Knowledge in Science, Engineering and Learning, and Advance the Capability of the Nation to Meet Current and Future Challenges.

An overview of the various activities that are included in the Organizational Excellence portfolio is included in this summary. Also included in this discussion is information on the E-Government and Line-of-Business initiatives to which the agency contributes and signed IT Resource Statements. The two tables on the following pages show first the Organizational Excellence portfolio by appropriation, and second the portfolio by its components—Human Capital, Travel, Information Technology (IT), Administrative Support, MREFC Oversight, and support for OIG and NSB along with their funding sources, as several are funded through more than one appropriation.

As part of its Agency Reform Plan, NSF launched its "Renewing NSF" initiative focusing on operational reforms in four areas: (1) make information technology work for us, (2) align NSF's workforce and work, (3) expand public and private partnerships, and (4) streamline, standardize, and simplify programs and processes. NSF will work to ensure that IT tools enhance employee productivity and satisfaction by enabling access to readily available, reliable, and fully integrated data that supports decision making. NSF will optimize the alignment of staffing and position descriptions with the changing landscape. NSF will maintain its already lean workforce through continuous improvements in personnel training and utilization, and through effective performance management. NSF will improve efficiencies in developing, implementing, and managing partnerships that maximize the scientific, economic, and societal impacts of its investments. NSF will also revise policies and business processes to increase standardization across NSF organizations and eliminate unnecessary complexity. These Agency reforms will allow NSF to continue to achieve its mission within a constantly evolving landscape in alignment with NSF's history of continued organizational improvement, and the Administration's government-wide agency reform activities as detailed in the President's Management Agenda (PMA).

[1] NSF (2018). Building the Future: Investing in Discovery and Innovation – NSF Strategic Plan for Fiscal Years (FY) 2018-2022. Retrieved from: www.nsf.gov/about/performance/strategic_plan.jsp



Organizational Excellence by Appropriation
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
Agency Operations & Award Management	$332.69	-	$345.64	$12.95	3.9%
Office of Inspector General	15.28	-	17.85	2.57	16.8%
Office of the National Science Board	4.32	-	4.21	-0.11	-2.6%
Major Research Equipment & Facilities Construction	0.32	-	1.00	0.68	212.9%
Program Support Subtotal:	144.88	-	156.36	11.48	7.9%
Research & Related Activities	*127.43*	-	*138.60*	*11.17*	*8.8%*
Education & Human Resources	*17.45*	-	*17.76*	*0.31*	*1.8%*
Total	**$497.49**	**-**	**$525.06**	**$27.57**	**5.5%**

Organizational Excellence by Major Component

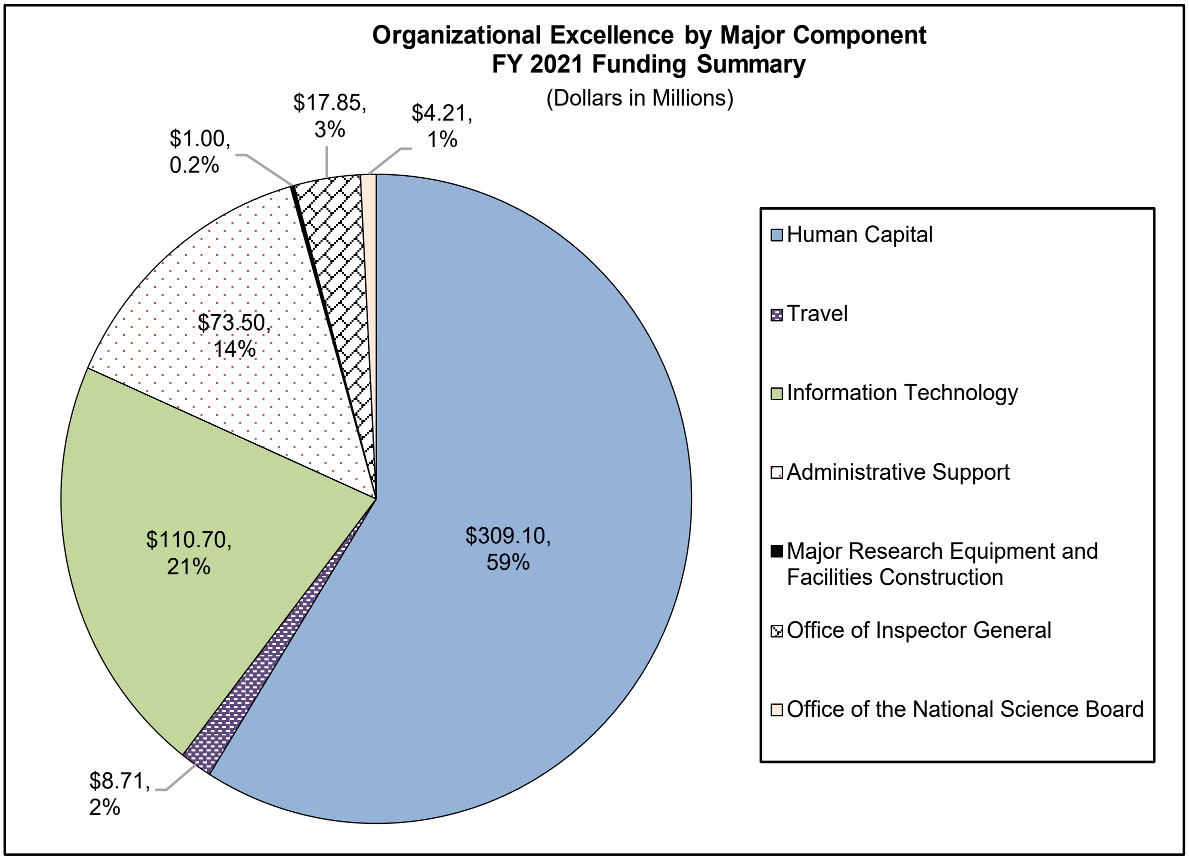
The table below shows the major components of Organizational Excellence. This table also shows the funding sources for the major components and activities, as several are funded through more than one appropriation.

Organizational Excellence by Major Component
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent	Funding Source
Human Capital	$290.66	-	$309.10	$18.43	6.3%	
Personnel Compensation & Benefits[1]	233.29	-	248.23	14.94	6.4%	AOAM
Management of Human Capital	11.96	-	8.07	-3.88	-32.5%	AOAM
IPA Appointments	45.42	-	52.79	7.37	16.2%	
Compensation	41.75	-	48.40	6.65	15.9%	RRA/EHR
Per Diem	3.67	-	4.39	0.72	19.7%	RRA/EHR
Travel	$7.85	-	$8.71	$0.86	10.9%	
NSF Federal Employee Staff	5.50	-	5.16	-0.34	-6.3%	AOAM
IPA Appointments	2.35	-	3.55	1.20	51.3%	RRA/EHR
Information Technology	$110.73	-	$110.70	-$0.02	0.0%	
Agency Operations IT	25.89	-	22.98	-2.91	-11.2%	AOAM
Administrative Applications Services & Support	7.10	-	5.91	-1.19	-16.8%	AOAM
Administrative Infrastructure Services & Support	14.95	-	13.67	-1.28	-8.5%	AOAM
Administrative Security and Privacy Services & Support	3.33	-	2.92	-0.41	-12.3%	AOAM
Administrative IT Management	0.51	-	0.48	-0.03	-5.9%	AOAM
Program Related Technology (PRT)	84.84	-	87.72	2.88	3.4%	RRA/EHR
Mission-Related Applications Services	55.98	-	55.93	-0.05	-0.1%	RRA/EHR
Mission-Related IT Operations & Infrastructure	21.64	-	25.00	3.36	15.5%	RRA/EHR
Mission-Related Security & Privacy Services	4.98	-	4.75	-0.23	-4.6%	RRA/EHR
Mission-Related IT Management	2.24	-	2.04	-0.20	-8.8%	RRA/EHR
Administrative Support	$68.33	-	$73.50	$5.16	7.6%	
Space Rental[2]	23.87	-	32.66	8.79	36.8%	AOAM
Operating Expenses	17.29	-	16.06	-1.23	-7.1%	AOAM
Building & Administrative Services	14.90	-	12.48	-2.42	-16.2%	AOAM
Other Program Related Administration	3.66	-	3.45	-0.21	-5.6%	RRA/EHR
E-Government Initiatives	1.50	-	1.37	-0.13	-8.4%	RRA/EHR
General Planning & Evaluation Activities	2.16	-	2.08	-0.08	-3.7%	RRA/EHR
Other Organizational Excellence Activities	8.62	-	8.85	0.23	2.6%	
Major Facilities Admin Reviews & Audits	0.98	-	0.22	-0.76	-77.5%	RRA-various
Evaluation and Assessment Capability	3.00	-	3.00	-	-	RRA-IA
Public Access Initiative	0.91	-	1.63	0.72	78.9%	RRA-CISE
Planning & Policy Support	3.73	-	4.00	0.27	7.1%	RRA-IA
Major Research Equipment & Facilities Construction	$0.32	-	$1.00	0.68	212.9%	MREFC
Office of Inspector General	$15.28	-	$17.85	$2.57	16.8%	OIG
Office of the National Science Board	$4.32	-	$4.21	-$0.11	-2.6%	NSB
Total	**$497.49**	**-**	**$525.06**	**$27.57**	**5.5%**	

[1] Funding levels for PC&B reflect direct appropriated funds only. In FY 2019, $6.34 million in Administrative Cost Recoveries (ACRs) were received bringing the total PC&B obligation to $239.62 million. ACRs of $5.18 million are estimated for FY 2021 to meet the total PC&B requirement $253.41 million.

[2] Funding levels for Space Rental in the FY 2019 Actual column reflect actual obligations after adjustments. Adjustments include -$11.17 million for FY 2019 rental costs funded in FY 2018 and +$3.29 million for FY 2020 rental costs funded in FY 2019. For more information on Space Rental costs, see the Space Rental narrative in the Agency Operations and Award Management (AOAM) chapter.



1. Human Capital: The FY 2021 funding amount for Human Capital is $309.10 million. The Human Capital component includes personnel compensation and benefits of NSF's federal employees as well as support for NSF's temporary employees—both those that are hired through authority provided by the Intergovernmental Personnel Act, known as IPAs, and those employed through NSF's own Visiting Scientist, Engineer, and Educator (VSEE) program. NSF's federal employee full-time equivalents (FTE) and VSEEs are funded through the AOAM account while IPAs are funded through two programmatic accounts—R&RA and EHR.

The use of IPAs and VSEEs, together commonly referred to as rotators, has been a defining characteristic of NSF since its inception in 1950, as it gives NSF a direct connection to the researchers and educators working at the frontiers of science and engineering. VSEEs count as regular federal FTE and are included in the regular AOAM FTE totals. IPAs are not included in the regular AOAM FTE totals.

NSF Workforce

The table below shows the agency's total workforce for FY 2021.

NSF Workforce
Full-Time Equivalents (FTE)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
FTE Allocation					
AOAM	1,357	-	1,357	-	-
Regular	1,315	-	1,315	-	-
Pathways Interns[1]	42	-	42	-	-
IPAs	198	-	205	7	3.5%
FTE Usage (Actual/Projected)					
AOAM	1,324	-	1,357	33	2.5%
Regular	1,304	-	1,315	11	0.8%
Pathways Interns[1]	20	-	42	22	112.8%
Office of the Inspector General	71	-	71	-	-
Office of the National Science Board	17	-	17	-	-
Arctic Research Commission	3	-	3	-	-
Total, Federal Employees (FTE) Usage	**1,415**	**-**	**1,448**	**33**	**2.3%**
IPAs (FTE)	166	-	205	39	23.6%
Detailees to NSF	3	-	3	-	-
Total, NSF Workforce (FTE)	**1,584**	**-**	**1,656**	**72**	**4.6%**

[1] The Pathways Intern program was established by Executive Order 13562, Recruiting and Hiring Students and Recent Graduates. The internship program offers part- or full-time paid internships in federal agencies to qualifying students (students in high schools, community colleges, four-year colleges, trade schools, career and technical education programs, and other qualifying technical education programs).

A discussion of NSF's FTE allocation and usage is included in the Personnel Compensation and Benefits section of the AOAM chapter. A more detailed discussion about IPAs is included in the Program Accounts: R&RA and EHR chapter. The OIG, NSB, and U.S. Arctic Research Commission chapters include a discussion of their respective workforces.

The Human Capital component also includes support for the Management of Human Capital, which is discussed in the AOAM chapter.

2. Travel: The FY 2021 Request for staff and IPA travel is $8.71 million. Staff travel accounts for about 59 percent of this total at a level of $5.16 million and is provided from the AOAM account. Travel for IPA appointments, which is supported by the R&RA and EHR accounts, is $3.55 million. For more detailed information about NSF staff and IPA travel funding, see the AOAM and Program Accounts: R&RA and EHR chapters, respectively.

3. Information Technology: NSF's FY 2021 Request for IT investments total $110.70 million. Funding for NSF's IT investment is provided from the AOAM, R&RA, and EHR accounts.

IT Investments by Appropriation

(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
Agency Operations & Award Management	$25.89	-	$22.98	-$2.91	-11.2%
Program Related Technology	84.84	-	87.72	2.88	3.4%
Research & Related Activities	*73.44*	-	*75.97*	*2.53*	*3.4%*
Education & Human Resources	*11.39*	-	*11.75*	*0.36*	*3.1%*
Total	**$110.73**	**-**	**$110.70**	**-$0.02**	**-**

Agency IT investments funded through the AOAM account support the agency's operations to ensure high quality, reliable, and secure administrative applications and associated IT infrastructure support and services to meet the needs of the Foundation. This funding accounts for about 21 percent of NSF's total IT investment at the FY 2021 Request. Additional detail regarding the AOAM funded IT investments can be found in the AOAM chapter.

Program Related Technology (PRT) investments support NSF's programmatic activities and associated services and are funded through the R&RA and EHR accounts. PRT investments are mission-related IT investments that support the merit review process, including pre-award planning and activities; receipt of proposals; processing proposals; reviewing proposals; award decisions, documentation, and notification; funding awards; post-award oversight; dissemination of award results; and award close-out. PRT investments account for 79 percent of NSF's FY 2021 Request for IT investments. More information on PRT can be found in the Program Accounts: R&RA and EHR chapter.

Investment priorities will support the Agency's commitment to Renewing NSF with a continued focus on implementing and scaling solutions that will further PMA priorities. Activities prioritized in FY 2021 include:

- Continue necessary technology transformations geared toward improving the user experience both internally and for citizen-facing websites and digital services. (Cross-Agency Priority (CAP) Goal 4: Improving customer experience with federal services)
- Continue development and implementation of advanced technologies such as artificial intelligence (AI) and blockchain to support NSF's mission. (CAP Goal 1: Modernize IT to increase productivity and security)
- Employ innovative and advanced technology capabilities in support of agency priorities, such as to transform the agency's workforce and provide platforms for development and testing of new technology tools and capabilities. (CAP Goal 3: Developing a workforce for the 21st century)
- Continuing support for the information technology infrastructure and systems that serve the agency, preserving secure, reliable operations to the greatest extent possible as well as maintain the security of NSF's infrastructure to protect and defend agency assets and respond to the ever-evolving threat landscape, prioritizing continued efforts to manage, modernize, and secure agency information systems. As part of this activity, NSF will allocate a minimum of $216,100 to the FY 2021 operations and maintenance costs for Continuous Diagnostics and Mitigation (CDM) tools and services. (CAP Goal 1: Modernize IT to increase productivity and security)
- Support the continued operation of iTRAK, the Foundation's financial management system, and NSF's Financial Services Support investment, distinct from the iTRAK investment, to ensure continued

interoperability between NSF's core financial functions, modernize NSF's financial management functions, and increase transparency and accuracy of reporting between iTRAK and other mission systems. (CAP Goal 2: Leveraging data as a strategic asset)
- Support continued use and refinement of the Technology Business Management (TBM) framework for managing IT as a business. (CAP Goal 10: Improving outcomes through federal IT spending transparency)

4. Administrative Support: FY 2021 funding for Administrative Support is $73.50 million. The activities that comprise this major component are:
- Space Rental at $32.66 million. More detailed information about Space Rental can be found in the AOAM chapter.
- Operating Expenses ($16.06 million) includes funding for various financial and award management and leadership activities such as post-award monitoring; contract close-out activities; large facility oversight; improper payments, financial statement, and internal controls reporting; Committee on Equal Opportunities in Science and Engineering activities; NSF's Enterprise Information System; and supplies, equipment, and training that are necessary for the accomplishment of NSF's mission. A detailed discussion about Operating Expenses can be found in the AOAM chapter.
- Building and Administrative Services ($12.48 million) includes administrative contracts that support NSF's facilities and business operations, administrative services, and infrastructure such as security system maintenance, ID issuance, continuity of operations support services, and Federal Register notices for panels and advisory committees. A detailed discussion of these activities can be found in the AOAM chapter.
- Other Program Related Administration (Other PRA) is funded at $3.45 million to support general planning and evaluation activities, which include agency-wide efforts such as the verification and validation of performance information, and E-Government efforts. A detailed discussion about Other PRA can be found in the Program Accounts: R&RA and EHR chapter.
- Other Organizational Excellence Activities ($8.85 million) funds the Evaluation and Assessment Capability (EAC) and Planning and Policy Support—two NSF-wide activities managed by the Office of Integrative Activities. It also includes support for the Public Access Initiative, an NSF-wide activity managed by CISE. For more information on EAC, Planning and Policy Support, and Public Access Initiative, see the IA and CISE narratives respectively, in the R&RA chapter.

5. Major Research Equipment and Facilities Construction: The FY 2021 Request includes $1.0 million within the MREFC account for oversight of NSF's major facility projects. For more information on this activity, see the MREFC chapter.

6. Office of Inspector General: FY 2021 funding for the OIG is $17.85 million. The staffing and operations of the OIG are supported through a separate OIG appropriation. Details about the OIG FY 2021 Request can be found in the OIG chapter.

7. Office of the National Science Board: FY 2021 funding for the NSB is $4.21 million. The staffing and operations of the NSB office are supported through a separate NSB appropriation. Details about the NSB FY 2021 Request can be found in the NSB chapter.

NSF FY 2021 Request Funding for E-Government Initiatives

The table below shows NSF's contributions and service fees for various E-Government and Line-of-Business initiatives. The FY 2021 levels are consistent with the funding amounts provided by the initiatives' respective managing partners.

NSF FY 2021 Estimated Funding for E-Government Initiatives

	FY 2021			Appropriations Account	
Initiative	Agency Contributions	Agency Svc. Fees	NSF Total	AOAM	R&RA
Grants.gov	$323,000	-	$323,000	-	$323,000
E-Travel	-	184,467	184,467	184,467	-
Geospatial LoB	25,000	-	25,000	-	25,000
E-Training	-	370,000	370,000	370,000	-
E-Rulemaking	-	17,253	17,253	19,862	-
USA Jobs	-	10,399	10,399	10,350	-
E-Human Resource Integration	-	24,634	24,634	24,634	-
Integrated Acquisition Environment (IAE)	-	719,644	719,644	21,000	698,644
Human Resources Management LoB	68,478	-	68,478	-	68,478
Financial Management LoB	139,094	-	139,094	-	139,094
Budget Formulation/Execution LoB	120,000	-	120,000	-	120,000
E-Payroll (incl. Shared Services)	-	314,640	314,640	314,640	-
Total	**$675,572**	**$1,641,037**	**$2,316,609**	**$944,953**	**$1,374,216**

LoB: Line-of-Business

IT Resource Statements

We jointly affirm that the Chief Information Officer (CIO) had a significant role in reviewing planned IT support for major programs and significant increases and decreases in IT resources reflected in this budget request.

Other than a minor financial systems upgrade on an existing contract to support Treasury G-invoicing mandates, NSF has no planned deviations from the requirements specified in M-19-16 regarding agency solicitation of new or modernized technology or services for which a Quality Service Management Office (QSMO) has been pre-designated.

Signed: Teresa Grancorvitz
Teresa Grancorvitz
Chief Financial Officer
National Science Foundation

Signed: ______________________
Dorothy Aronson
Chief Information Officer
National Science Foundation

I affirm that I have collaborated with component Leadership and the Chief Financial Officer (CFO) on the IT Budget submission, and that IT includes appropriate estimates of all enterprise IT resources included in the budget request/President's Budget.

I affirm that I have reviewed and had significant input in approving all major IT investments included in this budget request.

The CIO's common baseline rating for Element D ("D1. CIO reviews and approves major IT investment portion of budget request") is: c) Fully Implemented – Agency has developed and implemented its plan to ensure that all common baseline FITARA responsibilities are in place.

I affirm that I have reviewed and certified the use of incremental development practices, as appropriate for the agency's IT investments.

I affirm that the IT Budget submission explicitly identifies and includes any privacy requirements, as well as any associated costs, with respect to any IT resources that will be used to create, collect, use, process, store, maintain, disseminate, disclose, or dispose of personally identifiable information (PII).

Signed: ______________________
Dorothy Aronson
Chief Information Officer and
Senior Agency Official for Privacy (SAOP)
National Science Foundation

PROGRAM ACCOUNTS: RESEARCH AND RELATED ACTIVITIES (R&RA) AND EDUCATION AND HUMAN RESOURCES (EHR)

$156,360,000
+$11,490,000 / 7.9%

Funding from program accounts R&RA and EHR covers approximately 30 percent of the total Organizational Excellence portfolio. Three activities comprise program-funded Organizational Excellence: Intergovernmental Personnel Act costs, Program Related Administration, and Other Organizational Excellence Activities.

R&RA, EHR, and MREFC Organizational Excellence Funding Summary
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
IPA Costs	**$47.76**	**-**	**$56.34**	**$8.58**	**18.0%**
IPA Compensation	41.75	-	48.40	6.65	15.9%
IPA Per Diem	3.67	-	4.39	0.72	19.7%
IPA Travel	2.35	-	3.55	1.20	51.3%
Program Related Administration	**$88.49**	**-**	**$91.17**	**$2.68**	**3.0%**
Program Related Technology	84.84	-	87.72	2.89	3.4%
Other Program Related Administration	3.66	-	3.45	-0.21	-5.6%
Other Organizational Excellence Activities	**$8.62**	**-**	**$8.85**	**$0.23**	**2.6%**
Major Facilities Admin Reviews and Audits	0.98	-	0.22	-0.76	-77.5%
Evaluation & Assessment Capability (EAC)	3.00	-	3.00	-	-
Public Access Initiative	0.91	-	1.63	0.72	78.9%
Planning & Policy Support	3.73	-	4.00	0.27	7.1%
Total	**$144.88**	**-**	**$156.36**	**$11.49**	**7.9%**

Intergovernmental Personnel Act Costs

A portion of NSF's workforce consists of temporary staff hired through the Intergovernmental Personnel Act (IPA) authority. IPAs remain employees of their home institution while serving at NSF during their temporary appointments. They are not paid directly by NSF and are not subject to federal pay, benefits, or other limitations. NSF reimburses their home institution without overhead. IPAs are eligible to receive relocation expenses or a per diem allowance in lieu of relocation. Per policy released October 2016, NSF is continuing its pilot to require 10 percent cost sharing by the IPA's home institution of the IPA's academic-year salary and fringe benefits.

The agency uses IPA science and engineering staff to help ensure that the Foundation's funding decisions are based on the best input from the field and reflect fresh ideas and creativity. The expertise provided by these IPAs is essential to help shape the NSF research portfolio and support transformational advances across the frontiers of all fields of science, engineering, and education.

IPA Costs by Appropriation
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
IPA FTE Allocation[1]	198	-	205	7	3.5%
IPA FTE Usage (Actual/Projected)[1]	166	-	205	39	23.6%
Research and Related Activities (R&RA)					
IPA Compensation	$36.49	-	$43.58	$7.09	19.4%
IPA Per Diem	3.11	-	3.93	0.82	26.2%
Travel	2.10	-	3.28	1.18	56.0%
Subtotal, R&RA Costs	**$41.71**	**-**	**$50.79**	**$9.08**	**21.8%**
Education and Human Resources (EHR)					
IPA Compensation	5.26	-	4.82	-0.44	-8.4%
IPA Per Diem	0.55	-	0.46	-0.09	-16.7%
Travel	0.24	-	0.27	0.03	10.6%
Subtotal, EHR Costs	**$6.06**	**-**	**$5.55**	**-$0.51**	**-8.4%**
Total[1]	**$47.76**	**-**	**$56.34**	**$8.58**	**18.0%**

[1] Approximately three IPA FTE in FY 2021 are included in the IPA FTE Allocation and Usage lines of the table above but the costs are budgeted within Other Program Administration and included in the General Planning and Evaluation (P&E) activities section of this narrative.

The FY 2021 funding for IPA costs is $56.34 million representing an IPA usage level of 205 full-time equivalent (FTE) IPAs. R&RA funding for IPAs is $50.79 million supporting 172 IPA FTE. EHR funding for IPAs is $5.55 million supporting 30 IPA FTE. For both R&RA and EHR, per IPA FTE costs are estimated at a level commensurate with the FY 2019 Actual.

The FY 2021 total IPA compensation is $48.40 million, per diem is $4.39 million, and travel is $3.55 million. Funding for these three categories is associated with full use of NSF's increased IPA FTE allocation and projected IPA costs for FY 2021. Cost increases are estimated based on projected IPA FTE utilization, current IPA funding, and the need to provide competitive salaries in order to recruit the best researchers in the STEM fields.

Program Related Administration

Program Related Administration Investments
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Program Related Technology	$84.84	-	$87.72	$2.89	3.4%
Other Program Related Administration	3.66	-	3.45	-0.21	-5.6%
Total	**$88.49**	**-**	**$91.17**	**$2.68**	**3.0%**

The FY 2021 Request for Program Related Administration (PRA) is $91.17 million. PRA includes two categories of activities that support NSF Strategic Goal 3: Enhance NSF's performance of its mission,[1] and that are directly funded from NSF's program accounts:

- Program Related Technology (PRT); and
- Other Program Related Administration (Other PRA)

Program Related Technology ($87.72 million)
Information technology (IT) investments funded through the R&RA and EHR accounts support NSF's mission activities and is approximately 79 percent of NSF's total IT investment portfolio. These programmatic investments are called Program Related Technology. NSF's remaining $22.98 million IT investment is funded through the AOAM account and is discussed in the AOAM chapter.

Program Related Technology Investments
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual	
				Amount	Percent
Mission-Related Applications & Services	$55.98	-	$55.93	-$0.05	-0.1%
Mission-Related IT Operations & Infrastructure	21.64	-	25.00	3.36	15.5%
Mission-Related Security & Privacy Services	4.98	-	4.75	-0.23	-4.6%
Mission-Related IT Management	2.24	-	2.04	-0.20	-8.8%
Total	**$84.84**	**-**	**$87.72**	**$2.88**	**3.4%**

NSF accomplishes its mission by providing federal financial assistance to individuals and institutions whose proposals have been judged the most promising by a rigorous and objective review process. Each stage in NSF's proposal and award management process is supported electronically. The IT services and systems that support the proposal and review process are funded through the PRT investment, an essential element in our Nation's support for science, engineering, and education research.

NSF's FY 2021 information technology priorities for PRT are strategically aligned with the President's Management Agenda (PMA). The PRT investment will allow NSF to:

- Support the Agency's commitment to "Renewing NSF" with a continued focus on implementing and scaling solutions that will further PMA priorities. This investment allows NSF to:
  - Continue necessary technology transformations geared toward improving the user experience both internally and for citizen-facing websites and digital services. (Cross-Agency Priority (CAP) Goal 4: Improving customer experience with federal services)
  - Continue development and implementation of advanced technologies such as artificial intelligence (AI) and blockchain to support NSF's mission. (CAP Goal 1: Modernize IT to increase productivity and security)
  - Employ innovative and advanced technology capabilities in support of agency priorities, such as to transform the agency's workforce and provide platforms for development and testing of new technology tools and capabilities. (CAP Goal 3: Developing a workforce for the 21st century)
- Maintain the security of NSF's infrastructure to protect and defend agency assets and respond to the ever-evolving threat landscape, prioritizing continued efforts to manage, modernize, and secure agency information systems. (CAP Goal 1: Modernize IT to increase productivity and security)
- Support the continued operation of iTRAK, the Foundation's financial management system, to ensure continued interoperability with NSF's core financial functions. (CAP Goal 2: Leveraging data as a strategic asset)

[1] NSF (2018). Building the Future: Investing in Discovery and Innovation – NSF Strategic Plan for Fiscal Years (FY) 2018-2022. Retrieved from: www.nsf.gov/about/performance/strategic_plan.jsp

- Support the Financial Services Support investment, distinct from the iTRAK investment which supports core financials, to modernize NSF's financial management functions, and increase transparency and accuracy of reporting between NSF's core financial system (iTRAK) and other mission systems. (CAP Goal 2: Leveraging data as a strategic asset)
- Support continued use and refinement of the Technology Business Management (TBM) framework for managing IT as a business. (CAP Goal 10: Improving outcomes through federal IT spending transparency)

Mission-Related Applications and Services ($55.93 million)
Investments in this category fund the applications and services that support the merit review process, including pre-proposal planning; receipt of proposals; processing proposals; reviewing proposals; award decisions, documentation, and notification; funding awards; post-award oversight; dissemination of award results; and award close-out. These investments can be classified as:

- Mission Support Systems, a total of $42.59 million, which supports the following activities:
  - $22.29 million funds the operations and maintenance of NSF's mission support systems, which provide a suite of functionality supporting each stage in the NSF proposal and award management process. Work in this area incorporates ongoing needs for new functionality as it is incrementally deployed for production use
  - $20.30 million for continuous modernization of systems and services that support the merit review process. FY 2021 efforts will continue to prioritize modernization of public-facing digital services, improving experiences for agency customers. Specific investments include:
    - Proposal Management Efficiencies, $10.0 million: This investment prioritizes the continuous modernization of citizen-facing services, introducing new and enhanced functionality while retiring legacy technologies. (CAP Goals 1 and 4)
    - Public Access, $1.26 million: Supports continued use of the NSF Public Access Repository (NSF-PAR) as a controlled platform for integration with third-party services, leveraging application programming interfaces that support machine-to-machine communication to enhance use and discovery and reduce burden on the research community. (CAP Goals 1, 2, and 4)
    - Innovation Management (formerly known as "Make IT Work for Us"), $900,000: Furthers adoption of advanced tools and technologies to support the renewed merit review process. Specifically, NSF will continue efforts to consolidate, integrate, and streamline services through the application of advanced technology such as AI and machine learning, reducing administrative burden on the user. (CAP Goals 3 and 4)
    - Intelligent Automation of Grants Management Systems, $5.44 million: A new initiative in FY 2021, this investment provides for enhancements to IT systems/applications that support the grants management lifecycle, including those related to the Proposal Management Efficiencies investment. Efforts aligned to this initiative include modernization and enhancement releases that will require a significantly larger investment than those typically funded via the operations and maintenance component of Mission Support Systems.
    - Interactive Panel Systems Replacement, $2.70 million: A new modernization effort for FY 2021 to replace the current interactive panel system, which provides reviewers an application for collaborating with fellow panelists to review and rank proposals and recommend those proposals deemed most meritorious.
- NSF's Data Management and Delivery investment, $5.60 million: This activity centralizes and streamlines access to NSF data for agency staff and provides analytical and visualization capabilities key to data-based decision making. This investment will continue to enable NSF to prioritize efforts that support the Leveraging Data as a Strategic Asset (CAP Goal 2).
- Operations and maintenance of NSF's core financial system, iTRAK: The total FY 2021 investment for iTRAK is $6.57 million. Seventy percent of this request, $4.60 million, is funded by PRT and 30

percent is funded by AOAM. (CAP Goal 2)

- Financial services support, $2.24 million: Enables continued progress on account code structure modernization, largely impacting business mission-systems interfacing with iTRAK. (CAP Goal 2)
- Human Resource System Modernization, $900,000: This is a new investment for FY 2021. This activity will upgrade and enhance the existing agency systems for strategic management of human capital and administrative resource management as well as implement the upcoming payroll mandate, NewPay.

Mission-Related IT Operations and Infrastructure ($25.0 million)

The FY 2021 level maintains basic capabilities for the provision of agency services related to network, infrastructure, data center, customer support, and database administration. Investments in this area, supporting CAP Goals 1 and 10, include:

- Network ($7.38 million) – includes NSF's single network, with wired and Wi-Fi connectivity and virtual meeting support for NSF staff and visitors.
- Data Center and Cloud ($4.06 million) – includes the resources necessary to support and monitor access to applications that enable execution of NSF's mission.
- End User ($6.49 million) – funds NSF's help desk services for internal users (NSF staff) and external users (the research community including institutions, principal investigators, reviewers, and NSF visitors), which are available 13 hours per day, five days per week. The FY 2021 funding level also includes the costs necessary to refresh audio-visual equipment used to support virtual collaboration and implement improved services and tools to the agency's customers.
- Platform ($7.07 million) – reflecting NSF's use, management, and acquisition of hyper-converged hardware, software, and services.

Mission-Related Security and Privacy Services ($4.75 million)

Investments in this category support the portion of NSF's IT security program, which provides security and compliance oversight related to NSF's mission support systems. Specifically, this investment covers the mission-related portion of NSF's security operations, including network security, application security, security control testing and tools, automated vulnerability assessment tools, and remediation and intrusion detection services. (CAP Goal 1) At the FY 2021 Request, NSF will continue operations and monitoring support including offerings from the Continuous Diagnostics and Monitoring (CDM) program, as well as automated configuration management tools that manage security patches and provide proactive protection from viruses, spyware, and other threats.

Mission Related IT Management ($2.04 million)

IT Management includes support for the Chief Information Officer and senior IT leadership in the areas of IT strategy and planning, enterprise architecture, capital planning, vendor management, IT budget/finance, and IT strategic communications. In FY 2021, investments in this category will support NSF's continued use and refinement of the TBM framework, further enhancing the agency's ability to manage IT as a business. (CAP Goal 10)

<u>Other Program Related Administration ($3.45 million)</u>

In FY 2021, $3.45 million for NSF's Other PRA includes funding for two Foundation-wide activities:

- NSF support for federal E-Government initiatives that are mission-related.
- General planning and evaluation activities that are Foundation-wide.

Other Program Related Administration
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
E-Government Initiatives	$1.50	-	$1.37	-$0.13	-8.6%
General Planning & Evaluation Activities	2.16	-	2.08	-0.08	-3.5%
Total	**$3.66**	**-**	**$3.45**	**-$0.21**	**-5.6%**

E-Government Initiatives ($1.37 million)
The FY 2021 Request for NSF program-supported and mission-related E-Government (E-Gov) initiatives is consistent with the FY 2021 funding amounts provided by the initiatives' respective managing partners. The FY 2021 funding level reflects changes for the following initiatives:

- Budget Formulation/Execution line of Business increases nine percent based upon the expected funding level provided by the managing partner.
- Grants.gov decreases approximately one percent based upon the funding algorithm used to determine agency contributions.

General Planning and Evaluation Activities ($2.08 million)
FY 2021 funding for general planning and evaluation activities supports investments on broad programmatic and policy matters of NSF-wide scope and benefit. This includes activities such as the verification and validation of performance information; approximately three IPA FTE in the office of Budget, Finance, and Award Management and the Office of the Director; and certain costs associated with the American Association for the Advancement of Science fellowships program. Also included is $104,020 for interagency management councils that support cross-agency management reforms and efficiencies and $91,782 for Cross-agency Priority (CAP) Goals. The FY 2021 funding level is based on the level of general planning and evaluation activities and projects that occurred in FY 2019 and anticipated activities for FY 2021.

Other Organizational Excellence Activities

Other Organizational Excellence Activities
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Major Facilities Admin Reviews & Audits	$0.98	-	$0.22	-$0.76	-77.5%
Evaluation & Assessment Capability (EAC)	3.00	-	3.00	-	-
Public Access Initiative	0.91	-	1.63	0.72	78.9%
Planning & Policy Support	3.73	-	4.00	0.27	7.1%
Total	**$8.62**	**-**	**$8.85**	**$0.23**	**2.6%**

Major Facilities Administrative Reviews and Audits
In FY 2021, NSF currently anticipates an administrative review/audit for the National Ecological Observatory Network facility to include funding from BIO in the R&RA account. The estimate is based on the Annual Major Facilities Portfolio Risk Assessment conducted by BFA staff in close coordination with the cognizant program. Besides risk, this annual assessment also considers event-driven oversight activities per NSF policy, which are based on the American Innovation and Competitiveness Act (AICA). The current estimate is subject to revision based on the FY 2020 Portfolio Risk Assessment.

Evaluation and Assessment Capability (EAC) ($3.0 million)
EAC is an integral part of NSF's operations. It supports, coordinates, and conducts NSF-wide program evaluations and evidence generation and utilization to catalyze learning and improvement through collaboration with NSF's directorates and offices. EAC is an organizational unit managed by the Office of Integrative Activities (OIA) and funded via the IA budget in the R&RA account. More detailed information on EAC can be found within the IA narrative in the R&RA chapter.

Public Access Initiative ($1.63 million)
The goal of the NSF Public Access Initiative is to make the results of NSF-funded research available to the greatest extent possible, pursuant to the memorandum on Increasing Access to the Results of Federally Funded Scientific Research, released by the Office of Science and Technology Policy (OSTP) on February 22, 2013, and consistent with NSF's mission and long-standing policies supporting data sharing. It enables greater transparency and more access by more people to the results of NSF-funded research, and provides secure, predictable, and integrated management of publications, data, and other research products resulting from NSF funding. The Public Access Initiative is managed and funded through CISE in the R&RA account.

Planning and Policy Support ($4.0 million)
Planning and Policy Support is a foundation-wide activity in the IA budget of the R&RA account that supports select NSF-wide policy and planning activities. More detailed information on Planning and Policy Support can be found within the IA narrative in the R&RA chapter.

AGENCY OPERATIONS AND AWARD MANAGEMENT (AOAM) **$345,640,000**
+$12,950,000 / 3.9%

Agency Operations and Award Management Funding Summary

(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
Personnel Compensation & Benefits (PC&B)[1]	$233.29	-	$248.23	$14.94	6.4%
Management of Human Capital	11.96	-	8.07	-3.88	-32.5%
Travel	5.50	-	5.16	-0.35	-6.3%
Information Technology	25.89	-	22.98	-2.91	-11.2%
Space Rental[2]	23.87	-	32.66	8.79	36.8%
Operating Expenses	17.29	-	16.06	-1.23	-7.1%
Building & Administrative Services	14.90	-	12.48	-2.42	-16.2%
Total	**$332.69**	**-**	**$345.64**	**$12.95**	**3.9%**

[1] PC&B levels reflect direct appropriated funds only. In FY 2019, $6.34 million in Administrative Cost Recoveries (ACRs) were received bringing the total PC&B obligation to $239.62 million. ACRs of $5.18 million are estimated for FY 2021 to meet the total PC&B requirement of $253.41 million.

[2] Funding levels for Space Rental in the FY 2019 Actual column reflect actual obligations after adjustments. Adjustments include -$11.17 million for FY 2019 rental costs funded in FY 2018 and +$3.29 million for FY 2020 rental costs funded in FY 2019. For more information see the Space Rental

Investments in the AOAM account continue to be an NSF priority. This activity provides the fundamental framework through which the Foundation's science and engineering research and education programs are administered. AOAM investments support NSF Strategic Goal 3: Enhance NSF's performance of its mission[1] and priorities are framed by two strategic objectives:

- Strategic Objective 1: Attract, retain, and empower a talented and diverse workforce; and
- Strategic Objective 2: Continually improve agency operations.

AOAM funding is $345.64 million, reflecting increased space rental costs and an increase for pay and benefits for NSF's federal workforce, including a one percent cost of living adjustment (COLA).

[1] NSF (2018). Building the Future: Investing in Discovery and Innovation – NSF Strategic Plan for Fiscal Years (FY) 2018-2022. Retrieved from: www.nsf.gov/about/performance/strategic_plan.jsp

NSF AOAM Workforce

AOAM NSF Workforce
(Full-Time Equivalent (FTE) and Other Staff)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
NSF AOAM FTE Allocation					
NSF AOAM -- Regular	1,315	-	1,315	-	-
NSF AOAM -- Pathways Intern	42	-	42	-	-
Subtotal, FTE Allocation	**1,357**	**-**	**1,357**	**-**	**-**
NSF AOAM FTE Usage					
NSF AOAM -- Regular	1,304	-	1,315	11	0.8%
NSF AOAM -- Pathways Intern	20	-	42	22	112.8%
Subtotal, FTE Usage	**1,324**	**-**	**1,357**	**33**	**2.5%**
Detailees to NSF	3	-	3	-	-
Total	**1,327**	**-**	**1,360**	**33**	**2.5%**

NSF's FY 2021 FTE allocation is 1,357. The FY 2021 FTE estimated usage is 1,315 regular and 42 Pathways FTE.

Personnel Compensation and Benefits (PC&B)

Personnel Compensation & Benefits
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
Regular FTE Usage (projected)	*1,304*	-	*1,315*	*11*	*0.8%*
Student FTE Usage (projected)	*20*	-	*42*	*22*	*112.8%*
Regular FTE Base Salary	$179.35	-	$185.89	$6.54	3.6%
Student Salary	0.86	-	1.90	1.04	121.1%
Other Compensation[1]	1.75	-	2.34	0.59	33.4%
Awards	3.19	-	4.65	1.47	46.0%
Subtotal, FTE Compensation	**$185.15**	**-**	**$194.77**	**$9.63**	**5.2%**
Benefits	53.27	-	56.47	3.20	6.0%
Other Benefits[2]	1.21	-	1.17	-0.04	-3.1%
Subtotal, Benefits	**$54.48**	**-**	**$57.64**	**$3.16**	**5.8%**
COLA[3]	-	-	1.00	1.00	N/A
Total, PC&B	**$239.62**	**-**	**$253.41**	**$13.79**	**5.8%**
Source of Funds					
AOAM Appropriation	$233.29	-	$248.23	$14.94	6.4%
Administrative Cost Recoveries[4]	6.34	-	5.18	-1.16	-18.2%
Total	**$239.62**	**-**	**$253.41**	**$13.79**	**5.8%**

[1] Includes reimbursable details to NSF and terminal leave.

[2] Includes Federal Employee's Compensation Act (FECA) funding and transit subsidies.

[3] The COLA in FY 2019 cost approximately $3.92 million; which is reflected in the Regular FTE Base Salary line above. The COLA in FY 2021 reflects a one percent increase for civilian employees; this cost would be in addition to the Regular FTE Base Salary amount shown above.

[4] The ACR level for FY 2021 is estimated based on amount received in FY 2019.

The FY 2021 Request for PC&B is $253.41 million. Funding for PC&B reflects funding from two sources: $248.23 million in AOAM appropriated funds; and an estimated $5.18 million from ACRs received during the year.

The PC&B cost estimate will support the projected FY 2021 year-end usage of 1,315 regular FTE employees, a total of 42 Pathways intern FTE, associated cost of benefits, general workforce performance awards, and Senior Executive Service bonuses. The FY 2021 Request for PC&B also contains $922,000 for the Federal Transit Benefits Program and a one percent COLA. An increased level of awards spending for FY 2021 will enable NSF to strategically plan incentive awards and bonuses toward rewarding high-performing employees and those with mission critical skill sets.

Management of Human Capital

Management of Human Capital
(Dollars in Millions)

FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
$11.96	**-**	**$8.07**	**-$3.88**	**-32.5%**

The FY 2021 Request for Management of Human Capital is $8.07 million. This will enable NSF to maintain operational support activities, training and development programs essential for NSF's permanent and rotator staff, and contractual support for human capital initiatives. FY 2021 investments align with Cross-Agency Priority (CAP) Goal 3: Developing a workforce for the 21st century and support the following activities:

- Recruiting, hiring, and on-boarding of permanent and rotating staff, as well as processing support for pay, benefits, and incentive and other awards. The FY 2021 funding level ($2.0 million) is driven by reduced contract support for payroll, benefits, and time management activities. Supported by *Executive Order Enhancing the Effectiveness of Agency Chief Information Officers* (EO 13833),[2] NSF's Chief Information Officer will leverage direct hiring authority, if needed, for all/any IT positions that fall within the established criteria provided by the Director of the Office of Personnel Management.
- NSF's HR systems accessed through shared service providers, such as the Federal Personnel Payroll System, the time and attendance system (WebTA), and eRecruit capabilities using USAJobs. FY 2021 funding ($850,000) reflects the rising costs of the Interior Business Center's shared services support for various critical personnel management systems.
- NSF relies on strategic human capital support contracts for assistance in developing new approaches to critical human resource needs, including those identified and highlighted in NSF's Strategic Review process, Strategic Goal 3: Enhance NSF's performance of its mission, Strategic Objective 1: Human Capital—Attract, retain, and empower a talented and diverse workforce. FY 2021 funding ($1.53 million) reflects NSF's planned investment in business intelligence and other tools, which are anticipated to reduce the cost of the strategic human capital contracts.
- Contracts in support of training and development programs, such as the Learning Management System, LearnNSF, and related on-line training capabilities, as well as support for training and capacity-building activities including the NSF mentoring program, executive and supervisory training, and program management training. These training and development activities ($2.41 million) are designed to help ensure that the workforce, including permanent and rotating staff, as well as new supervisors and executives, are equipped with the tools needed to succeed as NSF employees.
- $1.14 million for workplace and work-life support of NSF's employees through health and family-

[2] www.whitehouse.gov/presidential-actions/executive-order-enhancing-effectiveness-agency-chief-information-officers/

friendly activities, including the health unit, employee assistance program, and childcare subsidy.
- Investments in outreach, career fairs, and other program support including activities such as the Federal Employee Viewpoint Survey are $140,000.

NSF Employee Travel

NSF Employee FTE Travel
(Dollars in Millions)

FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
$5.50	**-**	**$5.16**	**-$0.35**	**-6.3%**

FY 2021 funding for NSF employee FTE travel is $5.16 million. NSF employee FTE travel is based on the travel activity associated with utilization of 1,315 regular FTE. It includes travel-related funding for site reviews, outreach activities, and post-award monitoring and oversight related to the projected level of program activities at the FY 2021 Request. Travel costs for IPA FTE are discussed in the Program Accounts: R&RA and EHR narrative. A summary of total NSF travel is presented in the Organizational Excellence Overview.

Information Technology

NSF funds administrative information technology (IT) applications from the AOAM account while mission-related IT investments that support the merit review process are funded from program accounts. Resources to support mission-related IT investments are discussed in the Program Related Technology section of the Program Accounts: R&RA and EHR chapter. A summary of total NSF IT is presented in the Organizational Excellence Overview.

Administrative applications services and support; associated IT operations and infrastructure; security and privacy services; and related IT management services funded by the AOAM account are discussed below.

AOAM Information Technology
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
Administrative Applications Services & Support	$7.10	-	$5.91	-$1.19	-16.8%
Administrative IT Operations and Infrastructure	14.95	-	13.67	-1.28	-8.5%
Administrative Security & Privacy Services	3.33	-	2.92	-0.41	-12.3%
Administrative IT Management	0.51	-	0.48	-0.03	-5.9%
Total	**$25.89**	**-**	**$22.98**	**-$2.91**	**-11.2%**

IT investments for agency operations ensure high quality, reliable, and secure administrative applications and associated IT infrastructure and provide the support and services necessary to meet the needs of the Foundation.

NSF's FY 2021 AOAM Request funding for information technology reflects priorities that are strategically aligned with the President's Management Agenda and include:
- Continuing support for the IT infrastructure and systems that support the administrative operations of the agency, preserving secure, reliable operations to the greatest extent possible. (CAP Goal 1:

Modernize IT to increase productivity and security)
- Maintaining the security of NSF's infrastructure to respond to the ever-evolving threat landscape, prioritizing continued efforts to manage, modernize, and secure agency information systems. (CAP Goal 1: Modernize IT to increase productivity and security)
- Supporting the continued operation of iTRAK, the Foundation's financial management system, to ensure continued interoperability with NSF's core financial functions. (CAP Goal 2: Leveraging data as a strategic asset)
- Support continued use and refinement of the Technology Business Management (TBM) framework for managing IT as a business. (CAP Goal 10: Improving outcomes through federal IT spending transparency)

<u>Administrative Applications Services and Support ($5.91 million)</u>
Investments in this category support administrative applications, such as NSF's website, NSF's human resources management systems, and iTRAK.
- iTRAK is NSF's financial management system. In FY 2021, the total funding for iTRAK is $6.57 million. Seventy percent will be funded by the R&RA and EHR accounts and thirty percent will be funded by the AOAM account. The AOAM portion of the FY 2021 funding level is $1.97 million and will fund ongoing operations and maintenance of the system. (CAP Goal 2)
- Other administrative applications services funding is $2.81 million and will provide for operations and maintenance of agency administrative and collaboration tools, such as SharePoint and the NSF website. In FY 2021, NSF will prioritize operations and continued modernization of agency websites and digital services.
- A total of $1.13 million will fund continued operations and maintenance of the systems that support the strategic management of NSF human capital, including those that enable the effective recruitment, retention, development, and use of NSF staff in alignment with NSF's Strategic Goal 3: Enhance NSF's performance of its mission, Strategic Objective 1: Human Capital - Attract, retain, and empower a talented and diverse workforce.

<u>Administrative IT Operations and Infrastructure ($13.67 million)</u>
The FY 2021 Request maintains basic capabilities for the provision of agency services related to network, infrastructure, data center, customer support, and database administration. Specifically, the investments in this category, supporting CAP Goals 1 and 10, are classified as:
- Network ($3.12 million)–providing access to administrative applications, services, and technologies for virtual meeting support via a single network with wired and Wi-Fi connectivity for NSF staff and visitors. This investment also includes voice services via NSF's modernized voice over internet protocol (VoIP) solution.
- Data Center and Cloud ($1.96 million)–continuing agency use of cloud services and technologies to enable further reductions in NSF's data center footprint, as the agency plans and prepares for further cloud services adoption. An additional $496,800 to support Data Center Facilities and Power is referenced in the Space Rental section of this narrative.
- End User ($6.51 million)–providing help desk services and customer care support for internal users (NSF staff), as well as support for mobile devices, workstations, and peripherals.
- Platform ($2.08 million)–reflecting NSF's use, management, and acquisition of hyper-converged hardware, software, and services.

<u>Administrative Security and Privacy Services ($2.92 million)</u>
Investments in this category support the portion of NSF's IT security program which provides security and compliance oversight for NSF's administrative applications under the direction of the NSF Chief Information Security Officer. (CAP Goal 1) FY 2021 investments will prioritize preservation of secure, reliable operations and maintains current approaches to manage, modernize, and secure agency information.

The investment includes offerings from the Continuous Diagnostics and Mitigation program; automated configuration management tools that manage security patches and provide proactive protection from viruses, spyware, and other threats; application security; security control testing and tools; automated vulnerability assessment tools; and remediation and intrusion detection services.

Administrative IT Management ($480,000)
IT Management includes support for the Chief Information Officer and senior IT leadership in the areas of IT strategy and planning, enterprise architecture, capital planning, vendor management, IT budget/finance, and IT strategic communications. In FY 2021, investments in this category will provide for NSF's continued use and refinement of the TBM framework, further enhancing the agency's ability to manage IT as a business. (CAP Goal 10)

Space Rental

Space Rental
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Building Rental and Taxes	$24.69	-	$24.99	$0.30	1.2%
Utilities	1.16	-	1.44	0.28	24.3%
Security	5.54	-	5.70	0.16	2.8%
Parking Rental (including parking credits	0.36	-	0.53	0.18	50.0%
Total	**$31.75**	**-**	**$32.66**	**$0.91**	**2.9%**
Adjustments[1]	-7.88	-	-	7.88	-100.0%
Total After Adjustments	**$23.87**	**-**	**$32.66**	**$8.79**	**36.8%**

[1] Adjustments include -$11.17 million for FY 2019 rental costs funded in FY 2018 and +$3.29 million for FY 2020 rental costs funded in FY 2019.

In FY 2021, NSF will occupy over 700,000 square feet of space, primarily in one leased office building located in Alexandria, Virginia. The FY 2021 Request for Space Rental includes services provided by the General Services Administration (GSA) related to rent and taxes, utilities, and security provided by the Department of Homeland Security. In addition, rent paid for the parking structure to the owner of the NSF headquarters building in Alexandria is included. Parking credit estimates to be received in FY 2021 are applied to the FY 2021 Request.

With the advanced capabilities afforded at NSF's new Alexandria, VA location, increased transparency into costs allows for additional reporting of IT expenditures related to NSF's onsite Information Technology Data Center. The portion of the total Space Rental cost aligned to the TBM cost pool for "Facilities and Power" is $496,800.

Operating Expenses

Operating Expenses
(Dollars in Millions)

FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
$17.29	-	$16.06	-$1.23	-7.1%

The FY 2021 Request for Operating Expenses is $16.23 million. Operating Expenses include funding for supplies and equipment, contracts, and other costs necessary to enable accomplishment of NSF's research and education mission, as well as to support a wide variety of financial and award management, leadership, and other activities.

The key activities funded by NSF's FY 2021 Request for Operating Expenses include:

- A total of $7.58 million for training, equipment, communications devices, printing, and supplies for NSF's directorates and offices. This funding will support the regular FTE usage of 1,315 projected for FY 2021.
- Funding of $1.95 million supports grant outreach and oversight of major facilities including business systems reviews, portfolio risk assessment, NSF outreach activities, and guidance document development. The annual Large Facilities Workshop and associated Knowledge Sharing Gateway, used to coordinate the sharing of good practice and lessons learned, is an agency priority related to statutory requirements under the American Innovation and Competitiveness Act and Program Management Improvement Accountability Act.
- Funding of $1.76 million supports NSF's annual risk assessment, post-award monitoring desk reviews, post-award adjustment reviews, and documentation of the guidance and procedures for post-award monitoring and oversight processes. This funding enables NSF to complete 100-110 desk reviews as well as other oversight activities each year. The advanced monitoring activities are a critical component of the NSF advanced monitoring program and enhance NSF's performance of its mission by assessing the extent to which awardees maintain a control environment that ensures NSF awards are administered in compliance with federal regulations and NSF terms and conditions. Additionally, results of the oversight activities are leveraged for the annual Financial Statement Audit and support agency efforts to manage risk and continually improve grant operations.
- Funding of $1.76 million supports contract staff support in BFA, Division of Financial Management (DFM) to aid in accounting operations, financial statement and notes preparation, NSF property reporting, financial systems support and reporting, and audit deficiencies resolution assistance. This contract support is needed for DFM to meet federal financial reporting requirements and audit requirements.
- Funding of $719,000 supports NSF's Data Analytics Assurance Program that replaces the Internal Control and Quality Assurance Program by evolving the existing internal control framework, providing a stronger risk management for improving mission delivery, and improving the accountability and effectiveness of Federal programs and operations by establishing, assessing, correcting, and reporting on internal control.
- Funding of $448,000 supports NSF's Automated Acquisition Management Solution system for contract writing/E-procurement which includes licensing, subscription, deskside support, and training of new users on the system.
- Funding of $360,000 supports systems and related data analysis to continue to respond to evolving information needs to provide accurate, consistent information on financial data, funding rate, award size, and other statistics to NSF staff and the public. This information is disseminated via NSF's Enterprise Information System, the Budget Internet Information System, and other reporting

mechanisms. These activities support CAP Goal 2: Leveraging Data as a Strategic Asset.

- A total of $250,000 for reasonable accommodations that NSF is responsible for providing to persons with disabilities, including NSF employees, applicants, and those conducting business at NSF. Activities supported assist with maintaining NSF's model Equal Employment Opportunity status; not providing accommodations could be viewed as discrimination according to Sections 501 and 505 of the Rehabilitation Act of 1973.
- A total of $220,000 provides funding for the congressionally mandated Committee on Equal Opportunities in Science and Engineering (CEOSE) activity. CEOSE is an NSF advisory committee that provides advice on policies and programs to broaden participation of women, minorities, and persons with disabilities. The FY 2021 funding covers contractor services and meeting support for the CEOSE.
- Funding of $113,000 supports the AOAM-funded portion of the Integrated Acquisition Environment, an e-government initiative managed by GSA; a contracting information online knowledge management resource; the printing and mailing of 1099 forms; a monthly download to update routing numbers in NSF’s financial system (iTRAK); design and printing services for NSF’s annual reports including the Annual Financial Report, performance highlights brochure, and Congressional Request; and financial assistance award audit services to support incurred cost audits, accounting system audits, estimating system audits, and special projects which will provide NSF with information that will assist in the negotiation, award, administration, repricing, and settlement of large facilities financial assistance awards.
- Funding of $157,000 supports the negotiation and issuance of indirect cost rates for several organizations for which NSF is the cognizant agency.
- Funding of $140,000 provides the on-site, project management support to plan, coordinate, and execute NSF activities in connection with the Digital Accountability and Transparency Act responsibilities and operations.
- Funding of $105,000 supports simplified acquisition which includes purchase card program oversight, contract execution, and database management. Support for oversight of the purchase card program will be primarily funded with purchase card rebates, reducing the total costs to be paid from NSF’s AOAM account.

Building and Administrative Services

Building and Administrative Services
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
Information Dissemination	$3.49	-	$2.49	-$0.99	-28.5%
Workplace Management	6.76	-	6.74	-0.02	-0.3%
Panel Support, Meeting Management, and Proposal Services	4.65	-	3.24	-1.41	-30.3%
Total	**$14.90**	**-**	**$12.48**	**-$2.42**	**-16.2%**

The FY 2021 Request for building and administrative services is $12.30 million. This investment supports three sets of activities: information dissemination; workplace management; and panel support, meeting management, and proposal services.

Information Dissemination ($2.49 million)

Activities supported in this category align with CAP Goal 4: Improving customer experience with federal services and include:

- NSF website and application development and support. FY 2021 funding ($1.35 million) provides website and business application development and user experience support, NSF.gov maintenance, as well as intranet maintenance and associated licenses.
- Records management and the establishment and execution of records management policies and procedures. NSF is on track to comply with M-19-21 Directive, Transition to Electronic Records. FY 2021 funding ($404,000) supports digitization of records and shipments to and storage at the Federal Records Center and the National Archives and Records Administration.
- Graphic design ($400,000) includes the design and creation of layouts, graphics, animation, style sheets, and color schemes for use in NSF communications in print and on the web.
- Communications contract support ($239,000) which provides information to both the public and NSF staff regarding the NSF mission and related content.
- Congressional Record and Code of Federal Regulations requests ($100,000) for the Foundation.

<u>Workplace Management ($6.74 million)</u>
This investment category supports a wide range of activities including:
- Space management and facility operations, including development of space plans and assignments, space reconfigurations, facility service and maintenance, and transportation. FY 2021 funding ($1.33 million) reflects revised cost estimates based on current expenditures for building operations and maintenance at the Alexandria location.
- Activities related to property—the oversight and planning of mailroom, shipping and receiving operations, property receipt, inventory, and tracking. FY 2021 funding ($1.32 million) reflects revised cost estimates based on current expenditures at the Alexandria location.
- Core business activities and infrastructure support related to security and emergency management ($3.38 million), such as security badge issuance, management of NSF Continuity of Operations Plan activities, physical security, and access control; information and reception center; and personnel security adjudication support.
- Operations and maintenance for the Integrated Workplace Management System ($709,000) supporting space and workplace management to include conference room scheduling and asset inventory.

<u>Panel Support, Meeting Management, and Proposal Services ($3.24 million)</u>
This category supports NSF's merit review process by providing various services for NSF staff, panelists, members of advisory committees, committees of visitors (COVs) and guests. Activities include:
- Management and support of agency printing devices. FY 2021 funding ($637,000) for copier and printer maintenance and supplies reflects a reduction of the number of printing devices in support of the *Executive Order Promoting Efficient Spending* (EO 13589).[3]
- Library and research assistance ($131,000) for the Foundation. This funding provides contractual support for one librarian.
- Management of central conference space, including activities to oversee, operate, and maintain mission-critical audiovisual and communications equipment and resources, both physical and virtual. FY 2021 funding ($1.17 million) provides the resources needed to schedule, coordinate, and conduct NSF's onsite and virtual meetings and panels.
- Travel management services ($1.31 million) supports NSF staff, panelists, members of advisory committees, committees of visitors (COVs), and guests. Transportation of household goods and relocation assistance is also covered under this activity.

[3] https://obamawhitehouse.archives.gov/the-press-office/2011/11/09/executive-order-13589-promoting-efficient-spending

AOAM by Object Class

AOAM by Object Class
(Dollars in Thousands)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
Personnel Compensation	$178,541	-	$190,293	$11,752	6.6%
Personnel Benefits	54,434	-	57,940	3,506	6.4%
Travel and Transportation of Persons	5,560	-	5,157	-403	-7.2%
Transportation of Things	61	-	288	227	372.1%
Rental Payments to GSA	22,708	-	32,662	9,954	43.8%
Rental Payments to Others	81	-	220	139	171.6%
Communications, Utilities and Misc. Charges	1,512	-	1,274	-238	-15.7%
Printing and Reproduction	119	-	599	480	403.4%
Advisory and Assistance Services	41,287	-	39,664	-1,623	-3.9%
Other Services	9,964	-	8,432	-1,532	-15.4%
Purchases of Goods & Srvcs from Gov't. Accts	13,204	-	6,006	-7,198	-54.5%
Operations and Maintenance of Facilities	-	-	-	-	N/A
Operations and Maintenance of Equipment	252	-	49	-203	-80.6%
Supplies and Materials	762	-	852	90	11.8%
Equipment	4,207	-	2,206	-2,001	-47.6%
Total	**$332,692**	**-**	**$345,642**	**$12,950**	**3.9%**

Personnel Compensation and Benefits: Personnel compensation funds payroll, awards/bonuses, reimbursable details to NSF, overtime, and terminal leave. Personnel Benefits include the Government's contribution towards retirement systems, health and life insurance, thrift saving plans, special overseas allowances, unemployment insurance, transit subsidies, and employee relocations.

Travel and Transportation of Persons: These resources fund travel required for planning, outreach, and the increased oversight of existing awards recommended by the agency's Inspector General.

Transportation of Things: This category consists of household moves associated with bringing new staff to NSF.

Rental Payments to GSA: This category includes the rent charged by GSA for NSF's facility in Alexandria, Virginia.

Rental Payments to Others: This category includes rent paid for the parking structure to the owner of the new headquarters building in Alexandria.

Communications, Utilities, and Miscellaneous Charges: This category includes all costs for telephone and other communication lines and services, both local and long distance, and postage.

Printing and Reproduction: This category includes contract costs of composition and printing of NSF's publications, announcements, and forms, as well as printing of stationery and specialty items.

Advisory and Assistance Services: This category includes development, learning, and career enhancement opportunities offered through the NSF Academy; contracts for human capital operational activities, work life initiatives, outreach, and related services; assistance in award oversight and monitoring; and support for OMB Circular A-123 reviews.

Other Services: This category includes warehousing and supply services, mail handling, proposal processing, equipment repair and maintenance, building-related costs, furniture repair, contract support for conference room services, security investigations, and miscellaneous administrative contracts.

Purchases of Goods and Services from Government Accounts: This category includes reimbursable services purchased from other government agencies. Examples include GSA for security guard services, some electrical upgrades, and modest renovation services, and Department of the Interior for payroll services.

Operation and Maintenance of Equipment: This category includes management and operation of the central computer facility 24x7 year-round; operation of the customer service center and FastLane help desk; maintenance of database server hardware and related peripherals; software licensing fees; data communications infrastructure and network systems support; electronic mail support; and remote access (e.g., internet and World Wide Web).

Supplies and Materials: This category includes office supplies, library supplies, paper and supplies for the NSF central computer facility, and miscellaneous supplies.

Equipment: This category includes new and replacement computing equipment, desktop computers, data communications equipment, video-teleconferencing equipment, office furniture, file cabinets, and support equipment such as audio-visual equipment.

Appropriations Language

For agency operations and award management necessary in carrying out the National Science Foundation Act of 1950 (42 U.S.C. 1861 et seq.); services authorized by section 3109 of title 5, United States Code; hire of passenger motor vehicles; uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; rental of conference rooms in the District of Columbia; and reimbursement of the Department of Homeland Security for security guard services; ~~$336,900,000:~~$345,640,000: *Provided*, That not to exceed $8,280 is for official reception and representation expenses: *Provided further*, That contracts may be entered into under this heading in fiscal year ~~2020~~2021 for maintenance and operation of facilities and for other services to be provided during the next fiscal year.

Agency Operations and Award Management
FY 2021 Summary Statement
(Dollars in Millions)

	Enacted/ Request	Unobligated Balance Available Start of Year	Unobligated Balance Available End of Year	Adjustments to Prior Year Accounts	Transfers	Obligations Actual/ Estimates
FY 2019 Appropriation	$329.54	0.19	-$0.15	-$0.38	3.49	$332.69
FY 2020 Enacted	336.90	0.15				337.05
FY 2021 Request	345.64					345.64
$ Change from FY 2020 Enacted						$8.59
% Change from FY 2020 Enacted						2.5%

Explanation of Carryover

Within the Agency Operations and Award Management (AOAM) account, $146,243 in recovered no-year funds was carried over into FY 2020.

NSF Headquarters Relocation

- Amount: $146,243
- Purpose: Budget contingency funding not obligated in FY 2019.
- Obligation: Anticipated FY 2020 Quarter 4

OFFICE OF INSPECTOR GENERAL (OIG) **$17,850,000**
+$2,574,000 / 16.8%

The Appropriations Act that funds the National Science Foundation contains a separate appropriation for NSF's Office of Inspector General. Accordingly, this FY 2021 Budget Request identifies the resources needed to support OIG, including amounts for personnel compensation and benefits (PC&B), contract services, training, travel, supplies, materials, and equipment.

The FY 2021 Budget Request for OIG is $17.85 million, an increase of $2.57 million over the FY 2019 Actual of $15.28 million.

OIG Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 Enacted	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Total	**$15.28**	**$16.50**	**$17.85**	**$2.57**	**16.8%**
Full-Time Equivalents (FTEs)	71	71	71	-	N/A

Appropriations Language

For necessary expenses of the Office of Inspector General as authorized by the Inspector General Act of 1978, ~~$16,500,000,~~$17,850,000, of which $400,000 shall remain available until September 30, ~~2021.~~2022.

Office of Inspector General
FY 2021 Summary Statement
(Dollars in Millions)

	Enacted/ Request	Unobligated Balance Available Start of Year	Unobligated Balance Available End of Year	Adjustments to Prior Year Accounts	Obligations Actual/ Estimates
FY 2019 Appropriation	$15.35	$0.40	-$0.40	-$0.07	$15.28
FY 2020 Enacted	16.50	0.40			16.90
FY 2021 Request	17.85				17.85
$ Change from FY 2020 Enacted					$0.95
% Change from FY 2020 Enacted					5.6%

Explanation of Carryover

Within the Office of Inspector General (OIG) two-year account, $400,000 was carried over into FY 2020.

Office of the Inspector General

- Amount: $400,000
- Purpose: Funds are expected to be used to procure financial and forensic audit services. The selection of awards and institutions to be audited will require careful preparation and is subject to changing circumstances and new information that may require additional time to process.
- Obligation: Anticipated FY 2020 Quarter 4

OIG Responsibilities and Structure

OIG provides independent oversight of NSF's programs and operations. The office promotes effectiveness, efficiency, and economy in administering the Foundation's programs and prevents and detects fraud, waste, and abuse within NSF or by individuals who receive NSF funding. By statute, NSF OIG is organizationally independent from the agency, with the Inspector General (IG) reporting directly to the National Science Board and Congress. Given the geographic breadth of the projects NSF funds, OIG needs to be equipped to conduct audits and investigations across the continental U.S., Alaska, Hawaii, Puerto Rico, and Antarctica. To fulfill its important mission, OIG employs a diverse staff of scientists, attorneys, certified public accountants, criminal investigators, management analysts, data analysts, and information technology specialists. OIG's FY 2019 appropriation was just 0.19 percent of NSF's $8.0 billion appropriation and 0.05 percent of NSF's $33.50 billion portfolio of active awards, yet OIG provides a much greater return on investment and serves as an invaluable safeguard against fraud, waste, abuse, and whistleblower reprisal.

OIG's work is divided into two functional areas: The Office of Audits and the Office of Investigations, which are supported by the Office of Management, Office of Counsel, and the IG's Immediate Office. Highlights of the office's operational impact and strategic focus by functional area follow.

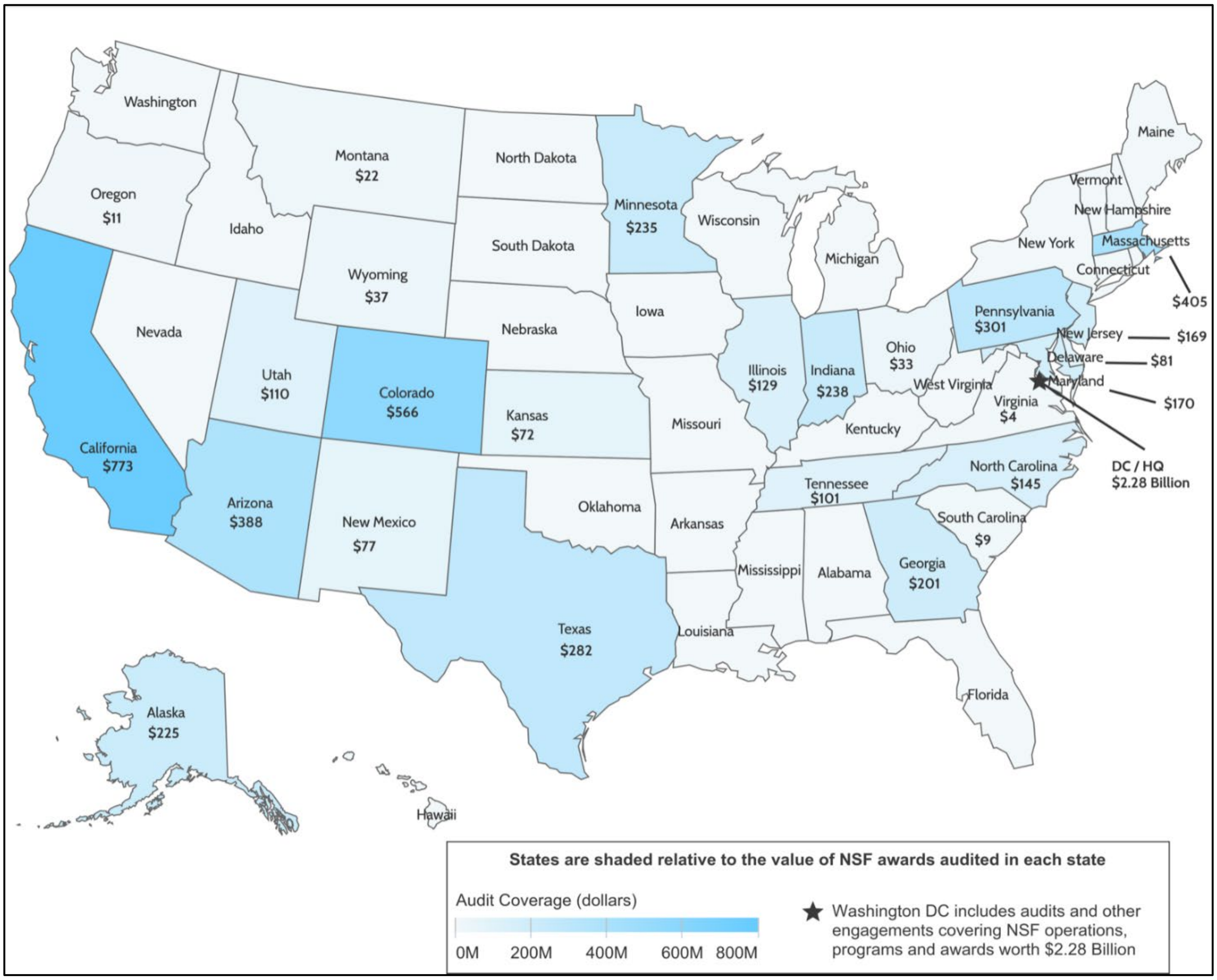
Audit Impact and Strategic Focus

OIG's Office of Audits (OA) conducts audits of NSF's contracts, cooperative agreements, and grants to universities and other research institutions, as well as internal audits of NSF's programs. These audits help ensure that financial, administrative, and programmatic activities are conducted economically, effectively, and in compliance with applicable regulations.

In FYs 2017 through 2019, OIG audited approximately $7.07 billion in NSF funding in 26 states and Washington, D.C.—resulting in 72 audit and other engagement reports containing a total of $10.0 million in questioned costs and 484 recommendations to recover misspent funds and improve awardee and NSF operations. Figure 1 shows the value of the awards audited in each state.

In FY 2019, OA identified more than $4.90 million in questioned costs and made 252 recommendations to strengthen program and grant operations. As a result of OIG audits, NSF recouped misspent funds and required awardees to improve their management of NSF awards and subawards to prevent future misuse of taxpayer money. Also, in response to recent audits, NSF strengthened controls over mobile devices, records management, and its large-scale, multi-user research facilities. These improvements increased the effectiveness and efficiency of NSF programs and made NSF a better steward of federal funds.

Figure 1. Audit Coverage October 1, 2016-September 30, 2019



Areas of Risk for Potential Audit Coverage in FY 2021

Many of the audits OIG performs are required by statutes (the annual financial statement and FISMA audits, audits required by the DATA Act and the Improper Payments Elimination and Reduction Act (IPERA), and a triennial review of the National Science Board's compliance with Sunshine Act requirements). OIG utilizes a risk-based approach to identify additional issues that would benefit from audits performed by in-house auditors. While additional areas may emerge by FY 2021, OA has currently identified four such high-risk areas:

Divestment of Major Facilities

NSF funds the construction, management, and operation of major research facilities, which are shared-use infrastructure accessible to a broad community of researchers and educators. NSF's major facilities typically have construction costs greater than $70.0 million, with total construction costs ranging from one hundred to several hundred million dollars over a multi-year period. Once construction is complete, NSF facilities may operate for 20 to 40 years with annual operations and maintenance budgets ranging between 6 and 10 percent of the original construction cost. With rising costs of operations, NSF needs to ensure it plans for the full lifecycle of the facility including its divestment. The objective of this audit is to determine if NSF identifies, plans for, and manages essential divestment opportunities for major facility projects.

Antarctic Infrastructure Modernization for Science
AIMS is one of NSF's most challenging major facility initiatives. According to NSF, the AIMS project will ensure that McMurdo Station remains a viable platform for supporting Antarctic science for the next 35 to 50 years. OA is increasing its monitoring and oversight efforts of the design, construction, and ongoing capital investment and support of AIMS. These efforts will help ensure NSF is properly managing the project and monitoring Leidos' compliance with contract terms.

Mid-scale Research Infrastructure
Mid-scale project means research instrumentation, equipment, and upgrades to major research facilities or other research infrastructure investments funded between $6.0 million and $100.0 million (i.e. exceeds the maximum amount that can be funded by the Major Research Instrumentation program but less than a major multi-user research facility project.) Mid-scale project oversight requirements are tailored to each project's unique characteristics such as the technical scope, the type and mix of work performed and an assessment of the associated technical and programmatic risks. This oversight model could cross multiple divisions and programs within NSF.

Regional Class Research Vessel
The RCRV project will help modernize the U.S. Academic Research Fleet through the construction of three new research vessels. The not-to-exceed total project costs is $353.97 million over nine years. This project is high risk, which NSF acknowledges. Some of the risks include potential delays or additional costs due to factors such as misunderstanding of requirements and contracting issues. NSF has a time-phased descoping plan to minimize impacts in case contingency funds are not sufficient to cover additional costs.

The audit objectives for this area would be fully developed once we begin background and survey work. Our previous work with large projects has indicated a key risk area occurs during the transition from construction to operations. During this phase, the co-mingling of funds intended for operations with funds intended to complete construction (or vice versa) present the highest risk. Additional areas of risk with any large construction project is the inappropriate use of contingency funds, or risk associated with the technical failures of the product. Our audits are designed in a way that allows us to evaluate all risks and choose the best approach after the survey phase.

<u>Audits of Recipients of NSF Grant Funds</u>
Discretionary audits of NSF recipients are an essential part of OA's efforts to protect NSF funds. All statutorily mandated audits and most in-house performance audits focus on NSF's internal operations. Because the bulk of NSF's funding is provided to the academic community via grants and cooperative agreements, robust oversight of that funding is imperative. Audits of NSF recipients determine whether awardees comply with the financial and administrative terms and conditions of the awards. They address the highest risk areas at institutions, identifying systemic issues, recapturing misused funds, and making recommendations ensuring proper stewardship of federal funds going forward.

Historically the OIG has procured audits of NSF recipients (which in FYs 2017-2019 covered between $22.0 million and $440.0 million in NSF funding) to provide this much-needed audit coverage over the recipient community. Beyond the findings specific to the institutions being audited, these audits can also identify evidence of behavior that could violate criminal or civil laws (which would be referred to OIG's Office of Investigations) or of inconsistent treatment of similar charges across the academic community (which can be shared with NSF staff, so they can clarify the issue). The impact of this work is not limited to the entities that are audited: NSF recipients carefully monitor the results of these audits to identify situations where they need to strengthen their own policies and procedures. OA typically uses independent public accounting firms to conduct these audits. At the Budget Request level, OA will be able to fund 4-5 of these audits.

OA will also conduct two desk review audits at small to medium sized institutions and continue to monitor the quality of Single Audits.

Investigative Impact and Strategic Focus

OIG's Office of Investigations (OI) conducts investigations of criminal, civil, and administrative wrongdoing related to NSF programs and operations, including all entities and individuals that receive NSF funds, as well as whistleblower reprisal investigations. OI also evaluates and investigates allegations of research misconduct such as data fabrication, data falsification, and plagiarism related to NSF-funded research. Since FY 2009, OIG investigations—civil, criminal, and administrative—have led to financial recoveries and savings to the federal government of more than $87.0 million, including almost $64.0 million in funds returned to NSF. OI's vigilance ensures that those who seek or receive NSF funds to conduct research are held accountable and serves as a meaningful deterrent to grant fraud and research misconduct.

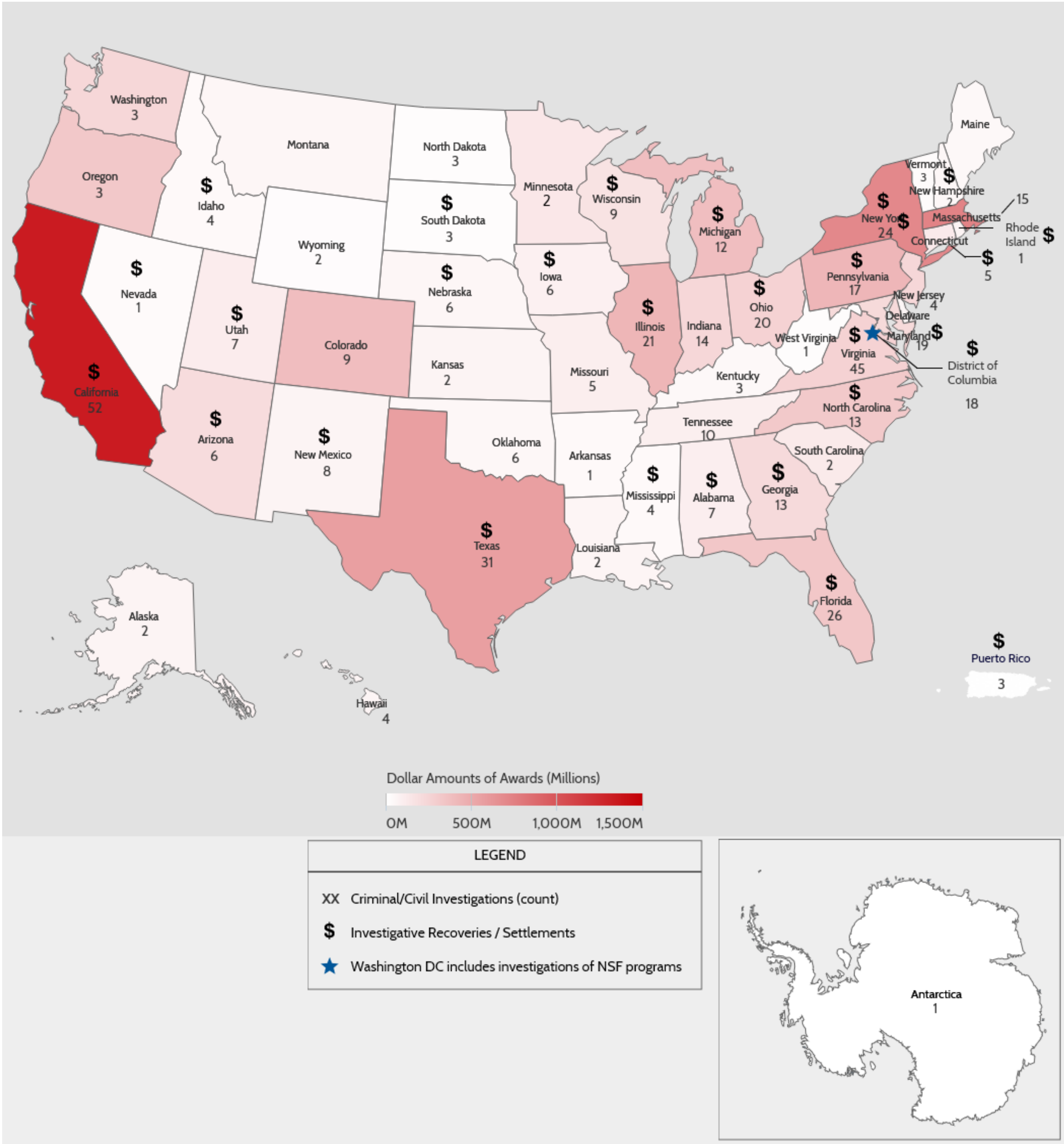
OI opens investigations based upon consideration of OIG's strategic goals, NSF Management Challenges, the seriousness and magnitude of the offense, the significance of programmatic vulnerability, and high-risk status of the program or institution. As illustrated in Figure 2, for FYs 2017 through 2019, OI's investigative oversight of NSF's $33.50 billion award portfolio included 492 investigations spanning 49 states, as well as Washington DC, Puerto Rico, and Antarctica.

<u>Talent Plan Investigations</u>
Recent congressional hearings have focused on the theft of U.S. federally funded research and development by foreign states who use talent plans to exploit the openness of American universities and the federal research enterprises. In FY 2018, OI initiated its first criminal investigations focused on potential misuse of NSF funding by members of foreign "talent plans." The volume and complexity of such investigations has increased throughout FY 2019, now amounting to a more than 20 percent increase in OI's workload. OI has confronted this national security threat in a number of ways. For instance, in FY 2019, OI hired an analyst with appropriate language qualifications on a term appointment to perform immediate, onsite translation of Chinese documents. While China is not the only foreign government exploiting the openness of American universities, many of our investigations concern Chinese talent plans. Within one month the analyst saved OIG more than her annual salary in translation costs. Further, her knowledge of the cases and ability to quickly bring matters to the attention of the investigators saved months of investigative time and increased investigation efficiency by an order of magnitude. In FY 2020, this position will be made permanent to allow OIG to cost effectively translate the large volume of documents in Mandarin Chinese generated by talent plan related investigations. In addition to the investigations it is working in this area, OI:

- Founded and now serves as co-leader of a Council of the Inspectors General on Integrity and Efficiency (CIGIE) Working Group designed to inform and assist investigative colleagues with the identification of the threat, predication of cases, and best practices in conducting such investigations;
- Collaborates with the FBI and other investigative partners to conduct outreach to internal and external stakeholders (e.g. grantees, institutions) to explain the risks posed by talent plan membership; and
- Conducts outreach and education to NSF, which has resulted in the issuance of new or amended agency advisories and policies to address the threat, including prohibition of talent plan members serving as employees or Intergovernmental Personal Act (IPA) rotators, requiring IPA rotators to be U.S. citizens, and increasing disclosure requirements for researchers seeking NSF funding.

OI's investigative work on these cases has resulted in award suspensions and terminations, recovering NSF funds for better use, as well as referrals to the U.S. Attorney's Office.

Figure 2. OIG Investigations October 2016 – July 30, 2019



<u>SBIR/STTR Investigations</u>

Since 2010, OI has conducted more than 150 investigations related to the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs, which remain among the most at-risk programs funded by NSF. With NSF's total annual SBIR/STTR award expenditures now approaching $200.0 million, protecting SBIR/STTR funds from fraud and abuse has become even more important. OI has successfully partnered with NSF program managers to improve SBIR/STTR processes and procedures to reduce the opportunity for fraud to occur. OI also conducts SBIR/STTR-related outreach at NSF awardee workshops, providing guidance to the small business community on how to properly handle federal funds and the consequences of not following the rules. OI's efforts have produced significant programmatic improvements and enhanced understanding throughout the research community. In addition, OI has led an OIG community working group focused on fraud in these programs to share best practices and lessons learned.

Support Offices' Actions and Impacts

Office of Management
OIG's centralized Office of Management (OM) provides support services for the entire office. This includes essential functions such as budget and finance, procurement, human resources and IT services as well as strategic planning and general administrative support. OM develops streamlined processes and uses cutting-edge tools to increase the efficiency and effectiveness of its operations. Specific responsibilities in OM include:

- Budget and administration—responsible for all budgetary, financial, and administrative business conducted by the office and works with NSF to provide human resources and procurement support.
- Training—training is scheduled/tracked to ensure staff take all mission-critical and required training.
- Investigative intake operation—all complaints are handled by an Intake Coordinator, who processes nearly 300 allegations annually. The external OIG Hotline website has been revamped to quickly identify substantive allegations, which the Intake Coordinator presents to Investigations management.
- Forensic accounting and data analytics—an inhouse forensic accountant skilled in data analytics helps manage the large amounts of information that investigators receive through subpoenas and other means. The forensic accountant reduces the need for investigative contract services by over 50 percent, saving $100,000 per year. The application of data analytics to vital functions such as procurement oversight yields further management efficiencies and cost savings.
- IT services—includes website maintenance and posting of reports, digital forensics, and data security as well as ongoing support of OIG-specific software applications and databases. Digital forensics has become much more critical in investigations, as most of the evidence being captured is electronic.

Office of Counsel
The Office of Counsel (OC) consists of the Counsel to the IG and two assistant counsels, one of which is part-time. It provides comprehensive legal advice and critical analysis to the IG and all OIG divisions, including legal review of externally issued OIG work products and certain correspondence. OC handles myriad subject areas, including audit-related support, ethics, appropriations law, acquisitions, information disclosure, privacy, personnel, and IG Act authorities. OC also supports the larger IG community through active participation in CIGIE projects and committees. On average, OC handles more than 150 actions per year, including routine reviews of reports, contracting matters, and other externally focused documents; Freedom of Information requests; and legal opinions on various matters. OC attorneys also participate in key meetings and decisions, conduct training, and publish legal updates. This level of routine involvement enables the office to identify and address potential legal issues and risk areas before they mature.

Immediate Office
The Inspector General's immediate office includes the Chief of Staff and Executive Assistant. The Chief of Staff handles all matters relating to external affairs, primarily congressional relations, and public/media contacts.

Government-wide Impact

Though small relative to many other OIGs, NSF OIG continues to make significant contributions to the Inspector General community and the government at large. For example:

- NSF's Inspector General has served as the vice chair of CIGIE since 2014, which includes:

1. Chairing CIGIE's IG Candidate Panel to help the White House identify strong candidates for vacant Presidentially Appointed Senate-confirmed IG positions;
2. Representing the IG community in a Five-Eyes effort focused on counter-fraud begun by the British government; and
3. Leading CIGIE's Grant Reform Working Group, which provides valuable feedback and insights to OMB staff as they consider grant-related changes.

- NSF OIG has conducted outreach to the federal IG community, provided training to other investigative agencies, and taken the lead to establish and run four IG community working groups to:

1. Prevent fraud within the SBIR/STTR programs;
2. Increase the use of government-wide suspension and debarment as tools to deter and reduce instances of fraud, waste and abuse;
3. Foster the next generation of senior investigative leaders within the IG community; and
4. Address emerging threats to U.S. national security through efforts by foreign governments to illegally obtain intellectual property and other research.

Financial Discussion

Office of Inspector General
Personnel Compensation and Benefits and General Operating Expenses
(Dollars in Thousands)

	FY 2019 Actual	FY 2020 Enacted	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
Personnel Compensation & Benefits[1]	$13,114	$13,935	$14,810	$1,696	12.9%
Travel & Transportation of Persons	211	210	275	64	30.3%
Advisory & Assistance Services[2]	1,480	1,801	2,185	705	47.6%
Rent	104	110	120	16	15.4%
Information Technology	104	100	100	-4	-3.8%
Communications, Supplies, Equipment and Other Services	263	344	360	97	36.9%
Training	*123*	*140*	*140*	*17*	13.8%
Other	*100*	*150*	*161*	*61*	61.0%
CIGIE Assessment	*40*	*54*	*59*	*19*	47.5%
Total	**$15,276**	**$16,500**	**$17,850**	**$2,574**	**16.8%**
Full-Time Equivalents	71	71	71	-	N/A

[1] FY 2021 includes expected within grade increases, COLA and increased performance awards.
[2] Includes the costs of the annual financial statements audit and the outsourcing of contracting services.

With an FY 2021 appropriation of $17.85 million, OIG will be able to maintain existing staff at 71 FTEs and continue operations as described above, including continuing its current efforts to address challenges posed by foreign talent plans. Over the past 5 years, the average cost per FTE increased by approximately 20 percent due to cost of living and benefit increases. OIG will also increase its performance awards to non-SES employees by 1 percent in FY 2021.

Funding at the requested level would also provide sufficient travel funds for OIG audit and investigative staff. We anticipate that those costs will increase by about 20 percent over current levels by FY 2021 due to several factors, including travel to the Antarctic for oversight work associated with the McMurdo modernization, as well as the expanding landscape of OIG investigations, as previously described.

OIG anticipates increased costs for the contract used to conduct the financial statement, FISMA and DATA Act audits, which is being recompeted in FY 2020. Funding at the requested level will be sufficient to cover that cost and to procure several discretionary audits of NSF recipients. Finally, funding at the requested level will enable OIG to replace IT equipment that is near the end of its useful life and invest in data analytics and computer forensics software to augment audits and investigations.

For these reasons, the Budget requests an increase of $2.57 million in FY 2021.

Inspector General Reform Act Statement

Section 6(g)(1) of the IG Act, 5 U.S.C. app. 3, was amended by the Inspector General Reform Act of 2008 (Pub. L. 110-409) to require a summary statement concerning OIG's annual budget request.

In accordance with this, we submit the following summary:

- NSF OIG's FY 2021 Budget Request is $17.85 million.
- The portion for training is $140,000.
- The portion for operation of the CIGIE is $59,000.[1]

The portion of the Budget Request for staff training is expected to suffice for all training needs in FY 2021. Because CIGIE's annual assessment is based on a percentage of each OIG's appropriation, the portion indicated for this purpose at the Budget Request level will suffice.

[1] This is an estimate of CIGIE's annual membership assessment, which is tied to each member OIG's annual appropriation.

OFFICE OF THE NATIONAL SCIENCE BOARD (NSB) **$4,210,000**
-$113,000 / -2.6%

The FY 2021 Budget Request for the Office of the National Science Board is $4.21 million, which is a decrease of $113,000 below the FY 2019 Actual of $4.32 million. This FY 2021 Request level will enable the Board to fulfill its policy-making and oversight responsibilities for NSF and continue its statutory responsibilities as outlined in the Organic Act, including activities related to the authorization of major research facilities projects.

NSB Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 Enacted	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
Total	**$4.32**	**$4.50**	**$4.21**	**-$0.11**	**-2.6%**
Full-Time Equivalents (FTEs)	17	18	17	-	N/A

Appropriations Language

For necessary expenses (including payment of salaries, authorized travel, hire of passenger motor vehicles, the rental of conference rooms in the District of Columbia, and the employment of experts and consultants under section 3109 of title 5, United States Code) involved in carrying out section 4 of the National Science Foundation Act of 1950 (42 U.S.C. 1863) and Public Law 86–209 (42 U.S.C. 1880 et seq.), ~~$4,500,000:~~$4,210,000: *Provided*, That not to exceed $2,500 shall be available for official reception and representation expenses.

National Science Board
FY 2021 Summary Statement
(Dollars in Millions)

	Enacted/ Request	Expired	Obligations Actual/ Estimates
FY 2019 Appropriation	$4.37	-$0.05	$4.32
FY 2020 Enacted	4.50		4.50
FY 2021 Request	4.21		4.21
$ Change from FY 2020 Enacted			-$0.29
% Change from FY 2020 Enacted			-6.4%

National Science Board in Context

The NSB, established by the NSF Act of 1950, has dual responsibilities to: provide national science policy advice to the President and Congress; and establish policies for NSF within the framework of applicable national policies as set forth by the President and the Congress. The Board consists of 24 presidentially-appointed members plus the Director of NSF as an ex officio member. Representing the broad U.S. science and engineering (S&E) research and education community, the Board serves collectively as an advisory body on S&E issues critical to the Nation. Board members serve six-year terms on staggered appointments and are drawn from industry, academe, non-profit organizations, government, and professional scientific societies representing the breadth of S&E disciplines. They are selected to represent all areas of the Nation based on their eminence in research, education, or public service.

The Board currently convenes at least four formally scheduled public meetings per year, with additional meetings as needed, to review and approve major NSF awards; provide guidance on new programs; oversee and provide policy direction to NSF; oversee the lifecycle of large facilities, including conducting site visits; and address significant S&E-related national policy issues. The Board initiates and conducts studies and reports on a range of policy topics and engages NSF's stakeholders nation-wide. The Board reviews NSF's priorities to ensure progress and consistency along the strategic direction set for NSF and to ensure balance among new investments and core programs.

Policy Responsibilities

The Board examines issues of importance to the S&E research and education communities, in general, and to NSF, in particular. Topics for exploration are determined through requests from Congress or the President, and as the Board identifies in consultation with the community and NSF management. Recent publications have examined topics such as the skilled technical workforce, mid-scale research infrastructure, operations and maintenance costs for NSF's large facilities, and the rise of China in S&E. Currently, the NSB is undertaking an effort to set a Vision for NSF for 2030.

The Board has several standing committees, and an *ad hoc* task force on the NSB Vision 2030 project to assist with its responsibilities.

The **Executive Committee** (EC) includes the Director of NSF, who chairs the Committee, and four elected members from the Board, of whom two are the NSB Chair and Vice-Chair. The Board has delegated to this Committee its authority to approve awards in the rare instances when immediate action is required between Board meetings.

The **Committee on Oversight** (CO) conducts independent oversight of NSF's operations, processes for risk management, audit plans and results, and processes for complying with laws and regulations; reviews Office of the Inspector General activities and NSF management responses; monitors audits and makes related recommendations to the Board; and oversees the Board's compliance with the Sunshine Act.

The **Committee on Strategy** (CS) provides a forum for developing the Board's strategic discussions of NSF's budget, programs, organization structure and agency vision; makes recommendations to the Board on annual Budget Requests and quadrennial Strategic Plans; and provides strategic guidance to the Board on NSF's programs.

The **Committee on National S&E Policy** (SEP) oversees development and production of the congressionally-mandated *Science and Engineering Indicators* (*Indicators*) report in collaboration with NSF's National Center for Science and Engineering Statistics (NCSES); helps ensure that the S&E information and policy resources developed by the NSB are high-quality, policy-relevant, and accessible in order to meet stakeholder needs; and helps fulfill the NSB's charge to provide ongoing information and policy advice to Congress and the President on S&E research, education, and workforce issues.

The **Committee on Awards and Facilities** (A&F) addresses strategic issues and recommends policies to the Board related to awards and MREFC projects; makes recommendations to the Board on awards and facilities; and provides lifecycle oversight on facilities and oversight on awards.

The **Committee on External Engagement** (EE) leads the NSB's communication and engagement efforts with government, industry, the public and the research and education communities, and helps the Board advance the pursuit of national policies for the promotion of research and education in S&E.

The **Subcommittee on Honorary Awards** (AWD) reviews nominations for two awards established by the Board: the Vannevar Bush Award and the Public Service Award.

The **Vision 2030 Task Force** (V2030) is leading the NSB's effort to develop a Vision that will guide the Board and NSF actions and priorities in the coming decade. The Board anticipates publishing its Vision 2030 report early in calendar year 2020.

Ongoing activities of the Board include review and approval of:
- Large awards, MREFC projects and other proposals as needed;
- NSF's Management Response to the Office of Inspector General Semi-annual Reports to Congress;
- Transmittal of the NSF, OIG, and NSB budget submissions to the Office of Management and Budget;
- Priority order of projects in the MREFC Account;
- Midscale Research Instrumentation-2 awards (and oversight of the Midscale Research Instrumentation-1 awards); and
- Inclusion of new projects requiring funding under the MREFC Account.

The Board also reviews and makes recommendations on:
- NSF's financial management reports,
- The operation of NSF's merit review system, and
- NSF's research infrastructure portfolio.

Office of the National Science Board
Personnel Compensation and Benefits and Other Operating Expenses
(Dollars in Thousands)

	FY 2019 Actual	FY 2020 Enacted	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
Personnel Compensation & Benefits (PC&B)[1]	$3,201	-	$3,331	$130	4.1%
Staff Development & Training	21	-	38	17	81.0%
Advisory & Assistance Services	608	-	517	-91	-15.0%
Travel & Transportation of Persons	354	-	221	-133	-37.6%
Communications, Supplies, & Equipment	136	-	100	-36	-26.5%
Representation Costs	3	-	3	-	N/A
Total	**$4,323**	**$4,500**	**$4,210**	**-$113**	**-2.6%**
Full-Time Equivalents (FTE)	17	18	17	-	N/A

[1] FY 2021 PC&B includes base salary costs and anticipated within grade and promotion increases.

Personnel Compensation and Benefits

The Board's FY 2021 Budget Request supports a core of full-time policy, communications, administrative, legal, and executive secretariat staff. In addition to providing institutional memory for the Board, the Board Office staff provides both the resources and expertise for coordinating and conducting science and education policy analyses and developing and implementing broad communication and outreach programs. Staff also advise the Board on legal aspects of its policies and activities and provides operational and administrative support that are essential for the Board to fulfill its mission. The Request reflects anticipated increases in NSB office staff pay and in performance awards spending in FY 2021.

Other Operating Expenses

The Staff Development and Training budget line supports various training events such as federal leadership training for management staff, Contracting Officer Representative (COR) training and recertification, and project management training, as well as facilitation services for staff retreats that have a professional development component.

The Board's Advisory and Assistance Services budget line includes some of the resources needed to produce reports such as the Congressionally mandated *Science and Engineering Indicators*. In recent years, the Board has created interactive digital products to facilitate accessibility and use of *Indicators* data in policy decisions and analysis. *Indicators 2018* included an electronic state data tool that allows for more frequent and timely updates and state one-pagers that highlight select data by state. For *Indicators 2020,* the Board will update the state data tool and state one-pagers, develop a series of thematic reports, and release *The State of U.S. Science and Engineering* in January 2020. In FY 2020, the Board will also produce its *Vision 2030*, which will provide strategic guidance to the NSB, NSF and the S&E enterprise over the next 10 years.

Other items in the Advisory and Assistance Services line support multimedia strategies, such as data-driven dynamic graphics, film, and video, to increase awareness and use of the Board's products by stakeholders. This budget line also supports maintenance of an electronic official records management system, which enables compliance with federal records requirements; the webcasting and archiving of all open Board meetings; transcription services necessary for compliance with the *Government in the Sunshine Act*; and board book management software, which facilitates effective and efficient NSB meetings.

The NSB's Travel and Transportation of Persons budget line primarily covers costs related to Board member travel to NSF headquarters for the Board's four annual meetings and a member-only retreat, for oversight of NSF's large programs and facilities, and for engaging stakeholders. To inform the NSB *Vision 2030* project, for example, the Board organized listening sessions in Washington D.C., Texas, Massachusetts, Missouri, Arizona, and South Dakota to hear from NSF stakeholders about the challenges and opportunities facing the S&E enterprise over the next 10 years. Also supported in this budget line is travel for invited speakers and participants in the NSB's activities, such as a panel on the future of fundamental S&E research that the Board organized at its February 2019 meeting.

The Communications, Supplies, and Equipment budget line funds communications services and information technology.

The FY 2021 Budget Request will support the Board's efforts to strengthen the U.S. S&E enterprise through its policy and information-related activities. Specifically, the Request will support the NSB's continued engagement with stakeholders—including Congress, the Administration, academia, the business community, and the general public—to better understand their diverse needs. In turn, this will help the NSB improve the usefulness of the resources it produces, ensuring that these stakeholders continue to have access to timely, comprehensible, and objective S&E data and policy guidance.

MAJOR MULTI-USER RESEARCH FACILITIES

Facilities:

MAJOR MULTI-USER RESEARCH FACILITIES

Major Multi-User Research Facilities Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
Total Research and Related Activities	**$1,026.38**	**-**	**$867.42**	**-$158.96**	**-15.5%**
Operations and Maintenance of Existing Facilities	684.44	-	598.38	-86.06	-12.6%
Federally Funded Research and Development Centers	331.44	-	264.04	-67.40	-20.3%
Operations and Maintenance of Facilities under Construction	8.50	-	5.00	-3.50	-41.2%
R&RA Design Stage Activities	2.00	-	-	-2.00	-100.0%
Major Research Equipment and Facilities Construction	**$284.95**	**-**	**$228.75**	**-$56.20**	**-19.7%**
Total, Major Multi-User Research Facilities	**$1,311.33**	**-**	**$1,096.17**	**-$215.16**	**-16.4%**

NSF investments in major multi-user research facilities (major facilities) provide large, state-of-the-art tools for research and education. These can include instrumentation networks, observatories, accelerators, telescopes, research vessels, aircraft, and simulators. In addition, scientific utilization of cyber-enabled and geographically distributed facilities continues to increase as a result of rapid advances in computer, information, and communication technologies. NSF's investments are coordinated with those of other organizations, federal agencies, and international partners to ensure they are complementary and well-integrated. Planning, operations, and maintenance of major facilities are funded through the R&RA account. Most construction is funded through the MREFC account.

In FY 2018, NSF created the position of Chief Officer for Research Facilities in the Office of the Director, to enhance oversight of major facilities throughout their complete lifecycle. The individual in that position serves as the senior agency official whose responsibility is oversight of the development, construction, and operations of major facilities across the Foundation, as required by Section 110 of the American Innovation and Competitiveness Act (P.L. 114-329).

The Program Management Improvement and Accountability Act requires an annual NSF portfolio review integrated with an agency Strategic Review. In FY 2019, the NSF Strategic Review evaluated practices in funding NSF's Major Facilities and lessons learned from the FY 2019 lapse in appropriations. One of the two areas of improvement identified was "[t]he implementation of agency-wide practices regarding funding increments that promote financial continuity and stability for the Major Facilities throughout the fiscal year." The key outcome of funding-continuity discussions surrounding the Strategic Review was that NSF Major Facilities should have at least three months of funding obligated to execute the NSF mission across any recognized boundaries of funding discontinuity or other potential shortfalls. NSF allocated funds in its FY 2019 spending plan to assist directorates and offices in the implementation of this new agency-wide practice to provide more robust "continuity of operations" for its Major Facilities.

The Facility Operation Transition activity proposed in the Integrative Activities (IA) section is the second year of a pilot program that reflects NSF's strategic commitment to successful operations and maintenance (O&M) of new major facilities as well as balancing portfolio funding between facilities and investigator research, both of which were emphasized in the NSB's Congressionally requested 2018 report entitled

"Study of Operations and Maintenance Costs for NSF Facilities" (NSB-2018-17).[1] NSB suggested a more flexible MREFC account as one way to achieve these goals. Owing to the challenges that would be introduced by maintaining separate construction and operations funding in the MREFC account, as well as the desire to maintain MREFC as a self-contained "capital" account, the recommended strategic funding is requested in the R&RA account instead. The funds in this activity will be used to (1) partially support initial O&M of new facilities so that the full O&M costs can be gradually absorbed into the managing division or directorate, and (2) partially support divestment of lower-priority facilities, the full cost of which may significantly impact individual division or directorate funding.

A total of $10.0 million is requested in FY 2021 for the Facility Operation Transition activity. Of this amount, $8.0 million will support O&M for NSF facilities that are in the pre-operations phase within the first five years of their operational life—the National Ecological Observatory Network (NEON), the Daniel K. Inouye Solar Telescope (DKIST), and the Vera C. Rubin Observatory. This funding will be divided among these three facilities in approximate proportion to their total O&M requirements. The requested amount is less than 10 percent of the O&M costs of these three facilities, so that most of the funding remains the responsibility of the managing directorates. The Facility Operation Transition funds will assist the research directorates in sustaining the core research needed to take advantage of the new facility capabilities. The remaining $2.0 million for this activity will support investments in facility divestment activities. The distribution of IA support between facilities O&M and divestment will be re-evaluated annually as new facilities come online and lower-priority facilities are removed from NSF's portfolio. This program will be reevaluated after FY 2022 to determine whether it should be modified, continued, or ended.

This chapter provides descriptions of each major facility supported through the R&RA account and provides funding information by lifecycle phase for each facility. The information presented for each facility follows the overall framework established by NSF for major facility projects. Information on projects under construction and funded through NSF's MREFC account is provided in the MREFC chapter. The following pages contain information on the budget requests for NSF's major facilities in FY 2021.

[1] National Science Board, *Study of Operations and Maintenance Costs for NSF Facilities* (NSB-2018-17), May 2018, www.nsf.gov/pubs/2018/nsb201817/nsb201817.pdf.

MAJOR MULTI-USER RESEARCH FACILITIES FUNDING, BY PROJECT

(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Operations and Maintenance of Major Facilities	**$1,024.38**	**-**	**$867.42**	**-$156.96**	**-15.3%**
Biological Sciences	***$73.93***	**-**	***$65.00***	***-$8.93***	***-12.1%***
National Ecological Observatory Network (NEON)[1]	73.93	-	65.00	-8.93	-12.1%
Engineering	***$11.57***	**-**	***$10.95***	***-$0.62***	***-5.4%***
Natural Hazards Engineering Research Infrastructure (NHERI)[2]	11.57	-	10.95	-0.62	-5.4%
Geosciences	***$357.37***	**-**	***$307.75***	***-$49.62***	***-13.9%***
Academic Research Fleet[3]	85.32	-	80.00	-5.32	-6.2%
Geodesy Advancing Geosciences and EarthScope (GAGE)[4]	6.92	-	12.05	5.13	74.1%
International Ocean Discovery Program (IODP)[5]	53.00	-	47.00	-6.00	-11.3%
National Center for Atmospheric Research (NCAR) FFRDC[6]	152.44	-	103.70	-48.74	-32.0%
Ocean Observatories Initiative (OOI)	44.01	-	43.00	-1.01	-2.3%
Seismological Facilities for the Advancement of Geoscience & EarthScope (SAGE)[4]	15.68	-	22.00	6.32	40.3%
Mathematical and Physical Sciences	***$363.56***	**-**	***$286.58***	***-$76.98***	***-21.2%***
Arecibo Observatory[7]	19.22	-	3.00	-16.22	-84.4%
Cornell High Energy Synchrotron Source (CHESS)[8]	5.00	-	-	-5.00	-100.0%
Green Bank Observatory (GBO) FFRDC[9]	10.26	-	7.30	-2.96	-28.8%
Large Hadron Collider (LHC) - ATLAS and CMS	16.00	-	20.00	4.00	25.0%
Laser Interferometer Gravitational Wave Observatory (LIGO)[10]	66.72	-	45.00	-21.72	-32.6%
National High Magnetic Field Laboratory (NHMFL)[11]	40.62	-	37.74	-2.88	-7.1%
National Radio Astronomy Observatory (NRAO) FFRDC	95.04	-	88.13	-6.91	-7.3%
NRAO O&M [12]	*49.83*	-	*39.45*	*-10.38*	*-20.8%*
Atacama Large Millimeter Array (ALMA) O&M	*45.21*	-	*48.68*	*3.47*	*7.7%*
National Solar Observatory (NSO) FFRDC	18.39	-	21.79	3.40	18.5%
NSO O&M [13]	*7.89*	-	*4.25*	*-3.64*	*-46.1%*
Daniel K. Inouye Solar Telescope (DKIST) [14]	*10.50*	-	*17.54*	*7.04*	*67.0%*
National Superconducting Cyclotron Laboratory (NSCL)[15]	28.50	-	15.50	-13.00	-45.6%
NSF's National Optical-Infrared Astronomy Research Laboratory FFRDC[16]	63.81	-	48.12	-15.69	-24.6%
NSF's National Optical-Infrared Astronomy Research Laboratory O&M (formerly the National Optical Astronomy Observatory (NOAO)) [17]	*29.16*	-	*22.23*	*-6.93*	*-23.8%*
GEMINI Observatory O&M [18]	*34.65*	-	*20.89*	*-13.76*	*-39.7%*
Vera C. Rubin Observatory O&M (formerly the Large Synoptic Survey Telescope) [19]	-	-	*5.00*	*5.00*	*N/A*
Office of Polar Programs	***$217.95***	**-**	***$197.14***	***-$20.81***	***-9.5%***
Antarctic Facilities and Operations (AFO)[20]	210.94	-	190.14	-20.80	-9.9%
IceCube Neutrino Observatory (ICNO)	7.01	-	7.00	-0.01	-0.00
Major Research Facilities Construction Investments	**$286.95**	**-**	**$228.75**	**-$58.20**	**-20.3%**
R&RA Design Stage Activities[21]	**$2.00**	**-**	**-**	**-$2.00**	**-100.0%**
Major Research Equipment and Facilities Construction	**$284.95**	**-**	**$228.75**	**-$56.20**	**-19.7%**
Total, Major Multi-User Research Facilities	**$1,311.33**	**-**	**$1,096.17**	**-$215.16**	**-16.4%**

FFRDC is an acronym for Federally-Funded Research and Development Center.

[1] NEON: FY 2019 Actual includes $8.93 million for continuity of operations into FY 2020.

[2] NHERI: FY 2019 Actual includes $8.50 million to upgrade the LHPOST facility. Excluded is $8.93 million of FY 2019 O&M costs obligated in FY 2018.

[3] ARF: Includes ship operations and upgrade support. FY 2019 Actual includes $3.0 million for continuity of operations into FY 2020. Regional Class Research Vessels (RCRV) began construction in FY 2017 and the final year of MREFC funding is FY 2019, included in the MREFC line below. Operations and maintenance of RCRV is not anticipated to begin until FY 2022.

[4] GAGE and SAGE: FY 2019 Actual reflects part of an operating year as funding for these cooperative agreements were re-phased for continuity of operations into FY 2020.

[5] IODP: FY 2019 Actual includes $5.0 million for continuity of operations into FY 2020.

[6] NCAR: FY 2019 Actual includes $17.80 million for continuity of operations into FY 2020 as well as $30.94 million in funds re-obligated from prior award.

[7] ARECIBO: FY 2019 Actual includes $12.30 million in carryover funds from the FY 2018 emergency supplemental appropriation -- Further Additional Supplemental Appropriations for Disaster Relief Requirements Act of 2018 (P.L. 115-123) -- for hurricane damage repairs and $2.03 million for continuity of operations into FY 2020. It excludes $2.69 million of FY 2019 O&M costs obligated in FY 2018.

[8] CHESS: In FY 2019, NSF stewardship of CHESS ended as NSF transitioned to funding the Center for High Energy X-Ray Sciences (CHEXS), a sub-facility at CHESS operated in partnership with Cornell University. This table does not include CHEXS as it is not a major facility.

[9] GBO: Previously under "Other AST Facilities". FY 2019 Actual includes $2.17 million for continuity of operations into FY 2020.

[10] LIGO: FY 2019 Actual includes $10.47 million for Advanced LIGO Plus enhancement and $11.25 million for continuity of operations into FY 2020.

[11] NHMFL: FY 2019 Actual includes $14.20 million for continuity of operations into FY 2020. Excluded is $9.34 million of FY 2019 O&M costs obligated in FY 2018.

[12] NRAO: As of Oct. 1, 2018, the Long Baseline Observatory (LBO) was reintegrated into NRAO as the Very Long Baseline Array (VLBA) at $3.82 million in FY 2019 and $3.43 million in FY 2021. Also included in FY 2019 is $8.09 million for continuity of operations into FY 2020 and $4.0 million for development of a next generation Very Large Array (ngVLA).

[13] NSO: FY 2019 Actual includes $3.50 million for development of DKIST level 2 (advanced) data products.

[14] DKIST: FY 2019 Actual includes $2.0 million to another awardee for cultural mitigation activities as agreed to during the DKIST environmental compliance process. Excluded is $8.0 million of FY 2019 O&M costs for DKIST obligated in FY 2018.

[15] NSCL: FY 2019 Actual includes $4.50 million for continuity of operations into FY 2020. FY 2021 is the final year of NSF stewardship of NSCL, after which NSCL will transition into the Department of Energy's Facility for Rare Isotope Beams.

[16] NSF's National Optical-Infrared Astronomy Research Laboratory was established at the start of FY 2020. The Lab encompasses operations of the Mid-Scale Observatories (MSO) and Community Science & Data Center (CSDC), which formerly comprised NOAO, together with operations of the Gemini Observatory and the Vera C. Rubin Observatory.

[17] NSF's National Optical-Infrared Astronomy Research Laboratory: FY 2019 Actual includes $5.73 million for continuity of operations into FY 2020, $2.50 million to support NSF transition activities associated with the creation of the Lab, approximately $412,000 in supplemental funding for U.S. Extremely Large Telescope program planning, and $1.18 million for other special projects.

[18] GEMINI: FY 2019 Actual includes $12.99 million to enhance Gemini's adaptive optics system, software capabilities, and public information and outreach activities in the era of multi-messenger astronomy.

[19] Vera C. Rubin Observatory: Excluded is $11.10 million in FY 2019 - FY 2021 pre-operations ramp up costs obligated in FY 2018.

[20] AFO: FY 2019 Actual includes additional funding to replace the aging pier at Palmer Station and to replace or refurbish other equipment and facilities.

[21] Design Stage Activities include support for potential next generation multi-user facilities. This line reflects FY 2019 funding of $2.0 million for the potential Leadership Class Computing Facility.

ACADEMIC RESEARCH FLEET (ARF) **$80,000,000**
-$5,320,000 / -6.2%

Academic Research Fleet Funding
(Dollars in Millions)

FY 2019 Actual[1]	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
$85.32	-	$80.00	-$5.32	-6.2%

[1] FY 2019 Actual obligations include $3.0 million for continuity of operations into FY 2020.

The U.S. Academic Research Fleet included 18 vessels in calendar year 2019. The vessels in the ARF range in size, endurance, and capabilities, enabling NSF and other federally- and state-funded scientists to conduct ocean science and technology research with a diverse Fleet capable of operating in coastal and open ocean waters. Funding for the ARF includes investments in ship operations; shipboard scientific support equipment; oceanographic instrumentation and technical services; and submersible support. Funding levels reported here reflect investments by the Division of Ocean Sciences (OCE) within GEO. In addition to operations, OCE has undertaken construction projects based on inter-agency planning and coordination as discussed in the *Federal Oceanographic Fleet Status Report*[1] published in May 2013. Details on these construction activities are contained in the Fleet Modernization section.

Total Obligations for ARF
(Dollars in Millions)

FY 2019 Actual[1]	FY 2020 (TBD)	FY 2021 Request	ESTIMATES[2] FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
$85.32	-	$80.00	$80.00	$87.17	$88.80	$88.80	$88.80

[1] FY 2019 Actual obligations include $3.0 million for continuity of operations into FY 202
[2] Outyear estimates are for planning purposes only.

For information on continuity of operations funding, see the opening narrative of this chapter.

The ARF serves as the main platform for the collection of data and testing of hypotheses about the structure and dynamics of the ocean, as well as the development and testing of novel technological instrumentation. Scientists contribute to advances in many areas including climate variability, marine ecosystems, fisheries, and ocean-related natural hazards, such as tsunamis, through use of these facilities. Participating graduate and undergraduate students interact with scientists and marine technicians, enabling them to gain first-hand exposure to ocean science field research. Increasingly, technological innovations allow research conducted at sea to be transmitted via satellite back to the classroom, broadening the educational impact of the vessels.

The ARF is financially supported through an interagency partnership, principally with the Office of Naval Research (ONR) and the National Oceanic and Atmospheric Administration (NOAA). The operating costs for the Fleet are divided proportionally among the vessel users based on usage over the past several years, including the Ocean Observatories Initiative's use of the Fleet. NSF coordinates with ship-operating and ship-user academic institutions both directly and through the University-National Oceanographic Laboratory System (UNOLS) organizational structure.

Funding for scientists using the Fleet is provided by NSF and other federal and state agencies. Within NSF, science is funded through competitive peer-reviewed proposals, most typically funded within OCE and

[1] www.nopp.org/wp-content/uploads/2010/03/federal_oceanographic_fleet_status_report.pdf

through selected programs in the Division of Earth Sciences, Division of Atmospheric and Geospace Sciences, OPP, and BIO. Approximately 25 percent of OCE proposals request ship time. Not reflected in this number is the science that utilizes samples or data collected on prior cruises, scientists piggy-backing on scheduled cruises to accomplish additional science, international scientists sailing with the ARF, and science funded by other agencies.

The FY 2021 funding level of $74.10 million will support approximately 1750 ship operating days. During FY 2020 the ONR-owned Global Class R/V *Revelle* will re-enter the Fleet after a one-year mid-life refit and the ONR-owned Global Class R/V *Atlantis* will enter her mid-life refit period which will have a one-year duration. In addition to being a general purpose research vessel, R/V *Atlantis* also serves as the support ship for the Deep Submergence Vehicle (DSV) *Alvin*, which is scheduled to undergo a major refit during the same period R/V *Atlantis* will be out of service. Additional details are included in the Fleet Modernization section below.

Fleet Operations/Management and Oversight

- Oversight: NSF provides oversight of the ARF through mechanisms defined in cooperative agreements with each ship-operating institution and through a separate cooperative agreement with the UNOLS Office. NSF is the cognizant agency for ship day-rate negotiations for the ARF, regardless of owner. In addition, NSF oversees the Fleet through Business Systems Reviews, site visits, ship inspections, participation at the UNOLS Council, and various committee meetings by NSF Program Directors. Several Program Directors within OCE at NSF, at NOAA, and at ONR are involved in the activities and oversight of the ARF.
- After an in-depth review of the application of rate structures on ARF ship-related activities, NSF and ONR have transitioned the accounting of Fleet activities into a Specialized Service Facility in accordance with OMB's Uniform Guidance for Federal Awards 2 CFR 200.468.
- Management: Management of an institution's ship-operating facilities varies with the scale of the operation, but the core responsibility typically resides with the director of the institution, the Marine Superintendent (for all aspects of the facility), and the ship's Captain (for at-sea operations). For larger multi-ship-operating institutions, a Chief of Marine Technicians, schedulers, and finance administrators may also be involved in facility management.
- Reviews: Based on projected science requirements identified in recent reports and workshops, a fleet of vessels supporting ocean science and technological research will be needed far into the future. Documents supporting this need include the *Final Recommendations of the Interagency Ocean Policy Task Force*[2] of July 19, 2010. Two applicable reports by the National Research Council (NRC) include *Science at Sea: Meeting Future Oceanographic Goals with a Robust Academic Research Fleet*[3] published in 2009, and *Critical Infrastructure for Ocean Research and Societal Needs in 2030*[4] published in 2011. In coordination with UNOLS and the other federal agencies that invest in ocean research, the Interagency Working Group on Facilities and Infrastructure (IWG-FI) published a *Federal Oceanographic Fleet Status Report*[5] in May 2013, reviewing the status and describing plans for modernizing the Federal Oceanographic Fleet, which includes both the Academic Research Fleet and the survey ships. This report was updated in March 2016.[6] In January 2015, the National Academy of Sciences Report *Sea Change 2015-2025 Decadal Survey of Ocean Sciences*[7] identified the U.S. Academic Research Fleet as having "the closest match between current infrastructure and the decadal science priorities" and emphasized the overall importance of ships in all of the NAS-identified ocean

[2] www.obamawhitehouse.archives.gov/files/documents/OPTF_FinalRecs.pdf
[3] www.nap.edu/catalog/12775/science-at-sea-meeting-future-oceanographic-goals-with-a-robust
[4] www.nap.edu/catalog/13081/critical-infrastructure-for-ocean-research-and-societal-needs-in-2030
[5] www.nopp.org/wp-content/uploads/2010/03/federal_oceanographic_fleet_status_report.pdf
[6] www.nopp.org/wp-content/uploads/2016/06/federal_fleet_status_report_final_03.2016.pdf
[7] www.nap.edu/catalog/21655/sea-change-2015-2025-decadal-survey-of-ocean-sciences

science and technology priorities. Ship operations and technical services proposals undergo external review by the research community every five years. Detailed annual reports describing activities accomplished are provided by the operating institutions and budgets are negotiated yearly since they are dependent on the number of days the ships will be at sea in support of NSF-funded research programs.

Fleet Modernization

- Oversight: The NSF coordinator for Fleet modernization activities is the Program Director for Ship and Submersible Support, within the Integrative Programs Section (IPS) in OCE, with additional IPS staff providing project management assistance as required.
- Ocean Class Research Vessels: ONR funded the design and construction of two new Ocean Class Research Vessels which have now been fully integrated into the ARF operating schedule. R/V *Neil Armstrong* operated by the Woods Hole Oceanographic Institution replaced the Global Class R/V *Knorr* and R/V *Sally Ride* operated by Scripps Institution of Oceanography replaced Global Class R/V *Melville.*
- Regional Class Research Vessels (RCRV): In March 2012, NSF leadership approved the request to advance the RCRV to the Conceptual Design Review (CDR) phase as a candidate MREFC project. Funds to initiate construction were requested and appropriated in FY 2017. Keel-laying for the first RCRV, which will be operated by Oregon State University and is named R/V *Taani,* was completed in November 2018. Keel-laying for the second RCRV, which will be operated by the East Coast Oceanographic Consortium and is named R/V *Resolution,* was completed in May 2019. The third RCRV is named R/V *Gilbert R. Mason* and will be operated by the Gulf-Caribean Oceanographic Consortium. Keel-laying for RV *Mason* is planned for Spring 2020. The RCRV will address requirements across government agencies for research vessels in support of ocean science research as discussed in the Fleet Status Report Update of 2016. For additional information on RCRV please refer to the MREFC chapter.
- DSV *Alvin*: The *Alvin* upgrade project consists of two phases:
  - Phase One, completed in 2014, consisted of a major overhaul of all vehicle systems and incorporation of a new titanium personnel sphere, which resulted in continued operation of the submersible at its historic depth rating of 4,500 meters.
  - Phase Two, funded in 2018, with $6.0 million, will enable operations to 6,500 meters water depth and thus expand the accessible area of operations for *Alvin* from approximately 60 percent of the seafloor to more than 95 percent. It will also enable relatively shallow, mid-water work in places where the water depth currently prohibits operations. The *Alvin* Upgrade Project Team at Woods Hole Oceanographic Institution is working with the Naval Sea Systems Command to design, fabricate, test, and certify all components necessary to complete the upgrade. The primary long-lead item remaining in the schedule is the variable ballast system, which will require design, fabrication, testing and certification of new pressure spheres. This system, as well as new foam floatation and other improvements, will be ready for incorporation into *Alvin* during the overhaul in 2020, concurrent with the mid-life refit of the support ship R/V *Atlantis*.

Renewal/Recompetition/Termination

Ships supported by NSF are operated by academic institutions, each having a cooperative agreement with NSF. All ship cooperative agreements were renewed in CY 2018 using a process including external panel review. All future cooperative agreements for ship operator awards for NSF-owned ships will undergo an open competition every ten years. Awardees are subject to additional oversight measures, including quarterly safety and financial reporting, the use of NSF Business System Reviews, and site visit inspections. In 2018, NSF retired R/V *Clifford A. Barnes,* operated by the University of Washington, which was replaced by the R/V *Rachel Carson* purchased by the University of Washington. In 2019, NSF extended the planned retirement date of R/V *Marcus G. Langseth* by one year to September 30, 2021 in order to avoid a hiatus in seismic research opportunities while shifting to a new model of providing access to capabilities comparable to those available via R/V *Langseth.* The focus of the additional period of operations is on providing opportunities for early career scientists to develop their skills, particularly as Principal Investigators.

ANTARCTIC FACILITIES AND OPERATIONS (AFO) **$190,140,000**
-$20,800,000 / -9.9%

Antarctic Facilities and Operations Funding
(Dollars in Millions)

FY 2019 Actual[1]	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
$210.94	-	$190.14	-$20.80	-9.9%

[1] FY 2019 Actual obligations include additional one-time funding to replace the aging pier at Palmer Station and to replace or refurbish other equipment and facilities.

Antarctic Facilities

OPP provides the infrastructure needed to support U.S. research conducted in Antarctica, including research funded by NSF and by U.S. mission agencies, for year-round work at three U.S. stations, on two research ships, and at a variety of remote field camps. Support to other agencies includes mission-essential satellite communications support at McMurdo Station for the Joint Polar Satellite System (JPSS), and the National Aeronautics and Space Administration's (NASA) Ground Networks for the relay of data. Through a partnership with the National Oceanic and Atmospheric Administration (NOAA), NASA, and the European Organization for the Exploitation of Meteorological Satellites, OPP supports the relay of real-time satellite-based weather information that informs global forecasting. In addition, OPP enables important climate monitoring activities for NOAA at the Clean Air Facility at South Pole Station. OPP also provides support for NASA's Long Duration Balloon program that enables research in fields ranging from astrophysics to cosmic radiation to solar astronomy and includes payloads from the National Institute of Standards and Technology (NIST); the South Pole Remote Earth Science and Seismological Observatory, the most seismically-quiet station on earth and a key site contributing to U.S. activities associated with the Comprehensive Test Ban Treaty and to U.S. Geological Survey and NSF efforts for global seismic monitoring; and access to sites that are key to precise orbit determinations for optimizing use of the Global Navigation Satellite System (GNSS).

Total Obligations for Antarctic Facilities
(Dollars in Millions)

	FY 2019 Actual[1]	FY 2020 (TBD)	FY 2021 Request	ESTIMATES[2] FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Antarctic Facilities and Operations	$206.94	-	$190.14	$213.56	$217.63	$221.79	$224.55	$224.55
Palmer Pier Upgrade	4.00	-	-	-	-	-	-	-
Total	**$210.94**	**-**	**$190.14**	**$213.56**	**$217.63**	**$221.79**	**$224.55**	**$224.55**

[1] FY 2019 Actual obligations include additional one-time funding to replace the aging pier at Palmer Station and to replace or refurbish other equipment and facilities.
[2] Outyear estimates are for planning purposes only. The current contract ends in 2025.

The FY 2021 Budget Request for Antarctic Facilities is $190.14 million. The reduction relative to FY 2019 is partially due to one-time investments made in FY 2019 to replace the aging pier at Palmer Station and to replace or refurbish other equipment and facilities. In FY 2021, funds will provide for station operations and science support at NSF's three Antarctic stations, various near and deep field camps, and two leased research vessels.

OPP contracts with a prime contractor for science support, operations, the leasing of research vessels, and the maintenance of the Antarctic stations and related infrastructure in New Zealand and Chile. The contractor is selected through a competitive process. Rotary and fixed-wing aircraft used in support of research are also provided through separate competitively awarded contracts. Other agencies and contractors provide technical support in areas of expertise such as engineering, construction, and communications. Following a major refurbishment program, the U.S. Coast Guard's *Polar Star* returned to service in 2014 and is expected to continue to conduct annual icebreaking services for the McMurdo Station resupply effort until the Coast Guard completes efforts currently underway to recapitalize the Nation's polar class icebreakers.

Management and Oversight

Helicopters provide support to field parties on Mr. Erebus on Ross Island and other remote camps in Antarctica. *Credit: Air Center Helicopters Incorporated.*

- NSF Structure: OPP staff, including subject matter experts in operational and scientific disciplines, have overall responsibility for managing Antarctic Facilities under the U.S. Antarctic Program (USAP); NSF budgets for and manages USAP on behalf of the Nation. This includes planning all activities and overseeing contractors. OPP's Antarctic Sciences section funds merit-reviewed research proposals for which access to Antarctica is essential to advancing the scientific frontiers and that can only be achieved or are best achieved with research work in/on Antarctica and the Southern Ocean. Research is conducted in a broad array of geo- and bio-sciences, including earth system science, and space and astrophysical sciences. The Antarctic Infrastructure and Logistics section of OPP enables research in Antarctica on behalf of the U.S. government through a network of stations, labs, equipment, and logistical resources.
- External Structure: The Antarctic prime support contract is currently held by Leidos Innovations Corporation. There are many separate subcontractors for supplies and technical services, and other services are procured through separate competitively-bid contracts.
- Reviews: OPP evaluates the performance of the Antarctic support contractor annually via an Award Fee Plan, which involves multiple tiers of review, including a Performance Evaluation Board (PEB) composed of representatives from OPP and BFA. In addition, OPP's performance is reviewed externally by Committees of Visitors and the OPP Advisory Committee. The USAP Blue Ribbon Panel (BRP) released a report on its review of the program in July 2012.[1] The initial NSF response to the USAP BRP report was released in March 2013 and progress to address recommendations is ongoing.[2] This budget request includes a request for the third year of funding for the Antarctic Infrastructure Modernization for Science (AIMS) project, a major part of the NSF response to the BRP report.

Current Status

- All facilities (stations, research vessels, and field camps) are currently operating normally.
- The USAP BRP report concluded that ushering in a new age of Antarctic science simply by expanding traditional methods of logistical support would be prohibitively costly. Instead, it recommended numerous ways to more efficiently and cost-effectively support research while maintaining high standards of safety and increasing the flexibility to support evolving science foci in the future.
  - For example, construction is underway to upgrade satellite communications systems to support operations and research, and construction activities to replace the Palmer Station pier to ensure

[1] www.nsf.gov/od/opp/usap_special_review/usap_brp/rpt/index.jsp
[2] www.nsf.gov/od/opp/usap_special_review/usap_brp/rpt/nsf_brp_response.pdf

long-term access to unique research in the peninsula region will begin in early FY 2022. NSF is also constructing a consolidated Information Technology and Communications building. This was phased to ensure continuous functionality as the AIMS project site construction gets underway in FY 2020.

- The National Science Board authorized NSF to award the AIMS project in FY 2019, with funds appropriated by Congress in that year. Leidos is in the process of completing the designs of all construction components. In FY 2021 Leidos will perform further site preparation work, procure construction materials, and begin on-site construction. Construction projects to be initiated will include the core utilities, outside cable plant, and Emergency Operations Center. During FY 2021 construction of the Vehicle Operations Center, lodging, and Central Services building will continue. For additional information on AIMS see the AIMS narrative in the MREFC Chapter.

Renewal/Recompetition/Termination

- In FY 2012, Lockheed Martin Corporation was awarded a 13.5-year contract, consisting of a five-year base period and four option periods, exercised based on performance, that total an additional 8.5 years. Leidos Innovations Corporation now holds the contract as it acquired the responsible division of Lockheed Martin in 2016.
- Contracts for fixed and rotary wing support are managed as assisted acquisitions by the Department of Interior, Office of Aviation Services. In 2019, a five-year contract for helicopter support was awarded to Air Center Helicopters, of Burleson, Texas. A five-year contract for fixed-wing aviation services was recently awarded to Kenn Borek Air of Calgary, Canada.
- U.S. policy directs NSF to maintain an active and influential presence in Antarctica, including year-round occupation of South Pole Station and two coastal stations.[3] As the scientific forefronts addressed there evolve over time, so do the research emphases at the three stations and the infrastructure needed to support them.

[3] www.nsf.gov/geo/opp/ant/memo_6646.jsp

ARECIBO OBSERVATORY (ARECIBO) **$3,000,000**

-$16,220,000 / -84.4%

Arecibo Observatory Funding
(Dollars in Millions)

FY 2019 Actual[1]	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
$19.22	-	$3.00	-$16.22	-84.4%

[1] Includes $12.30 million in supplemental appropriation funding for hurricane repairs and $2.03 million for continuity of operations into FY 2020. It excludes $2.69 million of FY 2019 O&M costs obligated in FY 2018.

The Arecibo Observatory is a center for multidisciplinary research and education with advanced observational facilities. The observatory's principal facility is one of the world's largest single-dish radio/radar telescopes, a 305-meter diameter reflector located near the town of Arecibo in western Puerto Rico on approximately 140 acres of U.S. Government-owned land. Arecibo is currently operated and managed by the University of Central Florida (UCF) and subrecipients, Yang Enterprises, Inc. (YEI) and Universidad Ana G. Méndez (formerly Universidad Metropolitana), under a cooperative agreement with NSF that began on April 1, 2018. The observatory serves over 350 users annually with a wide range of research and observing instrumentation in passive radio astronomy, solar system radar astronomy, and space and atmospheric sciences. A peer-review telescope allocation committee provides merit-based telescope time to users. The committee is common to the three fields, but specific subject matter experts from outside the observatory are consulted for reviews. NSF does not provide awards targeted specifically for use of Arecibo, although some Arecibo users are supported through NSF or NASA grants to pursue scientific programs that require use of the facility. For example, NSF awarded $5.80 million in 2018 to Brigham Young University for the development and deployment of an Advanced Cryogenic L-Band Phased Array Camera for Arecibo (ALPACA). With 40 beams, ALPACA will supersede the successful Arecibo L-band Feed Array (ALFA) 7-beam receiver installed at Arecibo in 2004, increasing the survey speed by a factor of five.

On September 20, 2017, Arecibo, along with the entire island of Puerto Rico, was severely impacted by Hurricane Maria. Damages were incurred by the physical infrastructure and the scientific equipment, including a broken 430 MHz line feed and some destroyed panels on the main reflector surface. Basic science operations (planetary radar and radio astronomy) restarted within weeks of the storm, at reduced and degraded performance levels. Funding for Arecibo repairs was provided in the Further Additional Supplemental Appropriations for Disaster Relief Requirements Act of 2018 (P.L. 115-123) totaling $16.30 million. Of the total provided, $14.30 million was identified for Arecibo of which $2.0 million was disbursed in FY 2018, for the most critical immediate concerns including debris cleanup. An award for the remaining $12.30 million for more complex repairs was made in FY 2019. The remaining repairs will take up to four years, carefully planned to prioritize the most critical structural repairs and to minimize impact to ongoing regular scientific observations. While scientific observations have been ongoing actively since late fall 2017, Arecibo does continue to operate at reduced and degraded performance. For example the overall sensitivity is reduced because the main reflector alignment is not yet complete and the 430 MHz line feed has not yet been repaired. The completion of the remaining repairs should bring Arecibo back to pre-hurricane performance levels.

Total Obligations for Arecibo
(Dollars in Millions)

	FY 2019 Actual[1]	FY 2020 (TBD)	FY 2021 Request	ESTIMATES[2] FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Operations & Maintenance (MPS)	$2.48	-	$1.50	$1.13	$1.00	$1.00	$1.00	$1.00
Operations & Maintenance (GEO)	4.44	-	1.50	1.13	1.00	1.00	1.00	1.00
Hurricane-related Repairs[3]	12.30	-	-	-	-	-	-	-
Total	**$19.22**	**-**	**$3.00**	**$2.25**	**$2.00**	**$2.00**	**$2.00**	**$2.00**

[1] Includes $530,000 in MPS and $1.50 million in GEO for continuity of operations into FY 2020. It excludes $2.69 million of FY 2019 O&M costs obligated in FY 2018.

[2] Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in March 2023.

[3] Further Additional Supplemental Appropriations for Disaster Relief Requirements Act of 2018 (P.L. 115-123) provided NSF $16.30 million to repair radio observatory facilities damaged by hurricanes that occurred during 2017. Of the total amount provided, $14.30 million was identified for Arecibo. $2.0 million was obligated in FY 2018, and the remaining $12.30 million was obligated in FY 2019 to fund repairs over a four-year period.

For information on continuity of operations funding, see the opening narrative of this chapter.

Arecibo is jointly supported by the MPS Division of Astronomical Sciences (AST) and the GEO Division of Atmospheric and Geospace Sciences (AGS). An external review of the AST portfolio was completed in 2012, and an external review of the AGS Geospace Section portfolio was completed in 2016.

In 2012, the AST Portfolio Review Committee recommended "continued AST involvement in Arecibo be re-evaluated later in the decade in light of the science opportunities and budget forecasts at that time."[1] The National Academies of Sciences, Engineering, and Medicine's (the National Academies') August 2016 report, *New Worlds, New Horizons: A Midterm Assessment*, reinforced this, with Recommendation 3.1 noting: "The NSF should proceed with divestment from ground-based facilities that have a lower scientific impact."[2]

The Geospace Section (GS) Portfolio Review Committee was charged by the NSF Advisory Committee for Geosciences to review the most promising Geospace science strategies and critical capabilities and to reconcile these with the science goals described by the 2013 Decadal Survey for Solar and Space Physics.[3] The GS is in AGS and its portfolio includes grant programs in upper-atmospheric sciences, the near earth space environment, sun-earth interactions, and space weather. This GS portfolio review[4] was carried out using the assumption of an inflation-adjusted, flat budget for GS over the next decade to FY 2026. The GS Portfolio Review Committee recommendations included the reduction of annual AGS Arecibo funding from $4.10 million to $1.10 million by 2020.

GEO commissioned a review from a second panel assembled by the National Academies that assessed the process by which the GS Portfolio Review Committee reached its findings and recommendations. The panel published the results of this review[5] in early 2017 and, for Arecibo, reiterated the recommendations of the GS Portfolio Review Committee.

Alongside scientific community reviews, NSF undertook a comprehensive environmental review of the potential operational changes. This process was formally concluded in November 2017, when NSF published a Record of Decision documenting its choice to collaborate with interested parties to maintain science-focused operations at Arecibo with reduced agency funding.

[1] www.nsf.gov/mps/ast/ast_portfolio_review.jsp
[2] www.nap.edu/catalog/23560/new-worlds-new-horizons-a-midterm-assessment
[3] www.nap.edu/catalog/13060/solar-and-space-physics-a-science-for-a-technological-society
[4] www.nsf.gov/geo/adgeo/geospace-review/geospace-portfolio-review-final-rpt-2016.pdf
[5] www.nap.edu/catalog/24666/assessment-of-the-national-science-foundations-2015-geospace-portfolio-review

NSF issued a solicitation in January 2017 requesting proposals to provide continued operations and management of Arecibo for five years at reduced funding. The planned NSF funding profile presented in the solicitation gradually tapered NSF support to $2.0 million by the fifth year of the award. In February 2018, NSF announced an award to University of Central Florida (UCF) to undertake formal transition activities for operations and management responsibilities for Arecibo in a cooperative agreement with NSF. The award continues science-focused operations that will maintain Arecibo's existing research lines of atmospheric, planetary, and astronomical research and continue its education and public outreach efforts. UCF has ongoing plans to secure partnerships and other funding sources for the operation and management of Arecibo. NSF is supporting UCF in these efforts and in the meantime has maintained steady support for Arecibo, rather than beginning the gradual tapering. The requested FY 2021 budget assumes new partnerships will be obtained, keeping Arecibo's overall budget for operations and management at the level necessary for full scientific operations.

Arecibo supplements NSF support with funding provided by other federal and non-federal sources. Since FY 2010, the NASA Near Earth Object Observation Program has committed $2.0 million annually to Arecibo for the planetary radar program; this increased to $3.60 million for FY 2013, with more observing time allocated to the NASA program. In FY 2020 and FY 2021, annual NASA support is expected to be approximately $4.65 million. UCF continues to actively seek other partnerships and funding sources.

Education and public outreach continues to be an area of emphasis. Arecibo hosts a Research Experiences for Undergraduates (REU) site, and Ph.D. students receive training through the use of the facility. Over 360 students have participated in REU programs at Arecibo. Arecibo also sponsors a major outreach program in Puerto Rico via the Angel Ramos Foundation Visitor Center as well as summer workshops for K-12 teachers. This center attracts more than 80,000 visitors each year; over 1.5 million people have visited since its opening in 1997. Approximately 25 percent of these visitors are K-12 students. There was a downturn in visitors immediately following the 2017 hurricanes, but as the island recovered the number of visitors began to return to the expected rates each month. Exhibits at the visitor center were updated, and physical renovations to the visitor center building were completed in FY 2016. These improvements were funded by the Angel Ramos Foundation and the Ana G. Méndez University System and were formally approved by NSF. With funds received from the Puerto Rico Department of Education, Arecibo has hosted numerous teacher workshops and has trained approximately 500 teachers. This program integrates formal activities at the Angel Ramos Foundation Visitor Center into the STEM curriculum in Puerto Rico. Arecibo also hosts several meetings each year within a wide variety of scientific disciplines.

An image of the Arecibo Radio Telescope in Puerto Rico. The platform suspension structure, including the Gregorian dome that houses the main suite of research instruments, is visible over the 305-meter primary reflector dish below. The 96-foot line feed hanging to the left of the Gregorian dome was broken off during Hurricane Maria into several pieces, also damaging the dish below. Repairs are underway. *Credit: Arecibo Observatory/NSF.*

<u>Operations and Maintenance</u>: Arecibo administers observing time to the astronomy and aeronomy communities via competitive observing proposals and conducts educational and public outreach programs at all levels. Observing hours among science programs are allocated based on the quality of proposals. About 75 percent of astronomy users conduct their observing remotely via networked control software, while radar observations typically employ on-site users.

Management and Oversight

- Funding: AST funding will maintain basic operations costs and science programs in passive radio astronomy. AGS funding will support basic operations costs and science programs in aeronomy and space physics, including space weather.
- NSF Structure: The lead NSF program officer in AST, in close cooperation with a program officer in AGS, and in consultation with community representatives, provide ongoing oversight. The program officers make use of detailed annual program plans, long-range plans, quarterly technical and financial reports, and annual reports submitted by the management and operations awardee. They also attend awardee governance committee meetings, as appropriate. To address issues as they arise, program officers work closely with other NSF offices such as the Office of the General Counsel and the Division of Acquisition and Cooperative Support and the Large Facilities Office in BFA. The MPS facilities team and the Chief Officer for Research Facilities, also provide high-level guidance, support, and oversight. AST and AGS program officers conduct periodic site visits and frequent, regular teleconferences with the managing awardee.
- External Structure: Management is via a cooperative agreement. In February 2018 NSF announced an award to UCF to undertake formal transition activities leading to UCF assumption of full operations and management responsibilities for Arecibo. The transition to UCF's management occurred on April 1, 2018. UCF has two sub-awardees: YEI for engineering staff and facilities management and the Universidad Ana G. Méndez for management of the visitor's center and the education and public outreach efforts.
- Reviews: In January 2017, NSF issued a solicitation requesting proposals to provide continued operations and management of Arecibo for five years, but at reduced funding. Proposals received in response to this solicitation were afforded extensive NSF internal review together with formal review by a panel of external experts in observatory management and operations. Additionally, AST and AGS jointly conduct annual external reviews of Arecibo program plans. The next formal annual external review of UCF's management is scheduled to take place in Spring 2020.

Renewal/Recompetition/Termination

The current cooperative agreement with UCF for the management of Arecibo was awarded in April 2018, when UCF succeeded the previous managing organization. This followed a competitive process for a new five-year cooperative agreement, consistent with NSB policy. This agreement is in effect through March 2023.

GEODETIC FACILITY FOR THE ADVANCEMENT OF GEOSCIENCE (GAGE) $12,050,000 +$5,130,000 / 74.2%

Geodetic Facility for the Advancement of Geoscience Funding
(Dollars in Millions)

FY 2019[1] Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
$6.92	-	$12.05	$5.13	74.2%

[1] FY 2019 Actual obligations reflect part of an operating year as funding for these continuing agreements was re-phased for continuity into

GAGE comprises a distributed, multi-user, national facility for the development, deployment, and operational support of modern geodetic instrumentation to serve national goals in basic research and education in the Earth sciences. GAGE focuses on studies of Earth's surface deformation at many scales with unprecedented temporal and spatial resolution. GAGE facilities support fundamental research and discovery on continental deformation, plate boundary processes, the earthquake cycle, the geometry and dynamics of magmatic systems, continental groundwater storage, and hydrologic loading. GAGE is managed and operated for NSF by UNAVCO, a consortium of 119 U.S. universities and non-profit institutions with research and teaching programs in geophysics and geodesy and 111 associate members from foreign institutions. GAGE was formed in late FY 2013 from the geodetic component of the EarthScope facility and related geodetic facilities previously managed by UNAVCO. The FY 2021 Request will enable GAGE to continue to provide key services for the geoscience research community, including global and regional observing networks, field and technical support for experiments worldwide, data management and distribution systems, and other related activities.

Over the last three decades, the Earth science research community has greatly refined our ability to determine the position and motion of points on Earth’s surface using space geodetic techniques, enabling high-resolution studies of Earth processes in a wide range of fields. Space geodesy applications are extremely broad and expanding to include important societal research on earthquake and tsunami hazards, volcanic eruptions, hurricanes, coastal subsidence, wetlands health, soil moisture, groundwater distribution, and space weather. Applications of geodetic techniques to understand the complex interplay between climate dynamics, continental ice sheet and mountain glacier dynamics, crustal isostatic adjustments, and sea level change are of foremost relevance to current global issues confronting humanity.

Total Obligations for GAGE
(Dollars in Millions)

	FY 2019 Actual[1]	FY 2020 (TBD)	FY 2021 Request	ESTIMATES[2] FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Operations & Maintenance	$6.92	-	$12.05	$12.64	$12.64	$12.00	$12.00	$12.00

[1] FY 2019 Actual obligations reflect part of an operating year as funding for the continuing agreement was re-phased for continutiy of operations into FY 2020.

[2] Outyear estimates are for planning purposes only. The current cooperative agreement ends September 2023.

For information on continuity of operations funding, see the opening narrative of this chapter.

To serve the research needs of the broad Earth science community, GAGE is organized under three primary service areas:

Geodetic Infrastructure

- Currently, the Network of the Americas (NOTA) includes 1,257 continuous Global Positioning System (GPS) and Global Navigation Satellite System (GNSS) stations (more than 800 of which transmit data in real-time with sub-second latency) distributed across the U.S., Mexico, and the Caribbean, with focus on the active plate boundaries. The FY 2021 Request includes funds to support a network that includes about 1,100 stations.
- The GAGE facility also provides operational and maintenance support for a network of 87 borehole strainmeters and 79 borehole seismometers deployed along the San Andreas Fault and above the Cascadia subduction zone and volcanic arc. Tiltmeters (26) and pore pressure sensors (23) are also collocated with the other borehole instruments. Together, data collected by these instruments enable scientists to study the full range of deformation in the solid Earth, from the rapid shaking associated with earthquakes, through more gradual motions related to slow slip events on faults and to Earth's evolving water cycles, up to long-term plate tectonics.
- Global geodetic arrays outside of the NOTA footprint are supported by GAGE in partnership with investigators. Eight hundred continuous GPS stations from over 60 networks around the world are now maintained and monitored, and have their data compiled into the GAGE data system. In addition, GAGE provides operational and maintenance support for 58 National Aeronautics and Space Administration (NASA)-supported stations, and the GNSS network that supports satellite orbit and clock corrections and the refinement of the International Terrestrial Reference Frame (ITRF). The ITRF is the foundation for high-precision global Earth science and other applications of geodesy such as land surveying.
- Community GPS/GNSS receiver and geodetic technology pool consists of over 700 GPS and GNSS receivers, ancillary equipment, and six terrestrial laser scanners, which can be used by investigators for short- and long-term deployments on research projects supported via multiple EAR and OPP science programs funded by NSF.
- GAGE supports the polar GPS network in Antarctica (ANET) and development of specialized GPS monumentation, power, and telemetry solutions for use in harsh environments. GAGE also provides portable campaign deployment geodetic instrumentation, training, and field support for experiments in the polar regions.
- Investigator Project Support includes project management, field engineering, and technical support services to plan and execute GPS surveys and permanent station installations. GAGE also maintains a staff focused on geodetic technology equipment testing services to evaluate new geodetic technologies and improve performance for science applications.

Geodetic Data Services

- Geodetic Data Services manages an archive of over 300 terabytes of data from GPS, terrestrial and airborne laser scanning, Synthetic Aperture Radar (SAR), and borehole geophysical instruments from all GAGE components including NOTA, global continuous geodetic networks, and campaign GPS observations; operates automated and manual systems to ensure the quality of all data stored in the archive; and provides systems to give the national and international research community timely access to these data.
- The archive of SAR imagery maintained and distributed by GAGE to support interferometric SAR imagery of continuous surface deformation at scales of 100 km to 1,000 km is complementary to discrete GPS measurement of displacement. UNAVCO, as the manager of GAGE, brokers for cost-effective community access to the SAR imagery acquired by foreign SAR satellite systems.
- In FY 2019, more than 15,000 unique users downloaded data from the GAGE archive. These data are used for a wide range of applications, including research, commerce, and education.

<u>Education and Community Engagement</u>

- The GAGE Education and Community Engagement program enables audiences beyond geodesists to access and use geodetic data and research for educational purposes, including technical short courses, student internships, web-based materials, and programs for strengthening workforce development and improving diversity in the geosciences.
- Scientific community activities include scientific and technical workshops that bring together the international geodetic community and publications designed to communicate GAGE activities and results to the community.
- External affairs maintain outreach efforts to policymakers and planning for coordination with the international geodesy community.

In addition to its role in providing observational data essential for basic Earth science research, GAGE also plays a significant role providing geodetic infrastructure support to NASA investigators and the international community by maintaining the Global GNSS Network (GGN). GGN supports the refinement of the ITRF and corrections to satellite orbits and clocks, all contributing to the capability for millimeter-level geodetic positioning, subtle observations of Earth's time-varying gravity field, and detection of millimeter-level changes in sea level. These capabilities, particularly precise geodetic positioning, have become essential tools for civil and commercial activity. Commercial surveyors and engineering firms download GAGE real-time GPS data daily to support precision positioning which is now a mainstay of their industry. GPS is also used extensively for terrestrial and marine navigation both commercially and by the general public.

Management and Oversight

- NSF Structure: The Division of Earth Sciences in GEO, through its Instrumentation and Facilities program, provides general oversight of GAGE to assure effective performance and administration. The program also facilitates coordination of GAGE programs and projects with other NSF-supported facilities and projects, and with other federal agencies, and evaluates and reviews the performance of UNAVCO in managing and operating GAGE. In addition, an Integrated Project Team consisting of representatives from EAR, Division of Acquisition and Cooperative Support, and the Large Facilities Office work with the cognizant program officer in addressing challenges and identifying potential barriers for success. The EAR Division Director and Integrated Activities Section Head provide other internal oversight.
- External Structure: GAGE is managed and operated by UNAVCO, which is incorporated as a non-profit consortium representing 119 U.S. universities and non-profit organizations with research and teaching programs that rely on geodetic technologies for Earth Science research. Each voting member institution of the Consortium appoints a member representative, and these member representatives elect the nine members of the UNAVCO Board of Directors, seven of which are drawn from member institutions, and two directors-at-large. The board members, who serve two-year terms, vet all internal program decisions associated with GAGE management and operation, through consultation with UNAVCO staff and GAGE advisory committees (one for each major GAGE component and additional *ad hoc* working groups appointed for special tasks). The Board of Directors appoints a president of UNAVCO to a renewable two-year term. The president is responsible for UNAVCO operations, all of which are managed through the UNAVCO Corporate Headquarters in Boulder, Colorado.
- Reviews: In FY 2019, EAR conducted a joint review of the data services activities of GAGE and its seismic facility counterpart Seismological Facility for the Advancement of GEoscience (SAGE).

Renewal/Recompetition/Termination

A successful NSF merit review of the proposal for the GAGE facility took place in 2017 and 2018, and funding for the current GAGE cooperative agreement began in FY 2019 and it will end in FY 2023. In preparation for the next recompetition that will begin in FY 2022, NSF is gathering input through several mechanisms. First, NSF requested the National Academy of Science, Engineering, and Medicine to explore different models to manage geophysical capabilities to serve the Earth Sciences community as one component of the decadal study "*Catalyzing Opportunities for Research in Earth Sciences*"[1]. The report from the workshop that explored different models can be found at https://www.nap.edu/catalog/25536. Second, NSF is convening an interagency working group to identify the needs other agencies have for the capabilities currently provided by SAGE and GAGE. Lastly, NSF will use internal processes to assess facility capabilities. The information from these activities will be used to draft the solicitation requesting proposals to support geophysical capabilities for Earth Sciences research and education.

[1] www8.nationalacademies.org/pa/projectview.aspx?key=51287

ICECUBE NEUTRINO OBSERVATORY (ICNO) **$7,000,000**
-$10,000 / -0.2%

IceCube Neutrino Observatory Funding
(Dollars in Millions)

FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
$7.01	-	$7.00	-$0.01	-0.2%

The IceCube Neutrino Observatory is the world's first high-energy neutrino[1] observatory and is located deep within the ice under the U.S. Amundsen-Scott South Pole Station in Antarctica. With the discovery in 2013 of very high-energy neutrinos from beyond our solar system, the Observatory has demonstrated that it represents a new window on the universe, providing unique data on the engines that power active galactic nuclei, the origin of high-energy cosmic rays, the nature of gamma ray bursts, the activities surrounding supermassive black holes, and other violent and energetic astrophysical phenomena. The energies and arrival directions of neutrinos are derived from the IceCube data stream and the collaboration has recently focused on studies of neutrino events in the medium to high-energy range. The number of high-energy neutrinos detected by IceCube has already exceeded 150 and so will provide a statistically robust basis for determining the flux of neutrinos from beyond our solar system.

Approximately one cubic kilometer of ice is instrumented with an array of photo-multiplier (PM) tubes to detect light produced when a neutrino interacts with an atomic nucleus in the ice within or near the instrumented volume of ice. Since completion in 2010, the ICNO has been taking data in its final configuration with an uptime of well over 99 percent. To handle the high data rates, initial analysis of the data is performed by a cluster of computers housed in a two-story building above the array. Data produced by this initial analysis are batched and sent via geostationary satellites to the IceCube Research Center at the University of Wisconsin.

Credit: USAP Photo Library, Sven Lidstrom (sic), NSF.

The Observatory includes a Deep Core Array (DCA) with tightly spaced PM tubes to detect low to medium energy neutrinos, thus opening the door to studies of neutrino oscillation measurements. The DCA will be upgraded in FY 2023 with seven additional strings of PM tubes under an NSF award issued in FY 2019. This addition will extend the sensitivity of ICNO to a lower energy range which will provide a bridge to studies of lower energy neutrinos measured by other neutrino observatories such as Super-Kamiokande in Japan.

In FY 2013, ICNO observed the first high-energy, astrophysical or cosmic neutrinos – revealing an

[1] Neutrinos are now known to exist over a broad range of energies described in electron-Volts, or eV; their energy range spans from well below 1 eV to 10 EeV (1 GeV = 10^9 eV; 1 TeV = 10^{12} eV; 1 PeV = 10^{15} eV, and 1 EeV = 10^{18} eV). Neutrinos with energies between 100 GeV and 100 TeV are refered to as medium range, and those over 100 TeV are refered to as high-energy neutrinos that generally originate outside the Solar system.

unobstructed view of the Universe at energies at which the Universe is opaque to light. In 2017, new data obtained by ICNO revealed some answers to questions about the origin of high-energy cosmic rays that had puzzled astrophysicists for more than a century. ICNO detected a high-energy neutrino of ~ 290 TeV and its arrival direction was consistent with the location of a known gamma-ray blazar TXS 0506 +056 - the nucleus of a giant galaxy that fires off particles in massive jets of elementary particles, powered by a supermassive black hole at its core. This evidence of the first known source of high-energy neutrinos and cosmic rays has inspired an ongoing quest for more data from similar or other sources. Thus ICNO results opened a new window to the Universe and ICNO exploration of scientific frontiers has already changed and expanded our understanding of the Universe.

Total Obligations for IceCube
(Dollars in Millions)

	FY 2019	FY 2020	FY 2021	ESTIMATES[1]				
	Actual	(TBD)	Request	FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Operations & Maintenance (GEO)	$3.51	-	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50
Operations & Maintenance (MPS)	3.50	-	3.50	3.50	3.50	3.50	3.50	3.50
Total	**$7.01**	**-**	**$7.00**	**$7.00**	**$7.00**	**$7.00**	**$7.00**	**$7.00**

[1] Outyear estimates are for planning purposes only. The current cooperative agreement ends March 2021.

The ICNO is presently led by the University of Wisconsin, Madison (UWisc) and was constructed with support from four countries (U.S., Belgium, Germany, and Sweden). The science collaboration is much broader, currently consisting of about 300 scientists from 27 U.S. institutions and 25 institutions in 11 other countries (Belgium, Germany, Sweden, Australia, Canada, Denmark, Japan, New Zealand, South Korea, Switzerland, and the United Kingdom). NSF's foreign partners contribute a *pro rata* share of operations and maintenance costs based on the number of PhD-level researchers involved.

Management and Oversight

- NSF Structure: Oversight of the ICNO is the joint responsibility of GEO's OPP and MPS's Division of Physics (PHY). Support for operations and maintenance, education and outreach, and research are shared by OPP and PHY, as well as other external organizations and international partners. NSF provides oversight through regular site visits by NSF managers and external reviewers.
- External Structure: The UWisc management structure for ICNO includes leadership by the project's principal investigator supported by the director of operations and two associate directors (one for science and instrumentation and one for education and outreach). A Collaboration spokesperson is selected by the Collaboration from the cadre of senior scientific leaders for a two-year term, with an option to be renewed once for at most four consecutive years. At lower levels, project management includes international collaboration representatives, as well as participation by staff at collaborating U.S. institutions. UWisc has in place an external Scientific Advisory Committee and a Software and Computing Advisory Panel that meet annually and provide written advice to the project. UWisc leadership, including the Chancellor, provides additional awardee-level oversight.

<u>Operations Costs</u>
Full operations and maintenance in support of scientific research began in FY 2011. The associated costs are and will continue to be shared by the partner funding agencies, U.S. (NSF) and non-U.S., in proportion to the number of PhD-level researchers involved (currently 79:73, resulting in a cost split of 52:48 percent, resepctively). The current NSF award for operations and maintenance constitutes the bulk of the U.S. contribution to general operation of the facility. In addition, work in support of facility operations is performed by students, postdocs, and senior researchers who are participating in research using ICNO data.

NSF provides research support via grants made in response to proposals that undergo the Foundation's normal merit-review process. Approximately $4.0 million is provided annually to investigators at U.S. institutions for research on more refined and specific data analyses and data interpretation (theory support) as well as for work on instrumentation upgrades.

The general operations of South Pole Station, reported in the Antarctic Facilities and Operations narrative, also contribute to supporting the ICNO. The cost of IceCube operations shown in the table herein includes only those that are project-specific and incremental to general South Pole Station operations. The expected operational lifespan of the IceCube Neutrino Observatory is 25 years, beginning in FY 2011.

Education and Outreach

IceCube provides a vehicle for helping to achieve U.S. and NSF education and outreach goals. Specific outcomes include the education and training of future leaders in astrophysics, including undergraduate students, graduate students, and postdoctoral research associates; K-12 teacher scientific and professional development, including development of new inquiry-based learning materials and use of the South Pole environment to convey the excitement of astrophysics and science generally to K-12 students; increased opportunity for involvement of students in international collaborations; increased diversity in science through partnerships with minority serving institutions; and enhanced public understanding of science through broadcast media and museum exhibits (such as the Adler Planetarium in Chicago, Illinois) based on IceCube science and the South Pole environment. NSF supports evaluation and measurement-based education and outreach programs under separate grants to universities and other organizations that are selected following standard NSF merit review.

Renewal/Recompetition/Termination

NSF re-competed the ICNO operations and maintenance activity in FY 2016. A new cooperative agreement was issued on April 1, 2016 for 60 months to the University of Wisconsin. The required mid-term review was held in March 2019; the external panel of experts found the ICNO management and operations activities to be very effective and recommended continuation for the rest of the current award period. This review also provides an important baseline of information for consideration in developing plans for the future.

INTERNATIONAL OCEAN DISCOVERY PROGRAM (IODP) **$47,000,000**
-$6,000,000 / -11.3%

International Ocean Discovery Program Funding
(Dollars in Millions)

FY 2019 Actual[1]	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
$53.00	-	$47.00	-$6.00	-11.3%

[1] FY 2019 Actual obligations Include $5.0 million for continuity of operations into FY 2020.

The International Ocean Discovery Program began in FY 2014 as the replacement for the Integrated Ocean Drilling Program and the prior Ocean Drilling Program. The IODP represents an international partnership of the scientists, research institutions, and funding organizations of 22 nations to explore the evolution, structure, and behavior of Earth as recorded in the ocean basins. The program management structure focuses on maximizing facility efficiency, while retaining the intellectual cooperation and exchange with NSF's international partners. IODP participants include the United States, Japan, ECORD (Austria, Canada, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom), the People's Republic of China, Korea, India, Australia, and New Zealand. NSF, the Ministry of Education, Culture, Sport, Science and Technology (MEXT) of Japan, and the European Consortium for Ocean Research Drilling (ECORD) provide drilling vessels and platforms. NSF provides the highly cost effective and world-ranging *JOIDES Resolution* as an IODP drillship through a cooperative agreement with Texas A&M University (TAMU). MEXT provides the much larger and higher daily cost *Chikyu* as an IODP drillship, which operates primarily in the vicinity of Japan, through the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) research and development organization. The British Geological Survey manages ECORD drilling contributions through single-use Mission-Specific Platforms.

The IODP vessels and platforms provide sediment and rock samples (cores); in-situ monitoring, sampling, and measurement from borehole observatories; shipboard and shore-based descriptive and analytical facilities; down-hole geophysical and geochemical measurements (logging); and opportunities to conduct experiments to determine in-situ conditions beneath the sea floor.

Total Obligations for IODP
(Dollars in Millions)

	FY 2019 Actual[1]	FY 2020 (TBD)	FY 2021 Request	ESTIMATES[2] FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Operations & Maintenance	$53.00	-	$47.00	$47.00	$47.00	$47.00	$47.00	$47.00

[1] FY 2019 Actual obligations Include $5.0 million for continuity of operations into FY 2020.
[2] Outyear estimates are for planning purposes only. The current cooperative agreement ends September 2024.

For information on continuity of operations funding, see the opening narrative of this chapter.

Annual operations and maintenance support for operating the *JOIDES Resolution* drilling vessel, the most-used IODP platform, represents NSF's primary contribution to the program. The *JOIDES Resolution* is leased from an offshore drilling contractor under a long-term contract. Due to the long lead-time in planning IODP science expeditions, the FY 2021 Request of $47.00 million for operations and maintenance of the *JOIDES Resolution* will support up to four expeditions per year in the ship's calendar year 2022 schedule. The exact number and the complexity of the expeditions will be determined when the final FY 2020 NSF operating plan is determined. Another commercial contractor provides down-hole-logging services. Databases and core repositories, preparing scientific publications emerging from *JOIDES Resolution* IODP expeditions, and management of international program proposal review through the IODP Science Support Office, represent additional NSF IODP science integration costs, made at minimal cost to NSF because of international contributions to the program. NSF also provides support for U.S. scientists to sail on IODP drilling platforms and to participate in IODP advisory panels through an associated program. The annual costs for the associated science integration and science support (not included in the table above) for FY 2021 are projected to be approximately $8.50 million, funded separately through the Division of Ocean Sciences (OCE).

The IODP scientific program emphasizes the following research themes:
- Climate and Ocean Change: Reading the Past, Informing the Future;
- Biosphere Frontiers: Deep Life, Biodiversity, and Environmental Forcing of Ecosystems;
- Earth Connections: Deep Processes and Their Impact on Earth's Surface Environment; and
- Earth in Motion: Processes and Hazards on Human Time Scales.

The umbrella IODP Forum provides a venue for all IODP entities to exchange ideas and views on the scientific progress of the program. In the current IODP, each drillship is governed by independent facility boards, each of which is unique and optimized for their respective drilling platform. In the case of the *JOIDES Resolution* Facility Board (JRFB), two advisory panels review proposals and provide science and safety advice. A U.S. scientist leads the JFRB, with other members from the scientific community, funding agencies, and the facility operator. The other IODP platforms use the JRFB advisory panels for drilling proposal review.

JOIDES Resolution underway for science expedition 352, August 2014. *Credit: Tim Fulton, IODP JRSO*

The importance of scientific ocean drilling is underscored by these remarkable facts—since the inception of the program, scientists from 98 countries have participated, resulting in more than 35,000 publications of which more than 11,000 were peer-reviewed, and more than 700 theses and dissertations. U.S. scientists serve as first authors on about 40 percent of the papers currently being published. U.S. scientists from over 150 universities, government agencies, and industrial research laboratories participate in the program. Samples and data have been distributed to well over 1,000 additional U.S. scientists. Scientists from these groups propose and participate in IODP cruises, are members of the program's advisory panels and groups, and supply data for planning expeditions and interpretation of drilling results.

Management and Oversight

- NSF Structure: OCE in GEO manages IODP operations of the *JOIDES Resolution* and the IODP Science Support Office under the NSF Ocean Drilling Program (ODP). NSF's ODP is located within the Integrative Programs Section, with one Program Director dedicated to its oversight. Additional NSF oversight of IODP is provided by the Integrated Project Team whose core members include the Program Officer, the liaison from the Large Facilities Offce, and the Grants and Agreements Officer from the Cooperative Support Branch. The Program Director has responsibility for three cooperative agreements supporting IODP:

    - *JOIDES Resolution* operations;
    - IODP Science Support Office; and the
    - IODP U.S. Science Support Program (USSSP).

- External Structure: All IODP participants except Japan provide financial contributions to *JOIDES Resolution* operations. Japan provides program support through substantial investment in *Chikyu* operations, with U.S.and Japanese scientisits enjoying reciprocal rights on each drilling vessel, and through curation of *JOIDES Resolution* core samples at Japan's Kochi Core Center.
- Each entity providing an IODP drilling platform is responsible for sample and data storage, publications, and other science costs associated with the respective platform operations.
- IODP *JOIDES Resolution* operations are determined by the JRFB, using advice and recommendations provided by the Science Evaluation Panel and the Environmental Protection and Safety Panel . Representation on the panels is determined by contribution level to *JOIDES Resolution* operations and exchange with other facility boards. NSF is a member of the JRFB.
- Reviews: An NSF-convened panel of outside experts, in consultation with the JRFB, review *JOIDES Resolution* facility performance yearly Substantive review of management performance regarding *JOIDES Resolution* operations occurred in the third year of the cooperative agreement (FY 2017) to guide the decision to consider a facility renewal proposal from Texas A&M University. Review of scientific progress in broader thematic areas is conducted under the authority of the IODP Forum.

Renewal/Recompetition/Termination

In FY 2013, to facilitate support for drilling proposal review, advisory panel meeting logistics, and other integrative activities for scientists participating in IODP activities (e.g., websites), the University of California, San Diego was selected, through a competitive merit-review process, to host the the IODP Science Support Office through award of a five-year (FY 2014—FY 2018) cooperative agreement. In January 2018, following external merit-review of a renewal proposal, NSF awarded a 5-year cooperative agreement for continued support of this Office through FY 2023.

In FY 2014, through a competitive process, Texas A&M University was selected to be the *JOIDES Resolution* Science Operator (JRSO) under a five-year (FY 2015—FY 2019) cooperative agreement which may be renewed for a second five-year period subject to successful performance. This cooperative agreement contains language encouraging the awardee to facilitate novel partnerships involving support of *JOIDES Resolution* operations between the U.S. scientific drilling community and commercial industry, thereby providing new intellectual opportunities and potential reduction in overall facility cost. The National Science Board in February 2019 authorized the NSF Director, at her discretion, to enter into a renewal of the cooperative agreement from October 1, 2019 through September 30, 2024. This renewal is now in place.

In FY 2015, to facilitate support for U.S. scientists participating on IODP platforms (i.e., salary and travel) and for U.S. IODP education and outreach efforts, a new cooperative agreement was awarded, after external merit-review, to the Lamont-Doherty Earth Observatory (LDEO) of Columbia University for operation of the U.S. Science Support Program for a five-year period (FY 2015—FY 2019). Based on successful performance by LDEO, NSF executed a five-year renewal of the award beginning October 1, 2019.

LARGE HADRON COLLIDER (LHC) – ATLAS AND CMS **$20,000,000**
+$4,000,000 / 25.0%

Large Hadron Collider Funding
(Dollars in Millions)

FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
$16.00	-	$20.00	$4.00	25.0%

The Large Hardon Collider, an international project at the European Organization for Nuclear Research (CERN) laboratory in Geneva, Switzerland, is the most powerful particle accelerator ever constructed. It produces the highest energy particle beams ever created at a laboratory, making it the premier facility in the world for research in elementary particle physics. The LHC is a superconducting particle accelerator, approximately 16.5 miles in circumference, where counter-circulating proton beams can collide with a total energy of up to 14 TeV (one TeV=10^{12} electron volts). The collisions occur at four discrete interaction points around the circumference of the accelerator where highly sophisticated detectors measure the characteristics of the debris produced in the proton-proton collisions. The LHC can also collide beams of heavy ions, such as lead. Major "high luminosity" upgrades to the accelerator and detectors are planned to be installed during a suspension in operation that is planned for 2025-mid-2027. The upgrades will significantly enhance the performance of the accelerator and the detectors so that they will be able to gather more than ten times the total amount of data collected previously. Detailed information on the upgrades can be found in the High Luminosity LHC (HL-LHC) narrative in the MREFC chapter.

More than 45 international funding agencies provide support for scientists to participate in experiments at the LHC. Participating scientists have self-organized into distinct scientific collaborations to operate each of the detectors at the LHC. U.S. participation in the LHC scientific program is defined by Memoranda of Understanding and supporting agreements among NSF, the Department of Energy (DOE), and CERN. CERN is responsible for carrying out the overall LHC program goals of operation and maintenance, planning and leading the implementation of upgrades to the accelerator, detectors, and research infrastructure, and achieving scientific goals. As the host laboratory, CERN is responsible for coordinating international participation in the LHC program. The United States, through a partnership between the DOE and NSF, made major contributions to the construction and operation of the A Toroidal LHC ApparatuS (ATLAS) and Compact Muon Solenoid (CMS) detectors, two large general-purpose particle detectors at the LHC. NSF additionally supports operation of the LHCb experiment, a special purpose detector that focuses on studying the properties of elementary particles containing b (or "bottom") and anti-b quarks. Researchers funded by NSF and DOE comprise the U.S.-ATLAS and U.S.-CMS collaborations, while the U.S.-LHCb collaboration is supported only by NSF. Currently, about 1,270 U.S. researchers participate in the ATLAS and CMS collaborations, including more than 100 post-doctoral fellows and about 450 students, of whom more than 250 are undergraduates. The U.S. researchers comprise about 25 percent of the total membership of the ATLAS and CMS collaborations. NSF supports about 20 percent of the U.S. ATLAS and CMS contingent (plus about 30 of the 1,282 members of the LHCb collaboration).

LHC data have resulted in major scientific discoveries. Foremost of these was the July 2012 announcement by the ATLAS and CMS collaborations of the discovery of a particle having properties consistent with the long-sought Higgs boson, a prediction of the Standard Model of particle physics. Its existence was a prediction of the theoretical framework describing the origin of the masses of elementary particles. The experimental confirmation of this theory at the LHC led to the award of the 2013 Nobel Prize in physics to François Englert and Peter Higgs. In 2018, the ATLAS and CMS collaborations announced observations of Higgs bosons coupling to pairs of t (or top) and b (bottom) quarks. Observing these extremely rare processes is a significant milestone for the field of high-energy physics as it allows physicists to test critical parameters of the Higgs mechanism in the Standard Model. The new results may also provide insight into one of the most puzzling aspects of the Standard Model: the wide range of masses among fermions, the class of particles that constitute matter and includes quarks and leptons. This analysis relied on the abundant data produced to confirm, with overwhelming statistical significance, that the strengths of these couplings are consistent with the predictions of the Standard Model.

The ATLAS and CMS collaborations continue to search for evidence of new physical phenomena beyond the Standard Model. The overall LHC research program includes searches for particles predicted by various proposed extensions to the Standard Model. These searches utilize the Higgs boson as a tool for discovery: investigating how it interacts with itself, searching for its possible coupling to dark matter, and scrutinizing the data for anomalies indicative of unanticipated phenomena. The experimental results to date have helped tighten constraints on different models and possibilities, homing in on the most exciting areas of investigation ahead. Further accumulation of data enables these investigations to be carried out with ever-greater precision as researchers look for small, but statistically significant, deviations of measurements from theoretical predictions.

This FY 2021 Request for the NSF LHC program funds operation activities by U.S. university-based researchers participating in high energy physics at the LHC. In FY 2017-FY 2019, LHC operations funding was reduced while planning for the high luminosity upgrade was underway. As of FY 2020, HL-LHC planning will have been completed and construction will begin. The LHC will resume full-time operation in May 2021, following a shutdown in 2018 and maintenance and installation of performance enhancements in 2019. The LHC's successor, the HL-LHC, and its concomitant detector upgrades, will be installed during a shutdown planned to run from the beginning of 2025 through mid-2027.)

Total Obligations for LHC
(Dollars in Millions)

	FY 2019	FY 2020	FY 2021	ESTIMATES[1]				
	Actual	(TBD)	Request	FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Operations & Maintenance	$16.00	-	$20.00	$20.50	$20.50	$20.50	$20.50	$20.50

[1] Outyear estimates are for planning purposes only. The current cooperative agreemenst ends December FY 2021 (CMS) and January 2022 (ATLAS).

A global cyber-infrastructure, the World-wide LHC Computing Grid or WLCG, is dedicated to LHC data processing, allowing scientists to remotely access and analyze vast data sets. The U.S.-ATLAS and U.S.-CMS collaborations continue to lead the development and exploitation of distributed computing within their respective international collaborative efforts. The WLCG and the Tier 2 computing centers funded by NSF enable the researchers at 92 U.S. universities and five national laboratories to access LHC data and computing resources and thus train students in both state-of-the-art science and computational techniques.

The High Energy Physics Advisory Panel, through the May 2014 report of its Particle Physics Project Prioritization Panel, recommended to DOE and NSF that the highest priority strategic goal for the U.S. particle physics research program, within a global context, should be continued support for involvement in the LHC program. Within the scope of supported activities, they recommended including design and development planning for the high luminosity upgrades. These upgrades will increase the luminosity, or proton-proton interaction rate, tenfold compared to the LHC's initial operating capabilities. This will necessitate significant enhancements to the detectors to exploit this scientific opportunity. NSF has been working with the U.S.-ATLAS and U.S.-CMS collaborations to plan for a possible contribution to this upgrade. Supplemental funds provided through the LHC operations award in FY 2016-FY 2018 enabled the U.S.-ATLAS and U.S.-CMS collaborations to prepare and complete their construction-ready planning. Subject to final NSB authorization, NSF plans to begin funding elements of the high luminosity detector upgrades to ATLAS and CMS in FY 2020.

Through the participation of young investigators, undergraduate and graduate students, and minority-serving institutions, the U.S.-LHC program serves the goal of helping to produce a diverse, globally-oriented workforce of scientists and engineers. Innovative education and outreach activities allow high school teachers and students to participate in this project.

Management and Oversight

- NSF Structure: A program director in the MPS Division of Physics is responsible for day-to-day project oversight. The Division of Acquisition and Cooperative Support in BFA provides financial and administrative support. An Integrated Project Team, with representatives from MPS, experienced program officers from other directorates within NSF, the Large Facilities Office (LFO) and other divisions in BFA, contributes to planning and oversight activities. The MPS Facilities team, together with the NSF Chief Officer for Research Facilities, also provide high-level guidance, support, and oversight.
- External Structure: U.S. program management occurs through a Joint Oversight Group (JOG), created by NSF and DOE. The JOG has the responsibility to see that the U.S.-LHC program is effectively managed and executed to meet commitments made under the LHC international agreement and its protocols. NSF operations support is provided through cooperative agreements with Princeton University for U.S.-CMS and with Stony Brook University for U.S.-ATLAS.
- Reviews: NSF and DOE conduct separate and joint external reviews of operation and detector upgrade activities. Each agency is fully cognizant of the activities of the other partner. Two joint review meetings per year assess operational performance, scientific and financial status, management issues, and plans for future activities. DOE and NSF conducted joint reviews of ATLAS and CMS operations in May 2019. The most recent JOG was held in October 2019. The next major joint review of operations will be held in June 2020. NSF conducted Final Design Reviews of the ATLAS and CMS upgrades in September 2019. In October 2019, NSF conducted external reviews of the budget impacts of the MREFC upgrades on the ATLAS and CMS operations programs.

Renewal/Recompetition/Termination

Funding for operations and maintenance for the NSF LHC program was renewed in FY 2017 following external review of proposals from ATLAS and CMS. NSF's review process culminated in the implementation of cooperative agreements for operation that will expire in FY 2022. ATLAS and CMS periodically conduct internal competitions among the U.S. universities within each collaboration to select the NSF PI and host institution for the Cooperative Agreement for operation. This process preceded the current awards, and it will be repeated prior to submission of the LHC operations proposal in FY 2022.

LASER INTERFEROMETER GRAVITATIONAL-WAVE OBSERVATORY (LIGO) — $45,000,000 / -$21,720,000 / -32.6%

Laser Interferometer Gravitational-Wave Observatory Funding
(Dollars in Millions)

FY 2019 Actual[1]	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual: Amount	Percent
$66.72	-	$45.00	-$21.72	-32.6%

[1] Includes $10.47 million in additional FY 2019 funding above the requested amount and $11.25 million for continuity of operations into FY 2020.

Einstein's theory of general relativity predicts that cataclysmic processes involving extremely dense objects in the universe, such as the collision and merger of two black holes, will produce gravitational radiation. On September 14, 2015, NSF's LIGO directly observed gravitational radiation from a black-hole merger, verifying this 100-year-old prediction. This is an achievement of historic importance for fundamental physics, astrophysics, and astronomy, as it opens an entirely new observational window on the universe. This achievement was announced to the world in a series of international press conferences on February 11, 2016. LIGO announced detection of a second black-hole merger on June 15, 2016. In October 2017, LIGO announced the first detection of a neutron star-neutron star merger, observed on August 17, 2017. This event was also observed in the electromagnetic spectrum, from gamma rays to radio waves, by 70 telescopes around the world. These observations had the far-reaching consequence of confirming that most of the elements heavier than iron were produced by neutron star-neutron star mergers. The 2017 Nobel Prize in Physics was awarded to Barry Barish, Kip Thorne, and Rainer Weiss for their "decisive contributions to the LIGO detector and the observation of gravitational waves."

In the first two observational periods beginning with the September 14, 2015 detection, LIGO detected gravitational waves from 10 stellar-mass binary black hole mergers as well as the one binary neutron star inspiral. During the first observing period, or "run" (O1), from September 12, 2015 to January 19, 2016, gravitational waves from three binary black hole mergers were detected. The second observing run (O2), which lasted from November 30, 2016, to August 25, 2017, saw a binary neutron star merger and a total of seven binary black hole mergers. The third observing run (O3), which began April 1, 2019 and is ongoing, has detected 33 candidate events as of November 2019. Of the 33 candidate events, 21 are believed to be binary black hole mergers, two are believed to be binary neutron star mergers, and the origin of the other candidates is less certain. The O3 run will continue through April 30, 2020. During O3, LIGO is observing about one detection candidate per week.

The European Advanced Virgo interferometer joined NSF's two Advanced LIGO detectors on August 1, 2017, in O2. While the LIGO-Virgo three-detector network was operational for only three and a half weeks, five events were observed in this period. One of these, GW170814, was the first binary black hole merger measured by the three-detector network, enabling the first measurements of gravitational wave polarization and providing an additional confirmation of the theory of general relativity. The Virgo interferometer also contributed to the detection of the binary neutron star merger. Virgo is also participating in the O3 run.

All these observations were made while LIGO is still in the process of fine-tuning its instrumentation to reach design sensitivity. The fourth observing run (O4) is planned to begin in 2021, incrementally increasing its sensitivity to reach the full capabilities of the current suite of instrumentation.

LIGO, the most sensitive gravitational-wave detector ever built, comprises two main facilities, one in Livingston Parish, LA and one in Hanford, WA. At each facility, an L-shaped vacuum chamber, with two four-km long arms joined at right angles, houses an optical interferometer. The interferometers are used to measure minute relative changes in the distances between the vertex of the L and mirrors at the ends of the arms that are caused by a passing gravitational wave. A passing gravitational wave causes the distance along one arm to lengthen while the other arm shrinks during one half cycle of the wave, and then the first arm shrinks while the other arm lengthens during the second half cycle. The predicted distortion of space caused by a gravitational wave from a likely source is on the order of one part in 10^{21}, meaning that the expected amplitude of the length change over the four-km length is only about 1/1000th the diameter of a proton. LIGO's four-km length was chosen to make the expected signal as large as possible within terrestrial and financial constraints: longer arms would result in a bigger signal but would entail larger construction costs. Looking for coincident signals from both interferometers increases LIGO's ability to discriminate between a gravitational wave and local sources of noise.

In 2015, LIGO completed installation of the "Advanced LIGO" upgrade, funded through the MREFC account. The upgrade enabled the design, fabrication, and installation of an improved apparatus expected to increase LIGO's sensitivity 10-fold relative to the initial LIGO apparatus (which had operated through 2009). The Advanced LIGO interferometers operated at about four times the initial LIGO sensitivity during O1, at about six times the initial sensitivity during O2, and at nine times the initial sensitivity during O3.

The value of obtaining complementary gravitational wave and electromagnetic signals from the same source has already been demonstrated in the enormous scientific impact resulting from the observation of a neutron star-neutron star merger. As the number of observations expands with enhanced sensitivity and localization, this will significantly increase our understanding of supernovae and neutron stars. Such scientific prospects help motivate the NSF Big Idea 'Windows on the Universe.'

Total Obligations for LIGO

(Dollars in Millions)

	FY 2019 Actual[1]	FY 2020 (TBD)	FY 2021 Request	ESTIMATES[2] FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Operations & Maintenance	$56.25	-	$45.00	$45.00	$45.00	$45.00	$45.00	$45.00
Facility Upgrades	10.47	-	-	-	-	-	-	-
Total	**$66.72**	**-**	**$45.00**	**$45.00**	**$45.00**	**$45.00**	**$45.00**	**$45.00**

[1] O&M includes $11.25 million for continuity of operations into FY 2020. Facility Upgrades reflects $10.47 million in additional FY 2019 funding above the requested amount to support the Advanced LIGO Plus enhancement.

[2] Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in September 2023.

For information on continuity of operations funding, see the opening narrative of this chapter.

LIGO researchers are planning a series of facility upgrades to take place in the coming years. The first of these enhancements, known as Advanced LIGO Plus (or "A+"), will significantly increase each interferometer's sensitivity in the mid and upper frequency range of its detection band. This is expected to lead to a four-fold increase in the detection rate for twin 30-solar-mass black hole coalescences, and nearly a seven-fold increase in the detection rate for the merging of pairs of 1.4-solar-mass neutron stars. In FY 2018, NSF awarded $10.0 million to LIGO for the A+ enhancement, with an additional $10.47 million in FY 2019. This award is part of an international effort among NSF, UK Research and Innovation (UKRI) and the Australian Research Council (ARC), who jointly support the U.S.-UK-Australian collaboration of researchers spearheading A+. The A+ upgrades are expected to start operating in 2024.

LIGO is pursuing an integrated program of periodic scientific operation of the LIGO observatories, interleaved with engineering studies and upgrades that continue to enhance operating performance. The operations budget also supports basic infrastructure maintenance, analysis, and dissemination of data

obtained from the interferometers, and maintenance of computational resources for data storage and analysis. Operations funding also enables strategic research and development in instrument science that is expected to lead to longer-term enhancements to operational performance.
A small part of the operations budget supports education and public outreach (EPO) activities. The LIGO Science Education Center (LIGO SEC), located on the Livingston Observatory site, hosts 50 hands-on inquiry-based learning exhibits and reaches over 15,000 students, teachers and members of the public each year. Its activities benefit from a partnership with Southern University Baton Rouge (SUBR), the San Francisco Exploratorium, the Baton Rouge Area Foundation (BRAF), and other collaborating educational entities. Trained docents from SUBR assist participants and serve as collegiate-age role models for young visitors. LIGO SEC programs are supported both through LIGO's operations cooperative agreement and through grants to SUBR and BRAF. The LIGO Hanford Observatory also promotes a highly successful program of outreach to K-12 students and the general public in the Washington State Tri-Cities region, reaching approximately 10,000 people each year. In 2019, LIGO Laboratory received $7.70 million from Washington State for the construction of a LIGO Hanford STEM Exploration Center to carry out a high-impact, interactive EPO program similar in mission to the LIGO SEC. Detailed facility design and construction planning is now underway. LIGO Laboratory members supported by the operations budget also contribute to many activities of the EPO working group of the LIGO Scientific Collaboration.

LIGO fostered a suitable environment to achieve the demanding technical performance requirements needed to detect gravitational waves. Innovations across a diverse range of technologies have led to new techniques with broad applications (for example, preparation of stainless steel for ultra-high vacuum application, adaptive laser beam shaping, and precision dielectric optical coatings). Other technological developments at LIGO have resulted in patents and commercial products (in-vacuum electrical connectors, high power electro-optic modulators).

The LIGO Scientific Collaboration (LSC), an open collaboration that organizes the major international groups doing research supportive of LIGO, has 108 collaborating institutions in 20 countries with nearly 1,300 participating scientists. The LSC plays a major role in many aspects of the LIGO effort. These include establishing priorities for scientific operation, data analysis and validation of scientific results, and contributing to instrumental improvements at the LIGO facilities and exploring future technologies, as well as fostering education and public outreach programs. NSF supports LSC activities in the United States at approximately $8 million per year, which is provided through regular disciplinary program funds.

Management and Oversight

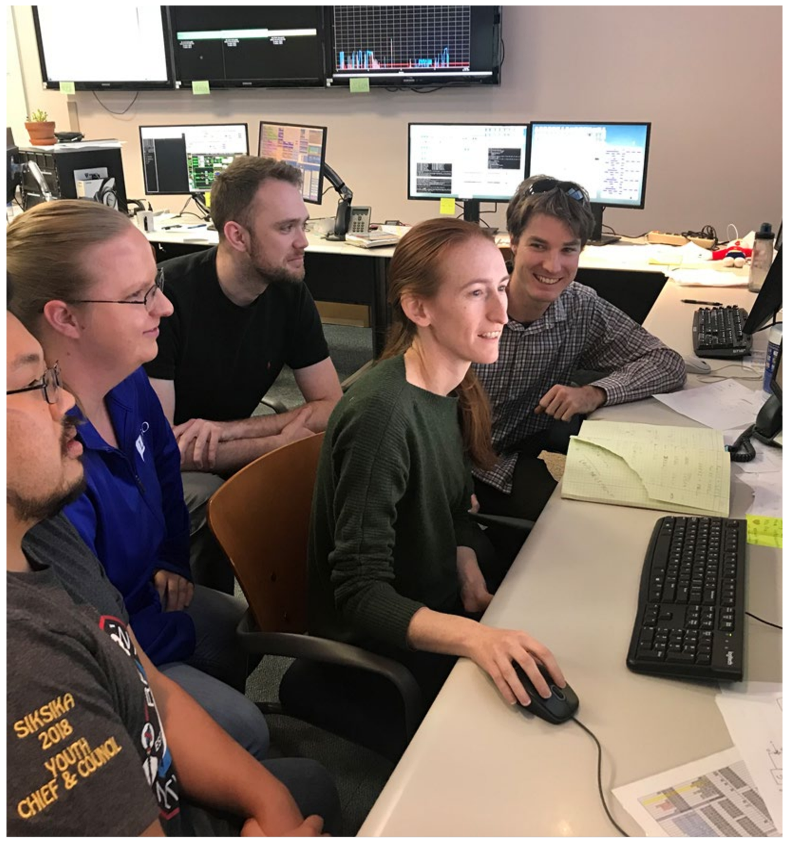
LIGO activities are funded through a five-year cooperative agreement that began October 1, 2018. NSF continually assesses the appropriate level of financial support by monitoring actual expenditures contained in quarterly activity-based financial reports from LIGO, and through annual external reviews of operations that examine performance relative to objectives defined in LIGO’s annual work plans. Infrastructure refurbishments recently accomplished, such as repairs and improvements to the vacuum system, as well as further work planned in 2020 will extend the facility life beyond 2030.

- NSF Structure: NSF oversight is coordinated internally by the LIGO program director in the MPS Division of Physics. The program director consults regularly with representatives from the Large Facilities Office and the NSF Division of Acquisition and Cooperative Support in BFA. The MPS Facilities team, together with the NSF Chief Officer for Research Facilities, also provide high-level guidance, support, and oversight.
- External Structure: LIGO is managed by the California Institute of Technology under a cooperative agreement. A subaward from California Institute of Technology to Massachusetts Institute of Technology supports a team of scientists and engineers that are fully integrated into all LIGO activities. The management plan specifies significant involvement by the user community, represented by the LSC, and collaboration with the other major gravitational-wave detector activities in Asia, Europe, and

Australia. External review committees organized by NSF help provide oversight through annual reviews.
- Recent Reviews: Reviews of observatory operation are held annually. Special purpose reviews using external expert panels have also been held as needed, examining topics such as long-term storage of the interferometer components set aside for possible deployment to India, LIGO computing plans, LIGO ultra-high vacuum system needs, and education and outreach planning. The most recent annual review was held in June 2019.

Renewal/Recompetition/Termination

In 2015 and 2016 MPS conducted a detailed consideration of whether to recompete the management of the LIGO Laboratory in conjunction with the current five-year award. As LIGO had just completed installation of the Advanced LIGO apparatus in early 2015, and its operational activities were focused on initial commissioning of the apparatus, NSF concluded recompetition was inappropriate. The NSB was apprised of this at their August 9-10, 2016 meeting, and the award was renewed for the period of October 1, 2018 to September 30, 2023. The 2015 study recommended that NSF, in partnership with the LIGO Scientific Collaboration and with input from the broader astrophysics community, again consider the circumstances and criteria for a possible recompetition midway through the current five-year period (i.e., 2020-21). NSF is currently planning to execute this consideration.



Scientists and graduate students in the LIGO Hanford Observatory control room conducting a series of experiments to improve the Hanford interferometer sensitivity. *Credit: Caltech/LIGO Laboratory.*

THE NATIONAL ECOLOGICAL OBSERVATORY NETWORK (NEON) $65,000,000
-$8,930,000 / -12.1%

The National Ecological Observatory Network Funding
(Dollars in Millions)

FY 2019 Actual[1]	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
$73.93	-	$65.00	-$8.93	-12.1%

[1] Includes $8.93 million for continuity of operations into FY 2020.

The most persistent challenges facing the ecological sciences today are a result of our limited understanding of the complex interactions between living and non-living systems operating over large spatial and temporal scales. Critical global challenges such as ecological effects of increasing atmospheric carbon dioxide, land-use change, emerging infectious diseases, and invasive species highlight the complexity of key processes that are connected across large spatial scales and play out over decades. As these and other threats arise more frequently and spread rapidly across continents, it is critical to improved understanding of ecological changes that the short- and long-term effects of these phenomena be systematically monitored and assessed, as well as become more predictable through mathematical and statistical modeling.

Assessment of ecological processes at a continental scale has been hindered by a lack of infrastructure to enable the research required to address complex ecological issues at the necessary spatial and temporal scales. NEON was designed to address this lack of infrastructure and enable vital research. NEON consists of 81 strategically located field sites (47 terrestrial and 34 aquatic), across 20 eco-climatic domains, with instruments, sensors, cameras, and manual biological and chemical sampling networked into an integrated research platform for regional- to continental-scale ecological research. The sensor networks, instrumentation, experimental infrastructure, natural history archive facilities, and remote sensing are linked via the internet to computational and analytical capabilities to create NEON's integrated infrastructure.

NEON was constructed to revolutionize ecological research and engage the research and education communities in the use of open data. In doing so, it provides over 170 standardized data products including meteorological, soil, organismal, biogeochemical, freshwater and remote sensing data for ecosystems at various temporal and spatial scales across the United States over a 30-year timeframe.

Using NEON data, scientists across the U.S. are now able to conduct regional- to continental-scale research projects on the fundamental biological processes underlying invasive species, emerging diseases, changing biogeochemical cycles, land-use changes, climatic variation, and biodiversity, as well as other grand challenges in ecological science. Researchers can also arrange to use the Observatory's infrastructure (field sites, instrumentation, airborne remote sensing, etc.) for their own studies to advance understanding of ecological processes.

Current Status

Battelle Memorial Institute (Battelle) is the current awardee for management of NEON. Battelle is a non-profit professional management organization that operates a number of scientific and technical facilities. Construction of NEON was completed in May 2019. NEON is collecting and analyzing biological and chemical samples, measuring physical properties, transmitting sensor data to headquarters, and delivering processed datasets and data products via the NEON data portal. Cyberinfrastructure enhancements are continuing and have improved data volume handling, processing capacity and capability, data discoverability and accessibility, and data security. Battelle is implementing community engagement plans that will support overall use of the data and resources that are now available to the community. The research community is using NEON data and infrastructure in its research as evidenced by the increase in the number of NSF investigator awards in FY 2018 and FY 2019, and the number of presentations at the 2019 Ecological Society of America and the 2018 American Geophysical Union meetings.

Total Obligations for NEON
(Dollars in Millions)

	FY 2019 Actual[1,2]	FY 2020 (TBD)	FY 2021 Request	ESTIMATES[3] FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Operations & Maintenance	$73.93	-	$65.00	$65.00	$65.00	$65.00	$65.00	$65.00

[1] $65,000 was obligated from the MREFC account in FY 2019 to complete project construction requirements. Approximately $1.35 million in MREFC funds are being held by NSF to mitigate remaining risks.
[2] includes $8.93 million for continuity of operations into FY 2020.
[3] Outyear estimates are for planning purposes only. The current cooperative agreement ends FY 2021.

For information on continuity of operations funding, see the opening narrative of this chapter.

Management and Oversight

NSF Structure
The NEON program is managed in BIO, with the Office of the Assistant Director (BIO/OAD) providing policy and programmatic guidance. Oversight resides within the Division of Biological Infrastructure (DBI) and Division of Environmental Biology (DEB). The NEON Program team within BIO consists of DBI and DEB senior managers, program officers, and a project manager. The Integrated Project Team (IPT), chaired by the NEON cognizant program officer and which includes representatives from the BFA Large Facilities Office (LFO) and the BFA Division of Acquisition and Cooperative Support, with additional participation from the Office of Legislative and Public Affairs, BFA Division of Institution and Award Support-Cost Analysis and Pre-Award Branch, Office of General Counsel, Office of International Science & Engineering, and the Office of the Director, as necessary, provides guidance and advice in the review and oversight of the project.

External Structure
In the Spring of 2016, leadership and management of the NEON project was transferred to Battelle, which oversees all aspects of project implementation and coordinates observatory operations. Within Battelle, the observatory director/chief scientist (OD/CS) provides overall scientific leadership and interfaces with the science community and other entities to support the scientific priorities and operations of NEON. A Science, Technology, and Education Advisory Committee (STEAC), composed of members of the NEON user community, provides oversight and guidance to the project and helps ensure that NEON will enable frontier research and education. The work of the STEAC is complemented by several Technical Working Groups that advise Battelle on the technical aspects of the project.

Reviews
The construction close-out review in April 2019 documented the completion of NEON construction scope and transition to operations. External evaluators were tasked with reviewing project documentation and confirm delivery of observatory capacity. Reviews of full operations and maintenance (O&M) are held annually. The 2019 review of O&M emphasized evaluation of data availability, accessibility, and quality; user community engagement; Battelle’s cost performance; and the facility’s cyberinfrastructure. Progress against the annual program plan and towards implementation of review recommendations is also monitored by BIO via biweekly teleconferences, bimonthly operations reports, and site visits as needed. In addition to these scientific and technical reviews, there are periodic reviews by organizations within BFA. To evaluate

the suite of business systems that support the management of NEON, a Business Systems Review was conducted in FY 2019 and included desk reviews of Battelle's policies, procedures, and technologies as well as site visits to Battelle Headquarters in Columbus, Ohio and NEON Headquarters in Boulder, Colorado.

Operations Costs

Operations and maintenance support began in FY 2014. In August of 2017, a supplemental operations award was authorized. For planning purposes, costs are held constant by BIO at the projected annual operations ceiling of $65.0 million.

Community Engagement

Battelle's community engagement efforts are led by the OD/CS. The community engagement programs facilitate increased awareness and understanding of ecological change and familiarize people with large, complex datasets. Staff are educating NEON users and the public through a YouTube channel,[1] presentations at local and national meetings, workshops and data institutes, and online learning modules. The data science team is facilitating access to and use of the data with open-source software packages and utilities. BIO and its Advisory Committee have assembled a subcommittee, composed of members of the research community, to evaluate engagement models that will inform a community-based strategy for mobilizing and sustaining NEON users. BIO also engages with other federal stakeholders, including Defense Advanced Research Projects Agency, Department of Energy, Department of Interior (DOI)/National Invasive Species Council (NISC), Department of Agriculture (USDA), DOI National Park Service, USDA Agricultural Research Service, United States Geological Survey, National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, and the Smithsonian Institution. Federal stakeholders are engaged through the NEON Interagency Working Group to help maximize the scientific impact of NEON through coordination when advantageous to the project.

Renewal/Recompetition/Termination

In July 2019, the NSF notified NSB of its intention to exercise the option to provide funding to Battelle for a fourth year. Therefore, the current O&M award to Battelle which began in November 2017 now ends in October 2021. Following the notification to NSB, a Dear Colleague Letter was released announcing NSF's intention to openly compete the management of NEON operations and maintenance and encouraging organizations to submit requests for information. The solicitation for the management of NEON operations and maintenance (NSF 20-530)[2] was released on December 23, 2019. BIO anticipates the timeline of the competition to be somewhat less than two years.

[1] www.youtube.com/neonscience
[2] www.nsf.gov/publications/pub_summ.jsp?WT.z_pims_id=505747&ods_key=nsf20530

NATIONAL HIGH MAGNETIC FIELD LABORATORY (NHMFL) **$37,740,000**
-$2,880,000 / -7.1%

National High Magnetic Field Laboratory Funding
(Dollars in Millions)

FY 2019 Actual[1]	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
$40.62	-	$37.74	-$2.88	-7.1%

[1] Includes $14.20 million for continuity of operations into FY 2020 and excludes $9.34 million of FY 2019 O&M costs obligated in FY 2018.

NHMFL develops and operates high magnetic field facilities that scientists and engineers use for research in condensed matter and material physics, materials science and engineering, chemistry, biology, biochemistry, neuroscience, energy, and the environment. The laboratory is managed by Florida State University (FSU), and consists of facilities at FSU, the University of Florida (UF), and Los Alamos National Laboratory (LANL). It is the world's premier high magnetic field laboratory with a comprehensive collection of high-performing magnet systems and extensive support services. The facilities are available to all qualified scientists and engineers through a peer-reviewed proposal process. There are approximately 2,000 users per year, including faculty and staff at the three host institutions. Stewardship and oversight of NHMFL is provided through the MPS Division of Materials Research (DMR), and the Fourier Transform Ion Cyclotron Resonance (FT-ICR) facility within NHMFL is overseen by the MPS Division of Chemistry (CHE).

The laboratory is an internationally recognized leader in magnet design, development, and construction, including the development of new superconducting materials. Many unique magnet systems have been designed, developed, and built by the Magnet Science and Technology Division of the NHMFL. The NHMFL holds numerous records for high magnetic fields, such as the highest field for a continuous-field magnet (45 Tesla), highest-field magnet for Nuclear Magnetic Resonance (36 Tesla), highest-field superconducting magnet for FT-ICR mass spectrometry (21 Tesla), and highest-field for a magnetic resonance imagining study of a living animal.

These unique facilities are available to thousands of users each year and help define and advance science frontiers in many disciplines through measurements with state-of-the-art resolution and accuracy enabled by the high magnetic fields.

Over the last several years, the NHMFL has contributed to major scientific accomplishments in the budding field of topological materials, an entirely new class of quantum materials prominently distinguished by the 2016 Nobel Prize in Physics. Two recent prominent results from the NHMFL include the first confirmation of the existence of a three-dimensional topological insulator state, and the first evidence of a long-sought-for quantum phenomenon known as chiral anomaly in a quantum material.

The record-high magnetic fields made available to scientists at the NHMFL enabled an unprecedented and confounding discovery, a phenomenon called re-entrant superconductivity that only exists for magnetic fields above 40 Tesla. A superconducting state arises, breaks down, and then re-emerges in a material under the application of an extremely strong magnetic field. This phenomenon violates current understanding and is likely to reveal unknown facets of superconductivity.

NHMFL's MRI at high magnetic fields (21.1 Tesla) has enabled in vivo imaging of brain function and cancer research in rats. In April 2017, NHMFL's new 36 Tesla Hybrid magnet reached a performance milestone of ultrahigh stability and homogeneity across the sampling volume. This stability has enabled the world's first nuclear magnetic resonance spectrum at 1.5 GHz, which opens new probing capabilities for chemists and biologists.

In 2016, the NHMFL opened its 21 Tesla Ion Cyclotron Resonance (ICR) magnet for user access, allowing enhanced resolution of complex chemical mixtures, such as intact proteins and petroleum crude oil, which have been heretofore intractable for rapid analysis. The ICR magnet impacts a broad array of research areas, such as chemistry, molecular biology, and earth science.

A major scientific impact is expected from the research on quantum materials conducted by researchers using the NHMFL magnets. These magnets allow for the exhibition, identification, and visualization of new and unusual quantum effects that lead to deeper understanding of quantum materials and enable the discovery of new ones. Another example of a potential area for advancement by NHFML is new imaging techniques for studying the brain. Magnetic resonance imaging and functional magnetic resonance imaging are currently based on imaging proton spin density and intrinsic tissue relaxation rates. With higher magnetic field strengths, NHMFL is investigating other nuclei to use that would result in new insights into mapping the brain and neuroscience.

Partnerships and Other Funding Sources: NHMFL collaborates with more than 60 private sector companies as well as a number of national laboratories. These include those supported by the Department of Energy, such as Oak Ridge National Laboratory, which hosts the Spallation Neutron Source, and Argonne National Laboratory, which hosts the Advanced Photon Source. Additionally, NHMFL collaborates internationally. The laboratory delivered and commissioned a 26 Tesla series connected hybrid magnet to the Helmholtz-Zentrum Berlin for neutron scattering experiments. Collaborations also exist with the International Thermonuclear Experimental Reactor in France, and national magnet laboratories in several countries, including the Netherlands, and Germany.

NHMFL provides a unique interdisciplinary and convergent learning environment. The Center for Integrating Research and Learning at NHMFL conducts education and outreach activities, which include a Research Experience for Undergraduates program, summer programs for teachers, a summer camp for middle school girls, and activities to raise the scientific awareness of the general public.

Total Obligations for NHMFL

(Dollars in Millions)

	FY 2019[1]	FY 2020	FY 2021	ESTIMATES[2]				
	Actual	(TBD)	Request	FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Operations & Maintenance (DMR)	$38.89	-	$36.01	$37.18	$36.09	$36.09	$36.09	$36.09
Operations & Maintenance (CHE)	1.73	-	1.73	1.73	1.73	1.73	1.73	1.73
Total	**$40.62**	**-**	**$37.74**	**$38.91**	**$37.82**	**$37.82**	**$37.82**	**$37.82**

[1] Includes $14.20 million in DMR funding for continuity of operations into FY 2020 and excludes $9.34 million of FY 2019 O&M obligated in FY 2018.

[2] Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in December 2022.

For information on continuity of operations funding, see the opening narrative of this chapter.

Management and Oversight

- NSF Structure: NHMFL is supported by DMR, with the DMR program director as the primary contact for most of the laboratory. CHE supports the FT-ICR Facility, which is overseen by a CHE program director. The Division of Acquisition and Cooperative Support (DACS) and the Large Facilities Office

(LFO) in BFA provide financial and administrative support and the MPS Facilities team, together with the NSF Chief Officer for Research Facilities, also provide high-level guidance, support, and oversight.

- External Structure: A consortium of FSU, UF, and LANL operates NHMFL under a cooperative agreement. FSU, as the agreement signatory, is responsible for administrative and financial oversight and for ensuring that lab operations are consistent with the cooperative agreement. The principal investigator, the NHMFL director, reports to the FSU Vice President for Research. Four senior faculty members are co-principal investigators. The NHMFL director receives guidance primarily from the NHMFL executive committee, the NHMFL science council, and the NHMFL diversity committee together with recommendations from an external advisory committee and the users' executive committee.

Reviews

NSF monitors annual plans and reports including user metrics and conducts monthly teleconferences with the NHMFL director. NSF conducts annual external reviews to assess the user programs, in-house research, long-term plans to contribute significant research developments both nationally and internationally, and operations, maintenance, and new facility development. Annual reviews also assess the status of education, training and outreach, operations and management efficiency, and diversity plans. In addition to these yearly scientific reviews, NHMFL undergoes periodic business systems reviews by LFO and DACS.

Recent reviews include:

- Renewal of NHMFL operations award approved by the NSB, August 2017.
- External Safety Review at all three sites of the NHMFL (July and September 2018).
- Site visit review with external panel of experts, September 2019.

Renewal/Recompetition/Termination

In May 2015, NSF determined that it was in the best interest of the U.S. science and engineering enterprise to renew rather than re-compete the NHMFL award. A renewal proposal was submitted in May 2016. In August 2017, the NSB authorized an award to FSU for the operation of NHMFL for 60 months starting in 2018. The current award for the operation of the NHMFL started in January 2018 and will end in December 2022. During 2020, MPS and DMR will assess the status and performance of NHMFL as well as the evolution of high-magnetic-field science to determine the path forward after 2022.

The National High Magnetic Field Laboratory, Tallahassee, Florida site. *Credit: NHMFL*

NATIONAL SUPERCONDUCTING CYCLOTRON LABORATORY (NSCL) **$15,500,000**
-$13,000,000 / -45.6%

National Superconducting Cyclotron Laboratory Funding
(Dollars in Millions)

FY 2019 Actual[1]	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
$28.50	-	$15.50	-$13.00	-45.6%

[1] Includes $4.50 million for continuity of operations into FY 2020.

The National Superconducting Cyclotron Laboratory Funding is a national user facility based at Michigan State University (MSU). With two linked superconducting cyclotrons, K500 and K1200, it is the leading rare isotope research facility in the United States and is a world leader in nuclear physics with the unique capability of producing radioactive beams at energies relevant to nuclear astrophysics. Funding for NSCL also supports the research program of the MSU nuclear science faculty. NSF's stewardship of NSCL will come to a close at the end of FY 2021, when NSCL transitions into Department of Energy's (DOE) Facility for Rare Isotope Beams (FRIB) at MSU.

Scientists at NSCL work at the forefront of rare isotope research. They create and study atomic nuclei that cannot be found on Earth and perform experimental research using beams of unstable isotopes to extend our knowledge of new types of nuclei, many of which are important to understanding stellar processes. Research activities include a broad program in nuclear astrophysics studies, the studies of nuclei far from stability using radioactive ion beams, and studies of the nuclear equation of state. NSCL is a leader in the era of multi-messenger astrophysics in that it provides data that is directly related to the origin of the elements in the Universe and the physical processes that drive quiescent stellar burning, core collapse supernovae and neutron star mergers. In addition, research is carried out in accelerator physics.

NSCL scientists employ a range of tools for conducting advanced research in fundamental nuclear science, nuclear astrophysics, and accelerator physics. Applications of research conducted at NSCL benefit society in numerous areas, including studies on the effects of ionizing radiation on DNA, tests of detectors to be used in space missions, development of data acquisition systems and software, and homeland security. The K500 was the first cyclotron to use superconducting magnets, and the K1200 is the highest-energy continuous beam accelerator in the world. Through the Coupled Cyclotron Facility, heavy ions are accelerated by the K500 and then injected into the K1200, enabling the production of rare unstable isotopes at much higher intensities. The laboratory operates an MSU-funded reaccelerator facility (ReA3) that enables experiments at very low energies—a domain of particular interest to nuclear astrophysics. NSCL is the only facility in the world to provide radioactive beams in this energy regime. Nearly one third of recently proposed experiments will use the ReA3. The mix of experiments is determined by proposals for beam use. An external program advisory committee selects the best proposals at a typical success rate of about 50 percent, with constraints on beam availability. The science output of NSCL is driven by these experiments, with most running five to fifteen days.


Undergraduate students reconfigure the MoNA detector for a new experiment. *Credit: NSCL and MSU*

Total Obligations for NSCL
(Dollars in Millions)

	FY 2019 Actual[1]	FY 2020 (TBD)	FY 2021 Request	ESTIMATES[2] FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Operations & Maintenance	$28.50	-	$15.50	-	-	-	-	-

[1] Includes $4.50 million for continuity of operations into FY 2020.
[2] The current cooperative agreement ends in FY 2021, after which the NSF-managed NSCL will transition to the DOE-managed Facility for Rare Isotope Beams.

For information on continuity of operations funding, see the opening narrative of this chapter.

Funding for NSCL has always had two components: operations and maintenance of the lab and the research activity of the MSU nuclear scientists whose research is based at NSCL. In FY 2019, the operations and maintenance support totaled $18.0 million and research support totaled $6.0 million, with an additional $4.50 million in advanced obligations to partially cover operations costs in FY 2020. The reduction in FY 2021 reflects the transfer of a portion of the NSCL research support to the MPS Division of Physics (PHY) core program, Nuclear Physics, as part of the planned transfer of NSCL operations and maintenance to the Department of Energy in FY 2022. The FY 2021 Budget Request reflects an additional reduction of $4.50 million in response to prior advanced obligations.

NSCL supports and enhances doctorate-level graduate education and post-doctoral research experiences. About 10 percent of all doctorates granted in nuclear physics in the United States are based on research at NSCL. The lab also provides research experiences for undergraduate students, K-12 students, and K-12 teachers. In a typical year about 800 users conduct research at NSCL; approximately 70 percent of those users are U.S. scientists.

Management and Oversight

- NSF Structure: MSU operates NSCL under a cooperative agreement with NSF. NSF oversight is provided through annual site visits by the cognizant program officer in PHY and other staff, accompanied by external experts. NSF uses the annual site reviews to assess the user program, operations, maintenance, facility efficiency, national and international research developments, and in-house research programs. The NSF program officer monitors lab operations and plans through monthly phone conferences with the NSCL director. The program officer consults regularly with the NSF Large Facilities Office and the NSF Division of Acquisition and Cooperative Support in BFA. The MPS Facilities team, together with the NSF Chief Officer for Research Facilities, also provide high-level guidance, support, and oversight.
- External Structure: MSU provides added support for NSCL, which is managed by a director and three associate directors (experimental research, education and outreach, and operations) as well as a chief scientist. The director has the authority to appoint associate directors and designate responsibilities, notifying NSF of changes. NSCL's research program is guided by a program advisory committee of external experts as well as an in-house expert and the chairperson of the NSCL user group. Opportunities for proposal submission occur once a year and the beam hour backlog is no longer than two years. Optimally the laboratory can provide about 5,000 beam hours to the scientific community each year, with actual output depending upon facility reliability factors and available funds.
- Reviews: An in-depth review in FY 2016 looked at results and achievements related to intellectual merit and broader impacts for the prior four years (FY 2012-FY 2015) as well as a review of proposed research, operations, and maintenance funding for the next five years (FY 2017-FY 2021). The most recent annual review took place in August 2019 and included review of NSCL's proposed research program, operations plan for that program, and maintenance plan for the last year of the cooperative

agreement (FY 2021). The report expressed overwhelming support for the management and operations of NSCL and endorsed NSCL's plan for the last year of the cooperative agreement. The next review is planned for Summer 2020.

Renewal/Recompetition/Termination

NSCL currently operates under a cooperative agreement with MSU, which is due to expire at the end of FY 2021. After that time, NSCL will transition to the new Facility for Rare Isotope Beams (FRIB),[1] which is being built by the DOE on the NSCL site. FRIB is scheduled to become operational in FY 2022 and will use much of the NSCL beamlines, instrumentation, and general infrastructure. MSU will be the performing institution under a cooperative agreement with DOE for the future FRIB. To facilitate interagency planning and coordinate the transition from the NSF-funded NSCL to the DOE-funded FRIB, a Joint Oversight Group of DOE and NSF personnel has been meeting regularly since 2010. DOE and NSF will coordinate transfer of facility stewardship as it transitions from NSCL to FRIB.

[1] https://frib.msu.edu/

NATURAL HAZARDS ENGINEERING RESEARCH INFRASTRUCTURE (NHERI) $10,950,000
-$620,000 / -5.4%

Natural Hazards Engineering Research Infrastructure Funding
(Dollars in Millions)

FY 2019 Actual[1]	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
$11.57	-	$10.95	-$0.62	-5.4%

[1] Includes $8.50 million in additional funding to upgrade the LHPOST facility. Excluded is $8.93 million in FY 2019 O&M costs obligated in FY 2018.

NHERI was established in 2015 by NSF as a distributed, multi-user, national research facility for use by the Nation's natural hazards engineering research community. NHERI provides researchers with access to state-of-the-art facilities and tools, unavailable through any other agency, to study the performance of civil infrastructure, including buildings, geostructures, and underground structures, in response to individual and combinations of natural hazards. These facilities provide essential research infrastructure to support two federally-mandated interagency programs: the National Earthquake Hazards Reduction Program and the National Windstorm Impact Reduction Program.

The portfolio of research investigations, which is funded separately through NSF's highly competitive, parallel proposal merit review process, involves large-scale experimentation linked to numerical modeling, and collection and sharing of data to increase the knowledge gleaned from investment in these facilities. Such research is essential to the development of more comprehensive and more realistic predictive models of how civil infrastructure responds to earthquakes, windstorms such as hurricanes and tornados, storm surge, and tsunamis. These advances, in turn, enable the design of more hazard-resilient civil infrastructure and improve safety for citizens during these events.

NHERI includes earthquake and wind engineering experimental facilities; a wave testing facility; a post-disaster, rapid-response research facility; cyberinfrastructure; computational modeling and simulation tools; and a research data repository. The research infrastructure investment also supports education and community outreach activities.

During FY 2015 and FY 2016, NSF established NHERI through eleven cooperative agreements:
- Network Coordination Office (NCO) at Purdue University,
- Cyberinfrastructure (CI) at the University of Texas at Austin,
- Computational Modeling and Simulation Center (SimCenter) at the University of California, Berkeley,
- Twelve-Fan Wall of Wind at Florida International University,
- Large-Scale, Multi-Directional, Hybrid Simulation Testing Capabilities at Lehigh University,
- Large Wave Flume and Directional Wave Basin at Oregon State University,
- Geotechnical Centrifuges at the University of California, Davis,
- Large, High-Performance Outdoor Shake Table (LHPOST) at the University of California, San Diego (UCSD),
- Boundary Layer Wind Tunnel, Wind Load and Dynamic Flow Simulators, and Pressure Loading Actuators at the University of Florida,
- Large, Mobile Dynamic Shakers for Field Testing at the University of Texas at Austin, and
- Post-Disaster, Rapid-Response Research (RAPID) Facility at the University of Washington.

The NCO serves as the national and international scientific leader, community focal point, and network-wide coordinator for NHERI governance and community-building activities. Key NCO activities include convening the governance groups; working with NHERI PIs to develop consensus-based policies and procedures for NHERI, and the annual NHERI-wide work plan; implementing the facility scheduling protocol to provide user access to the experimental facilities; leading development of a community science plan; running NHERI-wide education and community outreach programs; and building strategic partnerships. NHERI awardees and the natural hazards engineering community work together, through governance and awardee activities, to establish a shared vision for NHERI, set natural hazards engineering research and education agendas and priorities, and make NHERI a highly value-added and productive research infrastructure. Approximately $870,000 is included in the FY 2021 request for NCO activities.

The CI awardee serves as the integrator for enabling NHERI to be a virtual organization for the natural hazards engineering community, by providing an array of information, resources, and services, including the definitive NHERI website; research data repository (Data Depot); software service delivery platform with computational modeling, simulation, and educational tools (Discovery Workspace); collaboration tools; access to high-performance computing resources; and user training and support. The CI awardee also establishes and implements the NHERI-wide cybersecurity plan with all NHERI awardees.

The SimCenter develops a portfolio of computational modeling and simulation software and educational modules that reflects a balance of community-prioritized, new capabilities for earthquake, wind, and multi-hazard engineering research and education. The SimCenter's tools are integrated into the CI awardee's Discovery Workspace.

The experimental facilities provide well-maintained and fully-functioning facilities, services, and staffing to enable earthquake engineering, wind engineering, and post-disaster, rapid-response research requiring experimental work and data collection. Data generated by these experimental resources and their users are archived and shared in the publicly accessible NHERI Data Depot.

Along with direct operations and maintenance support for NHERI awardees, NSF provides support for research involving NHERI experimental facilities through separate, ongoing research and education programs. The primary NSF program supporting such activities is the Engineering for Civil Infrastructure (ECI) program in ENG's Division of Civil, Mechanical and Manufacturing Innovation (CMMI).

Total Obligations for NHERI
(Dollars in Millions)

	FY 2019	FY 2020	FY 2021	**ESTIMATES[2]**				
	Actual[1]	(TBD)	Request	FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Operations & Maintenance	$3.07	-	$10.95	$12.00	$12.00	$12.00	$12.00	
Facility Upgrade	8.50	-	-	-	-	-	-	-
Total	**$11.57**	**-**	**$10.95**	**$12.00**	**$12.00**	**$12.00**	**$12.00**	**-**

[1] Includes $8.50 million to upgrade the LHPOST facility. Excluded is $8.93 million of FY 2019 O&M costs obligated in FY 2018.

[2] Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in FY 2020.

In FY 2018 and FY 2019, NSF provided funding totaling $16.31 million to UCSD to upgrade its LHPOST facility from its current one degree of freedom to a full six degrees of freedom capability. In its upgraded configuration, the LHPOST will be able to reproduce all six components of motion (two horizontal and one vertical translational components, as well as pitch, roll, and yaw rotational components) experienced by the ground during earthquakes. The LHPOST experimental facility will be the only large-capacity facility in the United States capable of performing such tests and has the world's largest payload capacity. Because there are no overhead height restrictions, this facility can accommodate the tallest structures ever tested on any shake table.

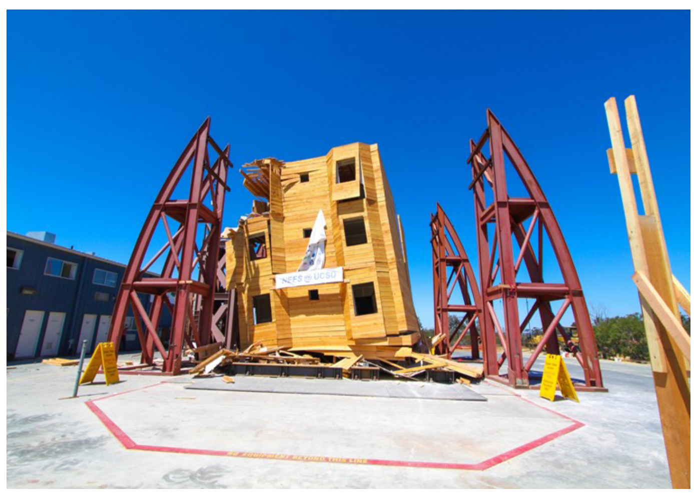
FY 2019 Operations and Maintenance obligations were lower than in previous years as NSF provided a significant amount of year five funding in the previous fiscal year to ensure continuity of operations.

Management and Oversight

- NSF Structure: NSF oversight is handled by two program officers in ENG/CMMI working cooperatively with staff from ENG; the Office of Budget, Finance, and Award Management (BFA); the Office of General Counsel; the Office of Legislative and Public Affairs; and the Chief Officer for Research Facilities in NSF's Office of the Director. Within BFA, the Large Facilities Office (LFO) provides advice to program staff and assists with agency oversight and assurance.
- External Structure: Each NHERI awardee is led by a principal investigator (PI), who is responsible for the overall award operations. The NCO awardee coordinates NHERI governance and network activities. Governance is comprised of the following groups: (a) a Council, which consists of the PI of each NHERI award, to provide collective and coordinated leadership for NHERI as a national facility; (b) Network Independent Advisory Committee (appointed by the NCO), with diverse representation from the broad scientific and engineering communities served by NHERI, to provide independent external guidance and advice to the Council; (c) User Forum, consisting of representatives from the broad scientific and engineering communities served by NHERI; and (d) Council-identified committees, comprised of internal awardee staff and/or users, to advise the Council on community priorities and needs for NHERI.
- Oversight: NSF provides oversight to NHERI awardees through 11 cooperative agreements. Awardee operations and activities are reviewed through monthly calls with the NHERI Council, quarterly and annual project reports (for the 11 cooperative agreements) submitted by awardees, which include metrics, annual work plans, project usage, and expenditures. In addition, NSF conducts annual reviews of the NCO, CI, SimCenter and RAPID facilities and through periodic site visit and reverse site visit reviews for the seven experimental sites.

Studies

- In FY 2010, NSF supported two studies to assess the need for earthquake engineering experimental and cyberinfrastructure facilities beyond 2014, as described in the Dear Colleague Letter (DCL) NSF 10-071.[1] One study, a workshop held by the National Research Council on Grand Challenges in Earthquake Engineering Research, was completed in FY 2011, and the second study was completed in FY 2012. These studies provided input to NSF for the determination of support for future earthquake engineering research infrastructure beyond FY 2014. The plan to support a smaller "second generation" Network for Earthquake Engineering Simulation (NEES) (NEES2) during FY 2015-2019 was presented to the National Science Board at their July 2012 meeting and described in DCL NSF 12-107.[2] The plan



The above image displays the University of California, San Diego outdoor shake table, which allows large structures to be tested against seismic activity. Here, a wooden building shows damage after testing. *Credit: UCSD/Jacobs School of Engineering.*

[1] www.nsf.gov/pubs/2010/nsf10071/nsf10071.jsp
[2] www.nsf.gov/pubs/2012/nsf12107/nsf12107.jsp

proposed a lower annual operations budget, reflected in the $8.0 million reduction from FY 2014 in NSF's FY 2015 Budget Request, from $20.0 million to $12.0 million, to allow larger investment in earthquake engineering research using NHERI facilities.

- In 2012, the National Institute of Standards and Technology and NSF jointly supported a workshop that led to a roadmap report for measurement science research and development for windstorm and coastal inundation impact reduction, which was published in January 2014.[3]
- In February 2013, NSF released solicitation NSF 13-537 to compete and operate NEES2 for FY 2015-FY 2019. Based on the merit review of proposals submitted under NSF 13-537, NSF made no award.
- Based on the above studies and report, NSF established the plan for NHERI in FY 2014. This led to the release of solicitations, NSF 14-605 and NSF 15-598, to establish 11 NHERI cooperative agreements through two competitions. Those competitions were completed in FY 2016. The 11 awards for NHERI operations involve commitments for five years, contingent on available funds and satisfactory performance.

Renewal/Recompetition/Termination

During FY 2019, the NSF Director granted ENG approval to extend NHERI through September 30, 2025, through support of renewal proposals to be submitted during 2020 and 2021 by the 11 NHERI cooperative agreement awardees, pending the outcomes of external merit review and available funds.

[3] www.nist.gov/customcf/get_pdf.cfm?pub_id=915541

OCEAN OBSERVATORIES INITIATIVE (OOI) **$43,000,000**
-$1,010,000 / -2.3%

Ocean Observatories Initative Funding
(Dollars in Millions)

FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
$44.01	-	$43.00	-$1.01	-2.3%

OOI is a networked observatory that includes deployed ocean instrumentation delivering long-term, time-series ocean data sets for multidisciplinary oceanographic research. All data and metadata are openly available to the public at the OOI website.[1]

In 2020, the OOI consists of a system of five arrays of instrumented platforms located at critical locations in the ocean and a cyberinfrastructure to deliver the data. The five arrays include:

- Two Global Arrays:
  - Station Papa Array in the Gulf of Alaska
  - Irminger Sea Array off Greenland.
- One Regional Cabled Array which supports seafloor and water column instrumentation and platforms on the continental shelf, slope, and in the ocean basin off the coast of Oregon and Washington.
- Two Coastal Arrays:
  - Endurance Array composed of two lines of moorings, one off the Washington coast and one off the Oregon coast with glider coverage around, along, and between these lines.
  - Pioneer Array composed of a rectangular array of moorings, gliders, and Autonomous Underwater Vehicles (AUVs) deployed on the continental shelf/slope 55 nautical miles south of Martha's Vineyard, MA.

Data from the OOI instruments are processed, stored, displayed, and served by the OOI Cyberinfrastructure. Users can view and download raw data and data products through the OOI Data Portal.[2]

The OOI facility supports user needs to conduct research and education across a wide range of science themes, within an expandable observing infrastructure spanning widely-differing ocean domains. The OOI infrastructure supports scientific instrumentation providing interdisciplinary measurements to investigate a spectrum of phenomena and processes including episodic, short-lived events (meteorological, tectonic, volcanic, geological, geophysical, and ecological), and subtler, long-term changes and emergent phenomena in ocean systems (circulation patterns, climate change, ocean acidification, geophysical events, and ecosystem trends).

The overarching scientific themes of the OOI span six multi-disciplinary domains, and each theme incorporates a multitude of research questions.

- *Ocean-Atmosphere Exchange*. Quantifying the air-sea exchange of energy and mass, especially during high winds, is critical to providing estimates of energy and gas exchange between the surface and deep ocean, and improving the predictive capability of storm forecasting and climate change models.
- *Climate Variability, Ocean Circulation, and Ecosystems*. As both a reservoir and distributor of heat and carbon dioxide, the ocean modifies climate, and is also affected by it. Understanding how climate variability will affect ocean circulation, weather patterns, the ocean's biochemical environment, and marine ecosystems is a compelling driver for multidisciplinary observations.

[1] www.oceanobservatories.org
[2] www.oceanobservatories.org/data-portal/

- *Turbulent Mixing and Biophysical Interactions*. Mixing occurs over a broad range of scales and plays a major role in transferring energy, materials, and organisms throughout the global ocean. Mixing has a profound influence on primary productivity, plankton community structure, biogeochemical processes (e.g., carbon sequestration) in the surface and the deep ocean, and the transport of material to the deep ocean.
- *Coastal Ocean Dynamics and Ecosystems*. Understanding the spatial and temporal complexity of the coastal ocean is a long-standing challenge. Quantifying the interactions between atmospheric and terrestrial forcing, and coupled physical, chemical, and biological processes is critical to elucidating the role of coastal margins in the global carbon cycle and developing strategies for managing coastal resources.
- *Fluid-Rock Interactions and the Subseafloor Biosphere*. The oceanic crust contains the largest aquifer on Earth. Thermal circulation and reactivity of seawater-derived fluids modifies the mineralogy of oceanic crust and sediments, leads to the formation of hydrothermal vents that support unique micro- and macro-biological communities, can form economically-important mineral deposits, and concentrates methane to form massive methane gas and methane hydrate reservoirs. The role that transient events (e.g., earthquakes, volcanic eruptions, and slope failures) play in these fluid-rock interactions and in the dynamics of benthic and sub-seafloor microbial communities remain largely unknown.
- *Plate-Scale, Ocean Geodynamics*. Lithospheric movements and interactions at plate boundaries at or beneath the seafloor are responsible for short-term events such as earthquakes, tsunamis, and volcanic eruptions. These tectonically active regions are also host to the densest hydrothermal and biological activity in the ocean basins. The degree to which active plate boundaries influence the ocean from a physical, chemical, and biological perspective are largely unexplored.

<u>Current Status</u>

The OOI Program Team successfully completed the FY 2019 Annual Work Plan (AWP) and is currently executing the FY 2020 AWP by operating the in-water instrumentation and completing retrieve/replace at-sea operations on an annual basis for the Global Arrays and the Regional Cabled Array, and on a semi-annual basis for the Coastal Arrays. The OOI Team is conducting quality assurance (QA) and quality control (QC) on the ocean data streams and delivering both raw data and processed datasets and data products to the public via the website. During FY 2019, the OOI website received a significant level of visits with up to 50 users and 135 pageviews per day, with a high precentage being new visitors. The OOI Program Team has made extensive progress in increasing community engagement and has develped and is agressively executing a new community engagment plan, which includes active outreach by the OOI science team to the science community on the QA/QC methods and procedures being used.

Operations plans at the FY 2021 Request level of $43.0 million will be developed in partnership with the awardee and the research community to minimize costs, assess impacts of any proposed de-scope activities, and maximize the scientific return of the facility.

Total Obligations for OOI

(Dollars in Millions)

	FY 2019	FY 2020	FY 2021	ESTIMATES[1]				
	Actual	(TBD)	Request	FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Operations & Maintenance	$44.01	-	$43.00	$43.00	$43.00	$43.00	$43.00	$43.00

[1] Outyear estimates are for planning purposes only. The current cooperative agreement ends September 2023.

After approval of a resolution in May 2018 by the National Science Board, NSF entered into a new cooperative agreement with the Woods Hole Oceanographic Institution (WHOI) for operation and management of the OOI and management responsibilities were transferred from the Consortium for Ocean

Leadership to WHOI on October 1, 2018. WHOI has major sub-awardees on the OOI Program Team to operate and maintain the marine infrastructure, manage the scientific data, and operate the cyberinfrastructure. The University of Washington operates the OOI Cabled Array. Oregon State University operates the Coastal Endurance Array. WHOI operates the Pioneer Coastal Array as well as the Global Arrays at the two remaining OOI global sites in the Irminger Sea and the Gulf of Alaska, and also serves as the overall Program Management Office (PMO). Management of OOI data is now distributed among the University of Washington, Oregon State University, and WHOI. Rutgers University manages the cyberinfrastructure hardware and WHOI manages the cyberinfrastructure software with support from Raytheon Corporation.

Management and Oversight

- NSF Structure: The Division of Ocean Sciences (OCE) in GEO manages OOI operations located within the Integrative Programs Section (IPS). The oversight, conducted through a coordinated effort between the IPS Section Head and the Ocean Sciences Section Head, includes the review of observatory metrics and data quality management, as well as integration of the OOI with any new science or infrastructure proposals and coordination with the science community. Additional NSF oversight of the OOI program is provided by the Integrated Project Team whose core members include the IPS Section Head, the Ocean Sciences Section Head, the Facilities Expert in OCE; the liaison from the Large Facilities Offce; the Grants and Agreements Officer from the Cooperative Support Branch; and a representative from CISE's Office of Advanced Cyberinfrastructure.
- External Structure: The awardee has a Science Oversight Committee (SOC) that provides input and guidance internally to WHOI for OOI infrastructure planning and management. NSF established the nine-member Ocean Observatories Initiative Facility Board (OOIFB) to provide input and guidance to NSF regarding the operation and management of the OOI. The OOIFB is independent of the SOC and held several meetings during FY 2019.
- Reviews: In October 2019, NSF conducted an External Panel OOI Program Annual Review on-site at WHOI, which was a focused review of the data distribution and cyberinfrastructure and community engagement aspects of the OOI program.

<u>Operations Costs</u>
The associated costs for Operations and Maintenance (O&M) of OOI infrastructure in support of scientific research have been and will continue to be solely supported by OCE. Support for scientific research using observatory data will be through the standard NSF proposal submission process to existing science programs in OCE. Since the data are openly available over the internet, researchers around the world also have access to the unique data sets that OOI is producing regardless of the source of their support.

<u>Education and Outreach</u>
The OOI website and cyberinfrastructure provides a portal to enable access to information related to the OOI arrays, science themes, marine technologies, latest research highlights, and live streaming video when available for use in education settings. The internal OOI SOC actively conducts outreach activities regarding the ocean science datasets to researchers, public, and education users.

Renewal/Recompetition/Termination

The new five-year OOI O&M cooperative agreement with WHOI began on October 1, 2018. In preparation for the next recompetition in FY 2022, NSF will continue to conduct an annual program review and engage with the OOIFB to receive input from the Ocean Sciences community. In addition, NSF will hold a focused mid-award program review in 2021 of the performance of the awardee. The information from these activities will be used to determine whether to proceed with renewal or recompetition.

SEISMOLOGICAL FACILITY FOR THE ADVANCEMENT OF GEOSCIENCE (SAGE) **$22,000,000**
+$6,320,000 / 40.3%

Seismological Facility for the Advancement of GEosciences Funding
(Dollars in Millions)

FY 2019[1] Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
$15.68	-	$22.00	$6.32	40.3%

[1] FY 2019 Actual obligations reflect part of an operating year as funding for the continuing agreement was re-phased for continuity of operations into FY 2020.

The Seismological Facility for the Advancement of GEoscience comprises a distributed, multi-user, national facility for the development, deployment, and operational support of modern digital seismic instrumentation to serve national goals in basic research and education in the earth sciences, earthquake research, global real-time earthquake monitoring, and nuclear test ban verification. SAGE is managed and operated for NSF by the Incorporated Research Institutions for Seismology (IRIS), a consortium of 125 U.S. universities and non-profit institutions with research and teaching programs in seismology, 21 educational affiliates, three U.S. affiliates, and 128 foreign affiliates. SAGE was formed in late FY 2013 from the seismic components of the EarthScope facility and seismic facilities previously managed by IRIS. The FY 2021 Request will enable SAGE to provide key services for the geoscience research community, including global and regional observing networks, field and technical support for experiments worldwide, data management and distribution systems, and other related activities.

Total Obligations for SAGE
(Dollars in Millions)

	FY 2019 Actual[1]	FY 2020 (TBD)	FY 2021 Request	ESTIMATES[2] FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Operations & Maintenance	$15.68	-	$22.00	$19.48	$15.00	$15.00	$15.00	$15.00

[1] FY 2019 Actual obligations reflect part of an operating year as funding for the continuing agreement was re-phased for continuity of operations into FY 2020.

[2] Outyear estimates are for planning purposes only. The current cooperative agreement ends September 2023.

For information on continuity of operations funding, see the opening narrative of this chapter.

The Earth's interior remains a major scientific frontier holding the key to understanding the origin of the planet. Recent developments in seismic sensor design and the acquisition, transmission, and storage of data have resulted in dramatic improvements in the resolving power of seismic imaging of the interior of the Earth. To serve the research needs of the broad Earth science community, SAGE is organized under three primary service areas:

Instrumentation Services

- The Global Seismographic Network (GSN) consists of over 150 permanently-installed broadband digital seismic stations, most of which have real-time data access. GSN stations provide critical data for a range of global Earth science research and support key national security needs such as nuclear test-ban treaty verification and natural hazards warning and response. GSN is operated in partnership with the U.S. Geological Survey (USGS).
- Portable Seismology (PS) includes a pool of over 5,200 portable seismometers that are made available to the Earth science research community for a wide range of principal investigator-driven experiments largely funded through the NSF merit review process to study a wide range of Earth processes.

- Polar Support Services supports the development of specialized seismic equipment for use in harsh environments and provides instrumentation, training, and field support for experiments in the polar regions.
- The Transportable Array (TA) is a continental-scale seismic observatory designed to provide a foundation for multi-scale integrated studies of continental lithosphere and deep Earth structure. After operating 1,700 stations in the lower 48 states between 2004 and 2015, the full 280-station TA network is now deployed in Alaska and western Canada. The TA stations collect data for use in studies of natural hazards including earthquakes, volcanoes, and tsunami; the plate tectonic process that have formed Alaska; Earth's magnetic field; and Earth's changing climate. NSF is in the process of transferring adopted stations to other Federal agencies for long-term operations and maintenance. Stations that are not adopted will be decommissioned in FY 2020 and FY 2021.
- The Magnetotelluric component exploits the natural variations in Earth's magnetic and electric fields to provide information on the distribution and composition of fluids in Earth's crust and upper mantle, which gives constraints on Earth's structure that are complementary to those resulting from seismology.
- Instrumentation Services-Coordinated Activities include efforts to develop the next generation of seismic instrumentation for large-scale scientific experiments; global-scale geophysical networks; and training courses to distribute best practices to partners worldwide.

<u>Data Services</u>
SAGE Data Services (DS) manages an archive of over 540 terabytes of seismic, magnetotelluric, and other data from all SAGE components, the EarthScope program, and numerous affiliated networks; operates automated and manual systems to ensure the quality of all data stored in the archive; and provides systems to give the national and international research community timely access to these data. In FY 2019, more than 22,000 unique users downloaded data from the SAGE archive. These data are used for a wide range of applications, including research and education.

<u>Education and Public Outreach</u>
The SAGE Education and Public Outreach program enables audiences beyond seismologists to access and use seismological data and research, including student internships, and programs for under-resourced educational institutions.

In addition to the three services mentioned above, the capabilities that SAGE provides have extensive societal impacts and supplement existing hazard monitoring efforts by US state and federal agencies. SAGE provides key seismic-related infrastructure support to the USGS and National Oceanic and Atmospheric Administration (NOAA). The SAGE Global Seismographic Network is co-funded with support from the USGS and enables earthquake and tsunami hazard warning and monitoring by USGS and NOAA, while also supporting the International Monitoring System that informs the Comprehensive Nuclear Test Ban Treaty Organization. SAGE instrumentation also aids in USGS volcano hazard studies. The magnetotelluric studies enabled by SAGE, which measure electromagnetic fields in the Earth, are being used to mitigate damage to the U.S. power grid associated with potential space weather events.

The SAGE facility is used by researchers supported by programs in the Division of Earth Sciences (EAR) and other divisions in GEO; including Geophysics, Tectonics, Frontier Research in Earth Sciences, GeoPRISMS, Marine Geology and Geophysics Programs, and the Earth Sciences Program and the Glaciology Program in the Antarctic Sciences Section of OPP. For NSF-sponsored research, SAGE supports deployment of portable seismic instruments and use of data managed by DS to solve major Earth science problems.

Management and Oversight

- NSF Structure: EAR in GEO, through its Instrumentation & Facilities program, provides general oversight of SAGE to help assure effective performance and administration. The program also facilitates coordination of SAGE programs and projects with other NSF-supported facilities, and with other federal agencies, and evaluates and reviews the performance of IRIS in managing and operating SAGE. In addition, an integrated project team consisting of representatives from EAR, BFA Division of Acquisition and Cooperative Support, and BFA Large Facilities Office work with the cognizant program officer in addressing challenges and identifying potential barriers to success. The EAR Division Director and Integrated Activities Section Head provide other internal oversight.
- External Structure: SAGE is managed and operated by IRIS, which is incorporated as a non-profit consortium representing 125 U.S. universities and non-profit organizations with research and teaching programs in seismology. Each voting member institution of the Consortium appoints a member representative, and these member representatives elect the nine members of the IRIS Board of Directors. The Board members, who serve three-year terms, vet all internal program decisions associated with SAGE management and operation, through consultation with IRIS staff and SAGE advisory committees (one for each major SAGE component and additional *ad hoc* working groups appointed for special tasks). The Board of Directors appoints a president of IRIS to a renewable two-year term. The president is responsible for IRIS operations, all of which are managed through the IRIS Corporate Office located in Washington, DC.
- Reviews: In FY 2019 EAR conducted a joint review of the data services activities of SAGE and its geodetic facility counterpart Geodetic Facility for the Advancement of GEoscience (GAGE).

Renewal/Recompetition/Termination

A successful NSF merit review of the proposal for the SAGE facility took place in 2017 and 2018, and funding for the current SAGE cooperative agreement began in FY 2019 and will end in FY 2023. In preparation for the next recompetition that would begin in FY 2022, NSF is gathering input through several mechanisms. First, NSF requested the National Academy of Science, Engineering, and Medicine to explore different models to manage geophysical capabilities needed by the Earth Sciences community as one component of the decadal study "*Catalyzing Opportunities for Research in Earth Sciences*".[1] The report from the workshop that explored different models can be found at https://www.nap.edu/catalog/25536. Second, NSF is convening an interagency working group to identify the needs other agencies have for the capabilities currently provided by SAGE and GAGE. Lastly, NSF will use internal processes to assess facility capabilities. The information from these activities will be used to draft the solicitation requesting proposals to support geophysical capabilities for EAR-funded research and education.

[1] www8.nationalacademies.org/pa/projectview.aspx?key=51287

FEDERALLY FUNDED RESEARCH AND DEVELOPMENT CENTERS (FFRDCS)

GREEN BANK OBSERVATORY (GBO)

$7,300,000
-$2,960,000 / -28.8%

Green Bank Observatory Funding
(Dollars in Millions)

FY 2019 Actual[1]	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
$10.26	-	$7.30	-$2.96	-28.8%

[1] Includes $2.17 million for continuity of operations into FY 2020.

GBO is a major NSF research facility and a Federally Funded Research and Development Center (FFRDC) located in Green Bank, West Virginia. It is operated by Associated Universities, Inc. (AUI) under a cooperative agreement with NSF. GBO enables leading ground-based research at radio wavelengths by offering access to telescopes, facilities, and advanced instrumentation to the U.S. scientific community, and it conducts an active program of education and public outreach. GBO is also the administrative site of the 13,000-square-mile National Radio Quiet Zone, where all radio transmissions are limited. Having telescopes within this quiet zone allows detection of faint astronomical signals that would otherwise be overwhelmed by anthropogenic radio signals.

The main scientific instrument at GBO is the 100-m Robert C. Byrd Green Bank Telescope (GBT), which became fully operational in 2002. The GBT is the world's largest fully steerable single-dish radio telescope, operating at frequencies from 0.2 GHz to 116 GHz. Its large sky coverage, very high sensitivity, and extensive suite of instruments make it a powerful and versatile telescope which enables advances in virtually all areas of modern astrophysics. The GBT offers excellent complementarity and synergy with interferometric arrays, such as the Very Large Array, the Very Long Baseline Array, and the Atacama Large Millimeter/submillimeter Array. It also plays a critical supporting role as a highly sensitive element of very long baseline interferometry, as well as a bistatic radar receiver for rapid and sensitive imaging of near-Earth objects and asteroids.

As recommended by the National Academies of Science, Engineering and Medicine's 2010 Decadal Survey of astronomy and astrophysics, the MPS Division of Astronomical Sciences (AST) conducted a community-based review of its portfolio in 2012. The Portfolio Review Committee recommended divestment of the GBT from AST funding because the strengths of the GBT were less aligned with the scientific priorities of the 2010 Decadal Survey compared to several other facilities. While affirming the need for divestment, subsequent reviews (e.g., the March 2016 and March 2017 reports of the Astronomy and Astrophysics Advisory Committee,[1] and the August 2016 mid-decadal report of the National Academies[2]) acknowledged the adverse impact of the potential loss of facilities like the GBT on the scientific community and suggested that NSF first consider collaborations with interested partners rather than complete closure of its facilities. NSF's response to this broad community input, starting with the 2012 Portfolio Review, included a multi-year comprehensive environmental review to assess the impact of various divestment options, as well as steps to allow greater flexibility for exploring cost-efficient operational models and sustainable partnerships for GBO.

In July 2019, after considering scientific priorities, budgetary constraints, viability of potential partnerships,

[1] www.nsf.gov/mps/ast/aaac/archived_aaac_annualreports.jsp
[2] www.nap.edu/catalog/23560/new-worlds-new-horizons-a-midterm-assessment

and the results of a comprehensive environmental review, NSF issued a Record of Decision (ROD) that included continued GBO operations with reduced NSF funding and increased partner contributions. Following issuance of the ROD and merit review of a proposal for operations and management of GBO, NSF awarded a new five-year cooperative agreement to AUI for the period FY 2020-FY 2024. Combined support from NSF, external partnerships, and other funding sources will keep GBO vital for scientific progress.

Total Obligations for Green Bank Observatory

(Dollars in Millions)

	FY 2019 Actual[1]	FY 2020 (TBD)	FY 2021 Request	ESTIMATES[2] FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Operations & Maintenance	$10.26	-	$7.30	$7.12	$7.33	$7.55	$7.55	$7.55

[1] Includes $2.17 million for continuity of operations into FY 2020.

[2] Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in FY 2024.

For information on continuity of operations funding, see the opening narrative of this chapter.

GBO Operations and Maintenance

The FY 2021 Request of $7.30 million encompasses support for direct telescope operations at GBO, including maintenance, infrastructure upgrades, and telescope management, as well as funds allocated for education and public outreach.

Partnerships and Other Funding Sources

In FY 2019, GBO received approximately $4.30 million from other sources, mostly from non-federal partners, including Breakthrough Listen, West Virginia University, and the NSF-funded North American Nanohertz Observatory for Gravitational Waves (NANOGrav) consortium. External (non-NSF) contributions represented approximately 35 percent of the total operations budget of GBO. These long-standing partnerships are anticipated to continue over the period FY 2020-FY 2024. Many of the GBO partnerships involve guaranteed allocations of observing time on the GBT in exchange for operations funding. Other partnership development efforts are continuing.

Management and Oversight

- NSF Structure: An AST program officer carries out continuing oversight and assessment for GBO by making use of detailed annual program plans, technical and financial reports, and annual reports submitted to NSF. The AST program officer attends AUI governance and advisory committee meetings. To address issues as they arise, NSF has an Integrated Project Team for GBO, which includes representatives from other NSF offices, such as the Office of General Counsel, as well as the Division of Acquisition and Cooperative Support and the Large Facilities Office in BFA. The MPS Facilities team, together with the NSF Chief Officer for Research Facilities, also provide high-level guidance.
- External Structure: Management is through a cooperative agreement with AUI. AUI manages GBO through its own community-based oversight and users committees. The GBO director reports directly to the AUI Vice President for Radio Astronomy.

- Reviews: NSF conducts annual reviews of the program operating plan and reports, including external advice from community representatives. The first review under the new cooperative agreement is scheduled for Fall 2020.


Views showing the Green Bank Telescope in the Fall (left) as well as the unblocked aperture and fully steerable structure (right). *Credit: GBO/AUI.*

Renewal/Recompetition/Termination

GBO is currently supported through a cooperative agreement. NSF received a proposal from AUI in March 2019 for the operations of GBO for a five-year period. The proposal was reviewed by an external review panel and the award was made October 1, 2019. The award enables continued operations and further development of GBO from FY 2020 to FY 2024.

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH (NCAR) **$103,700,000**
-$48,740,000 / -32.0%

National Center for Atmospheric Research Funding
(Dollars in Millions)

FY 2019 Actual[1]	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
$152.44	-	$103.70	-$48.74	-32.0%

[1] FY 2019 Actual obligations include $17.80 million for continuity of operations into FY 2020 as well as $30.94 million in funds reobligated from prior award.

NCAR is an NSF-sponsored FFRDC serving a broad research community, including atmospheric and geospace scientists and researchers in complementary areas of the environmental sciences and geosciences. Based in Boulder, Colorado, NCAR is managed under a cooperative agreement between NSF and the University Corporation for Atmospheric Research (UCAR), a university-governed and university-serving organization comprising 117 degree-granting academic institutions.

NCAR provides world-class research programs, services, and facilities that enable the research community to advance our understanding of the sun-atmosphere system. These include the 534-petaflops NCAR-Wyoming Supercomputing Center, the Mauna Loa Solar Observatory, two research aircraft, a transportable ground-based radar system, an atmospheric sounder, and other surface sensing systems. NCAR staff work in close partnership with academic and other researchers. In 2019, 93 percent of NCAR's 746 peer-reviewed publications were published in collaboration with authors at other institutions, and NCAR hosted 1,119 academic visitors from 343 different institutions.

Total Obligations for NCAR
(Dollars in Millions)

	FY 2019	FY 2020	FY 2021	ESTIMATES[2]				
	Actual[1]	(TBD)	Request	FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Aircraft Support	$11.00	-	$10.50	$10.50	$10.50	$10.50	$10.50	$10.50
Computational Infrastructure	37.70	-	33.70	33.70	33.70	33.70	33.70	33.70
Other Facility Support	31.09	-	27.50	27.50	27.50	27.50	27.50	27.50
Research & Education Support	41.71	-	32.00	32.00	32.00	32.00	32.00	32.00
Facility Upgrades	30.94	-	-	-	-	-	-	-
Total	**$152.44**	**-**	**$103.70**	**$103.70**	**$103.70**	**$103.70**	**$103.70**	**$103.70**

[1] FY 2019 Actual obligatons include $17.890 million for continuity of operations into FY 2020 as well as $30.94 million in funds reobligated from prior award.

[2] Outyear estimates are for planning purposes only. The current cooperative agreement ends September 2023.

For information on continuity of operations funding, see the opening narrative of this chapter.

Facility Upgrades: In FY 2018, NSF awarded $26.64 million for essential upgrades to NCAR's facilities and programs. This includes a major renovation of the Research Aviation Facility, which is now underway.

<u>Partnerships and Other Funding Sources</u>
NCAR leverages NSF support with funding provided by other federal agencies and non-federal sources. In FY 2019, NCAR received approximately $49.76 million in support from other federal agencies, including the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric

Administration (NOAA), the Department of Energy (DOE), the Department of Defense (DOD), and the Federal Aviation Administration (FAA), and $11.58 million from non-federal sources. This funding supports research collaborations that directly enhance NCAR's NSF-sponsored research and facilities.

Major Investments in FY 2021

In FY 2021, investments at NCAR will focus on fundamental research aimed at improving our ability to predict atmospheric, chemical, and space weather hazards, and increasing our understanding of the variability in the Earth's climate system at regional and global scales. In all of these areas, NCAR scientists will work with their university colleagues to further understand the fundamental processes that control the Earth's climate and weather systems. This will include research thrusts in areas such as the role of the chemical composition of the atmosphere, the structure and nature of hurricanes and other severe weather events, and the impacts of processes on the surface of the Sun on space weather and weather on Earth. A continuous process of community prioritization will inform activities undertaken in FY 2021.

Advanced Observational Facilities

NCAR operates two NSF aircraft: a C-130Q Hercules and a Gulfstream-V, both of which are highly modified and equipped with specialized instrumentation, to enable the support of research activities designed to provide new insights into atmospheric chemical processes, the dynamics and coupling of the atmosphere's layers, and interactions between the atmosphere and Earth's surface. The two aircraft will support community-originated projects deemed by NSF, via separately-managed external peer review, to be of exceptional scientific merit, consistent with the research prioritization mentioned above. In addition to the C-130Q and G-V aircraft, NCAR provides support for a number of other atmospheric and solar observing platforms including specialized Doppler weather radars, lidar systems, upper atmosphere observing capabilities, an advanced coronagraph, and other experimental systems. During 2019, NCAR's aircraft and other facilitites supported community field campaigns that studied lightning, in-cloud icing, lake-system high impact weather, surface-atmosphere heat and water exchange, east Pacific tropical convection, and the total solar eclipse. Instrumentation deployed at the NCAR Mauna Loa Solar Observatory monitors the entire solar atmosphere and its critical magnetic environment. These observations are broadly used to improve fundamental understanding of solar activity, space weather, and solar storm characterization, and to better inform forecasts of the latter which can result in the disruption to critical civilian (and military) infrastructure.

Petascale Computational Infrastructure

NCAR operates a petascale supercomputing facility in Cheyenne, Wyoming (the NCAR-Wyoming Supercomputing Center), that supports high-end community modeling and data analysis programs in atmospheric, solar, and other Earth Systems processes and has over 1,800 unique users. These include the Community Earth System Model , the Weather Research and Forecasting Models (WRF), and the Model for Prediction Across Scales, which use mathematical formulas to simulate and better understand the chemical and physical processes that drive Earth's climate and weather system. NCAR leads the development of these community models and supports many thousands of researchers in the U.S. and worldwide—for example, in 2019, the cumulative number of registered WRF users exceeded 48,600, and was growing by an average of 4,100 per year. NCAR also maintains extensive data archives, providing access to a vast collection of observational, experimental, and modeling data, together with sophisticated analysis and visualization facilities, and training and support for users of all levels.

Research and Education Support

As an internationally recognized center of excellence, NCAR operates scientific research programs that include the following areas:

- studies of large-scale atmospheric and ocean dynamics that contribute to an understanding of the past and present Earth System processes;
- global and regional atmospheric chemistry, including atmospheric connections to geochemical and

biogeochemical cycles;
- the variable nature of the sun and the physics of the corona and the interaction of the solar wind with the Earth's magnetic field;
- the physics of clouds, thunderstorms, precipitation formation, and their interactions and effects on local and regional weather; and
- examination of human society's impact on atmospheric composition, weather, and climate, and response to global environmental change.

Research collaborations with university colleagues are integral to NCAR's success as an institution, and NCAR serves as a focal and meeting point for the broader atmospheric and related sciences community. NCAR also maintains extensive partnerships and collaborations with the private sector through directed research and technology transfer. This work focuses on developing information and analysis platforms tailored to the specific needs of stakeholders in a variety of sectors, including energy, aviation, and agriculture.

Educational activities include the SOARS (Significant Opportunities in Atmospheric Research and Science) program that integrates research, education, and mentoring to bridge the undergraduate-to-graduate transition and to broaden participation in the atmospheric and related sciences. NCAR further supports the scientific community by providing fellowships, internships, workshops, and colloquia for students and visiting scientists, and disseminates knowledge of the geosciences. Professional training courses, innovative and award-winning science education websites, as well as the directed activities of NCAR's education and outreach programs, are further examples of how NSF's goal of integrating research and education is attained through NCAR activities.

Management and Oversight

- NSF Structure: NSF's Division of Atmospheric and Geospace Sciences (AGS) within GEO, the Division of Acquisition and Cooperative Support (DACS), and the Large Facilitities Office (LFO) oversee NCAR and the cooperative agreement under which UCAR manages NCAR. The cooperative agreement encourages interactions between NCAR scientists and AGS staff and ensures close coordination between AGS and NCAR management. The cooperative agreement contains requirements for AGS's oversight of the NCAR program and UCAR management activities that affect NCAR. UCAR submits for AGS approval an annual program plan for NCAR that details how resources will be used, and an annual report on the previous year's scientific accomplishments and achievements. UCAR also reports annually to NSF on its activities as NCAR's manager. Annual strategic planning by AGS, UCAR, and NCAR ensures that scientific and facility priorities align with those of NSF.
- External Structure: UCAR works in partnership with NSF and the university community to ensure that NCAR's strategic mission is implemented effectively and for the benefit of NCAR's stakeholders in the atmospheric and geospace sciences.
- Reviews: A Committee of Visitors (COVs) is convened periodically to evaluate AGS activities, including the oversight of NCAR. The next AGS COV is expected to take place in FY 2020. In FY 2018, as part of the recompetition process (see below), NSF conducted an extensive review of UCAR's financial viability and accounting systems. No significant issues were raised.
- AGS conducts periodic comprehensive reviews of NCAR's science programs and facilities, and UCAR's management of NCAR. The most recent review was conducted as a series of site visits to NCAR by teams comprising members of the research community with expertise in the atmospheric and related sciences and in the management of scientific centers and facilities. The site visit teams found that NCAR continues to be a world-leading research center, providing essential services and capabilities that foster excellence throughout the atmospheric and geospace sciences community.

Renewal/Recompetition/Termination

The cooperative agreement for the management and operation of NCAR was recently recompeted. Following an extensive and robust proposal review process, a new award was made to UCAR. This award began on October 1, 2018, and is for five years, extendable for a further five years subject to satisfactory performance. The decision on whether to extend the award will be based upon the outcome of a comprehensive review of NCAR's science programs and management that is expected to be held at approximately the mid-point of the award, during FY 2021.

The NCAR Mesa Laboratory, designed by architect I.M. Pei, in Boulder, CO. *Credit: UCAR.*

NATIONAL RADIO ASTRONOMY OBSERVATORY (NRAO) **$88,130,000**
-$6,910,000 / -7.3%

National Radio Astronomy Observatory Funding[1]
(Dollars in Millions)

FY 2019 Actual[2]	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
$95.04	-	$88.13	-$6.91	-7.3%

[1] This table aggregates the request NRAO and ALMA base operations.
[2] Includes $8.09 million for continuity of operations into FY 2020.

NRAO conceives, designs, builds, operates, and maintains state-of-the-art radio telescopes used by scientists from around the world. Operating synergistically with optical, infrared, x-ray, gamma-ray, and gravitational wave telescopes, NRAO facilities enable discovery over a remarkably broad range of key problems in modern astrophysics that reach from within our solar system to the most distant galaxies in the universe. Using NRAO observing capabilities and data archives, scientists: carry out precision cosmological measurements; test fundamental physics; probe deep into the earliest, most intense, and optically obscured phases of planet, star, galaxy, and black hole formation; reveal the cool gas from which stars form; provide essential tools for studying magnetic fields and high-energy cosmic phenomena; and seek to detect the sources of gravitational waves.

As a Federally Funded Research and Development Center headquartered in Charlottesville, Virginia, NRAO operates the Karl G. Jansky Very Large Array (VLA) near Socorro, New Mexico; the Very Long Baseline Array (VLBA), with 10 sites throughout the continental United States, Hawaii, and the U.S. Virgin Islands; and is the North American implementing organization for the international Atacama Large Millimeter/submillimeter Array (ALMA) in Chile. In support of these radio telescopes, NRAO also operates the Central Development Laboratory (CDL) in Charlottesville, which develops next-generation electronics and detectors for radio astronomy. These observing facilities for radio astronomy are available to any qualified researcher, regardless of affiliation or nationality, on the basis of scientific, merit-reviewed proposals. In addition to conducting NSF-funded astrophysical observations, the VLBA is used for fundamental support of the International Celestial Reference Frame, under an agreement with the United States Naval Observatory (USNO). NRAO facilities annually serve over 2,500 users worldwide; moreover, continued high demand for ALMA has resulted in the most proposals ever received for an astronomical facility in response to a single proposal call.

NRAO facilities have enabled a remarkable array of ground-breaking discoveries in the last year alone, ranging from imaging storms on Jupiter to radio detections of merging neutron stars, which are multi-messenger events. The most impressive scientific result, fundamentally enabled by the inclusion of ALMA as a cornerstone of the Event Horizon Telescope effort, was the direct imaging of a black hole event horizon. This result is already seen as one of the great scientific achievements of the century, and would not have been possible without utilization of ALMA and the close collaborative effort between the United States, international communities, and NRAO. The VLA and ALMA produced a stream of ground-breaking results in the fields of star and planet formation and astrochemistry over the last year. For example, the combination of high-resolution ALMA dust imaging and Very Large Telescope imaging of the ionized gas in the protoplanetary system, PDS 70, has shown evidence for accretion onto planets themselves, for the first time. The CDL has continued to excel in its mission to support the evolution of NRAO facilities by developing the technologies and expertise critical for the next generation of radio astronomy instrumentation.

In September 2017, Hurricane Maria damaged the VLBA facility on St. Croix, Virgin Islands. Funding for repairs was provided in the Further Additional Supplemental Appropriations for Disaster Relief Requirements Act of 2018 (P.L. 115-123). Of the total $16.30 million provided for observatory repairs, $2.0 million was identified for NRAO and obligated in FY 2018. These repairs are scheduled for completion in FY 2020.

Total Obligations for NRAO
(Dollars in Millions)

	FY 2019 Actual[1]	FY 2020 (TBD)	FY 2021 Request	ESTIMATES[2] FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Operations & Maintenance[3]	$49.83	-	$39.45	$40.53	$40.96	$39.10	$40.19	$41.31
Telescope Operations	*14.24*	-	*11.28*	*11.60*	*11.72*	*11.18*	*11.50*	*11.82*
Development	*9.81*	-	*7.77*	*7.98*	*8.07*	*7.70*	*7.92*	*8.14*
Science Operations	*8.03*	-	*6.35*	*6.53*	*6.59*	*6.30*	*6.47*	*6.65*
Administrative Services	*13.60*	-	*10.77*	*11.06*	*11.18*	*10.67*	*10.97*	*11.28*
Directors Office	*3.15*	-	*2.49*	*2.55*	*2.58*	*2.46*	*2.53*	*2.60*
Education and Public Outreach	*1.00*	-	*0.79*	*0.81*	*0.82*	*0.78*	*0.80*	*0.83*
ALMA Operations	45.21	-	48.68	50.63	52.66	57.77	56.96	59.24
Total	**$95.04**	**-**	**$88.13**	**$91.16**	**$93.62**	**$96.87**	**$97.15**	**$100.55**

[1] Includes $8.09 million for continuity of operations into FY 2020 ($3.16 million for NRAO and $4.93 million for ALMA) and $4.0 million (under NRAO) for development of a next generation Very Large Array (ngVLA).

[2] Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in FY 2026.

[3] Operations funding for VLBA is included in the NRAO total funding at $3.82 million in FY 2019, $3.43 million per year for FY 2020-FY 2022, and then $2.74 million per year for FY 2023-FY 2026.

For information on continuity of operations funding, see the opening narrative of this chapter.

Partnerships and Other Funding Sources

NRAO supplements NSF Division of Astronomical Sciences (AST) support with funding provided by other NSF sources, other federal agencies, and non-federal sources. In FY 2019, NRAO received approximately $100,000 from non-AST sources at NSF, $1.20 million from other federal agencies, and $1.50 million from U.S. universities, foreign scientific and technical institutes, and other non-federal and industrial sources. The development of new telescopes, instrumentation, and sensor techniques is conducted in partnership with relevant industries through competitive sub-awards to various large and small aerospace companies, radio antenna manufacturing firms, and specialized electronics and computer hardware and software companies. USNO provided $4.14 million in funding for the VLBA for FY 2019, $4.19 million for FY 2020, and plans to provide $4.30 million for FY 2021.

Telescope Operations ($11.28 million)

This encompasses support for direct telescope and array operations of the VLA including maintenance, infrastructure upgrades, and telescope management.

Development ($7.77 million)

The FY 2021 Request continues to support development programs including next generation electronics and detectors for radio astronomy, as well as planning and development of technologies for a next-generation centimeter wavelength facility (next generation Very Large Array, or ngVLA).

Science Operations ($6.35 million)

This includes telescope time allocation, staff research, science training and education, and science community outreach.

Administrative Services ($10.77 million)
This includes internal common costs used to allocate common and management expenses across the total pool of observatory activity, such as business services, utilities, and other facility costs at the operating locations, observatory management, and the library.

Director's Office ($2.49 million)
This supports the director's office and managing organization costs.

Education and Public Outreach ($790,000)
NRAO supports a comprehensive outreach program that makes radio astronomy information available to the public.[1] NRAO also supports a visitor and education center and conducts active educational and public outreach programs. The VLA visitor center attracts over 20,000 public visitors each year.

ALMA Operations ($48.68 million)
Operations funding supports a share of observatory operations in Chile, a technical development program, and the North American ALMA Science Center (NAASC) in Socorro, New Mexico. The NAASC provides technical and scientific support for the broad astronomical community that uses ALMA. The NAASC also organizes summer schools, workshops, and courses in techniques of millimeter and submillimeter astronomy.

Management and Oversight

- NSF Structure: In consultation with community representatives, an AST program officer carries out continuing oversight and assessment for NRAO and ALMA by making use of detailed annual program plans, long-range plans, quarterly technical and financial reports, and annual reports. The AST division director participates in the international ALMA Board and attends Associated Universities Incorporated(AUI)/NRAO governance and advisory committee meetings. To address issues as they arise, AST has a dedicated Integrated Project Team which includes representatives from other NSF offices, such as the Office of General Counsel, OISE, and the Division of Acquisition and Cooperative Support and the Large Facilities Office in BFA. The MPS Facilities team and the NSF Chief Officer for Research Facilities also provide high-level guidance, support, and oversight.

ALMA is in science operations following the completion of construction in 2015. An international partnership between North America, Europe, and East Asia, ALMA provides orders-of-magnitude improvement in observing sensitivity and image quality over previous facilities. *Credit: ALMA (ESO/NRAO/NAOJ).*

- External Structure: Management is through a cooperative agreement with AUI, which manages the observatory through its own community-based oversight and users committees. The NRAO director reports to the AUI president. Oversight of the international ALMA project is vested in the ALMA Board, which includes a member from NSF; coordination and management of the merged international efforts are the responsibility of the Joint ALMA Observatory whose staff includes the ALMA director. An international review committee advises the ALMA Board.

[1] https://public.nrao.edu/

- Reviews: NSF conducts annual reviews of the NRAO Program Operating Plan and strategic planning documents, ALMA operations, and the AUI Management Report. A comprehensive mid-term review will be conducted in 2021.

Renewal/Recompetition/Termination

Following a solicitation issued in FY 2014 (NSF 14-568), management and operation of NRAO (including ALMA) was competed and NSB authorized a cooperative agreement with AUI for Oct. 2016 – Sept. 2026.

NATIONAL SOLAR OBSERVATORY (NSO) $21,790,000 +$3,400,000 / 18.5%

National Solar Observatory Funding[1]
(Dollars in Millions)

FY 2019 Actual[2]	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Request Amount	Change over FY 2019 Request Percent
$16.39	-	$21.79	$3.40	18.5%

[1] This table aggregates funding for NSO and DKIST base operations.

[2] Includes $3.50 million in additional FY 2019 one-time funding.

FY 2021 reflects the level of the National Solar Observatory budget commensurate with requirements to operate the Daniel K. Inouye Solar Telescope (DKIST), the construction of which is scheduled to be completed in June 2020. The FY 2021 Budget Request funds both the DKIST operations requirement (science operations and data center) and the NSO Integrated Synoptic Program (NISP).

As a Federally Funded Research and Development Center, NSO is headquartered on the campus of the University of Colorado, Boulder and provides leadership to the solar astronomy community through management of the construction of DKIST as well as its subsequent operation once completed as planned in FY 2020. When completed, DKIST will be the world's most powerful solar observatory, poised to answer fundamental questions in solar physics by providing transformative improvements over current ground-based facilities. DKIST will enable the study of magnetic phenomena in the solar photosphere, chromosphere, and corona. Determining the role of magnetic fields in the outer regions of the Sun is crucial to understanding the solar dynamo, solar variability, and solar activity including flares and coronal mass ejections. Solar activity can affect civil life on Earth through phenomena generally described as space weather and may impact the terrestrial climate. The relevance of DKIST's science drivers was reaffirmed by the National Academy of Sciences 2010 Astronomy and Astrophysics Decadal Survey: *New Worlds, New Horizons*[1] as well as the 2012 Solar and Space Physics Decadal Survey: *A Science for a Technological Society*.[2] In FY 2020, DKIST achieved first sunlight through the entire optical system, with data collected by the first of its instruments installed, the Visible Broadband Imager (VBI).

NSO also operates the NISP program, which consists of the Global Oscillations Network Group (GONG) and the Synoptic Optical Long-term Investigations of the Sun (SOLIS). GONG is a coordinated worldwide network of six telescopes specifically designed to study solar oscillations and, more recently, to provide critical data products for the prediction of space weather. NSO routinely provides detailed synoptic solar data from the NISP program used by individual researchers and other government agencies through the NSO Digital Library. NSO data are also made available to the user community via the Virtual Solar Observatory.

In 2012, the MPS Division of Astronomical Sciences (AST) conducted a community-based review of its portfolio. Prior to receiving the Portfolio Review Committee (PRC) report,[3] NSF had instructed NSO to begin divestment of the facilities on Kitt Peak, including the McMath-Pierce Solar Telescope and the Vacuum Tower (no longer in use), thereby accelerating the already-planned divestment by a few years. The PRC endorsed this decision. The PRC recommended continued operation of the Dunn Solar Telescope (DST) at Sacramento Peak through 2017 and a 50.0 percent reduction in funding of NISP. The status of the

[1] www.nap.edu/catalog.php?record_id=12951
[2] www.nap.edu/search/?term=13060&x=0&y=0
[3] www.nsf.gov/mps/ast/ast_portfolio_review.jsp

transition of NSO-operated facilities is as follows:

- *McMath-Pierce Solar Telescope, Kitt Peak, AZ*: NSO ceased operating the McMath-Pierce Solar Telescope as a national user facility at the end of FY 2017. In late FY 2018, following a divestment options study and environmental impact analysis, NSF made a five-year award to the Kitt Peak National Observatory Visitor Center, part of NSF's National Optical-infrared Astronomy Research Laboratory, to repurpose the McMath-Pierce facility as an astronomy outreach and education center. This Windows on the Universe Center for Astronomy Outreach will highlight all of NSF's research facilities related to astronomy and astrophysics.
- *Sacramento Peak Observatory, Sunspot, NM*: This facility includes the DST and associated infrastructure. NSO ceased operating Sacramento Peak Observatory as a national user facility at the end of FY 2017. In FY 2019, following thorough programmatic and environmental evaluations of transition options, NSF decided to pursue a potential transition to limited operation of Sacramento Peak by a consortium led by New Mexico State University, which was memorialized in a Record of Decision published in February 2019.
- *NSO Integrated Synoptic Program (GONG and SOLIS)*: GONG now has a component of its operations funding provided through a five-year (August 2016 – August 2021) interagency agreement with the National Oceanic and Atmospheric Administration (NOAA). This NOAA funding supports the use of GONG and its data products for operational space weather forecasting through August 2021. (Also see Partnerships section below). NSO is in the process of relocating the SOLIS facility from Tucson to the Big Bear Solar Observatory (BBSO) on Big Bear Lake, CA.

Total Obligations for NSO

(Dollars in Millions)

	FY 2019[1]	FY 2020	FY 2021	ESTIMATES[2]				
	Actual	(TBD)	Request	FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
NSO Operations & Maintenance	$4.39	-	$4.25	$4.38	$4.52	$4.65	$4.65	$4.65
DKIST Operations	8.50	-	17.54	18.08	18.62	19.13	19.13	19.13
Facility Upgrades	3.50	-	-	-	-	-	-	-
Total	**$16.39**	**-**	**$21.79**	**$22.46**	**$23.14**	**$23.78**	**$23.78**	**$23.78**

[1] Facility Upgrades include $3.50 million in one-time funding for development of DKIST level 2 (advanced) data products. DKIST Operations excludes $2.0 million provided to another awardee for cultural mitigation activities as agreed to during the compliance process and $8.0 million of FY 2019 O&M costs obligated in FY 2018.

[2] Outyear funding estimates are for planning purposes only. The current cooperative agreement ends September 2024.

Facility Upgrades

In FY 2019, NSF awarded $3.50 million (second year of a two-year award) for development of DKIST level 2 (advanced) data products, making DKIST data more accessible to and usable by the solar research community.

Partnerships and Other Funding Sources

The managing organization for NSO is the Association of Universities for Research in Astronomy, Inc. (AURA), which comprises 47 U.S. member institutions and three international affiliate members. NSO partners include NOAA, the National Aeronautics and Space Administration, industrial entities, and universities and institutes that collaborate with NSO on solar instrumentation development. New Mexico State University operates the DST at Sunspot Solar Observatory through a consortium of universities while NSO continues to maintain the site infrastructure. NSO has partnered with BBSO to operate the SOLIS facility in Big Bear, CO.

The Administration's National Space Weather Strategy and Action Plan (March 2019)[4] highlighted the importance of the impacts of space weather on critical infrastructure and society in general, and the importance of operational space weather forecasting. Space weather forecasting requires both accurate models of the heliospheric environment and precise observational data inputs to those models. NSO's GONG program provides operational data products on a routine basis that are used as inputs to predictive space weather models from the U.S. Air Force and the NOAA Space Weather Prediction Center. NSO is continuing the process of upgrading the GONG facility with $2.50 million of funding provided in FY 2016, with the upgrade now expected to be completed in FY 2020. NSF and NOAA are currently in the fourth year of a five-year interagency agreement whereby NOAA provides approximately $800,000 per year in funding support for GONG operations.

NSO Operations ($4.25 million)
NSO Base Operations includes the offices at NSO's Boulder, Colorado headquarters and the world-wide NSO Integrated Synoptic Program consisting of the GONG array and the SOLIS telescope. NSO also supports U.S. education goals by promoting public understanding and support of science and by providing education and training at all levels.

DKIST Operations ($17.54 million)
Support for DKIST operations is through the R&RA account, while DKIST construction support was through the MREFC account. FY 2019 was the final year of construction funding for DKIST and the facility is expected to become fully operational in FY 2020.

Management and Oversight

- NSF Structure: NSF oversight is handled by a program officer in AST working cooperatively with staff from MPS, the Office of the General Counsel, and the Office of Legislative and Public Affairs. Within BFA, the Large Facilities Office provides advice to program staff and assists with agency oversight and assurance. Representatives from some of the above NSF offices comprise the NSO Integrated Program Team, which meets on a semi-annual basis to discuss outstanding program issues. The MPS Facilities team and the NSF Chief Officer for Research Facilities also provide high-level guidance and oversight.
- External Structure: AURA is the managing organization for NSO. The NSO director reports to the president of AURA, who is the principal investigator on the current NSF cooperative agreement. AURA receives management advice from its Solar Observatory Council, composed of members of its scientific and management communities. NSO utilizes a users committee for the purposes of self-evaluation and prioritization. The users committee, composed of scientists with considerable experience with the observatory, reviews for the NSO director all aspects of NSO that affect user experiences. The NSF program officer for NSO has frequent (at least weekly) discussions and interactions with NSO management, especially the NSO Director. In addition to NSF reviews of the project, the program officer attends the semi-annual meetings of the Solar Observatory Council and the periodic Users Committee meetings (see below) as an *ex officio* observer. The program officer conducts periodic site visits to NSO facilities and attends community science meetings in order to keep abreast of the latest happenings in the solar community

Reviews
- NSF conducts regular reviews of NSO's Annual Progress Report and Program Plan (APRPP). The most recent APRPP review was in March 2019.
- In July 2019 a comprehensive midterm review of NSO's long-range plan for the second five years of the cooperative agreement was conducted.
- NSO also participates in reviews of the DKIST project. Recent reviews include: a DKIST Project

[4] www.whitehouse.gov/wp-content/uploads/2019/03/National-Space-Weather-Strategy-and-Action-Plan-2019.pdf

Execution Plan and Construction Status review (April 2019), an Earned Value Management system surveillance (April 2019), and an incurred cost audit for the American Reinvestment and Recovery Act award for DKIST construction (August 2018–June 2019).

Renewal/Recompetition/Termination

In August 2014, NSB authorized a renewed cooperative agreement with AURA for management and operation of NSO. The renewal award started in June 2015 and will run through September 2024. In order to prepare for a potential two-year re-competition process, in mid-2022, NSF will evaluate the current status of NSO operations and the performance of the managing organization, AURA. The goal will be to determine whether to begin a re-competition of the award for management and operations of the NSO in accordance with NSF policy

NSF'S NATIONAL OPTICAL-INFRARED ASTRONOMY RESEARCH LABORATORY **$48,120,000**
-$15,690,000 / -24.6%

NSF's National OIR Astronomy Research Laboratory Funding[1]
(Dollars in Millions)

FY 2019 Actual[2]	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Percent
$63.81	-	$48.12	-$15.69	-24.6%

[1] Established in early FY 2020, this lab encompasses operations of the mid-scale observatories and Community Science & Data Center, which formerly comprised NOAO, together with operations of the Gemini Observatory and the Vera C. Rubin Observatory.

[2] Includes $12.99 million in additional funding for Gemini special projects and $5.73 million for continuity of funding into FY 2020.

At the start of FY 2020, NSF launched NSF's National Optical-Infrared Astronomy Research Laboratory (henceforth "the Lab"), a Federally Funded Research and Development Center (FFRDC) that will be the foundational hub of U.S. ground-based, optical-infrared (OIR) astronomy in the era of the Vera C. Rubin Observatory, multi-messenger astrophysics (MMA), data intensive science, and Extremely Large Telescopes (ELTs). The Lab integrates into a single center the programs and activities that have previously been associated with the National Optical Astronomy Observatory (NOAO), the Gemini Observatory, and the Vera C. Rubin Observatory operations (the Lab does not encompass the Rubin Observatory construction project).[1]

The Lab enables the U.S. research community to pursue a broad range of modern astrophysical challenges, from studying rapidly moving small bodies within the Solar System, to characterizing the most distant galaxies in the early universe and indirectly observing dark matter and dark energy. The Lab is a strategic priority for the MPS Division of Astronomical Sciences (AST) to facilitate U.S. leadership in OIR astronomy. The Lab will optimize scientific synergies, promote efficient operations among NSF-funded night-time OIR assets, and provide a cornerstone for future NSF investment in the next generation of OIR facilities. The Lab's telescopes will also be used to further NSF's Big Idea, "Windows on the Universe: The Era of Multi-Messenger Astrophysics," through their participation in MMA research, providing a more complete understanding of the nature of matter and energy and helping answer some of the most fundamental questions in contemporary science.

The Lab's facilities, telescopes, and data systems are open to all qualified astronomers regardless of institutional affiliation. It provides services to approximately 1200 scientists annually, 800 of whom are based in the United States. Doctoral dissertation students and non-thesis graduate students from U.S. institutions use the facilities for a broad range of research projects. The Lab currently employs 430 people in Arizona, Hawai'i, and Chile, including engineers, technicians, support scientists, administrative support staff, postdoctoral fellows and interns. As NSF builds towards the Vera C. Rubin Observatory operating at full capacity, the need for new staff at the Lab to support operations is expected to steadily increase in the forthcoming years.

Lab telescopes continue to make ground-breaking discoveries in all areas of astronomy. Observations from Gemini have been used to determine the location of a repeating Fast Radio Burst (FRB) in a nearby galaxy, making it the closest known example to Earth and only the second repeating FRB to have its location

[1] See the MREFC chapter for information on the Vera C. Rubin Observatory construction project.

pinpointed. FRBs are sudden rapid explosions of energy from space that typically last only a few milliseconds and can only be found with radio telescopes. Optical telescopes like Gemini can subsequently be used to identify and characterize the host galaxy, hopefully shedding some light on the possible source of these remarkable objects.

Using Gemini and the Lab's Mayall Telescope at Kitt Peak, astronomers have uncovered two historic events in which the Andromeda Galaxy underwent major changes to its structure. The motions of 77 clusters of stars around the bright disk of the galaxy have been measured and associated with two distinct populations, a young group associated with stellar streams, and an older, more randomly distributed group. The two populations both orbit the Andromeda Galaxy, but their orbital axes are nearly perpendicular to each other. These data shed light not only on the formation and evolution of the Andromeda Galaxy, but on our own Milky Way Galaxy as well.

Overview of NSF's National OIR Astronomy Research Laboratory Programs and Activities

Gemini Observatory

Over the last two decades, NSF has been a leading partner in operations of the two 8.1-meter Gemini telescopes, located on Maunakea in Hawai'i at an altitude of 4,200 meters and on the 2,700-meter summit of Cerro Pachón in Chile. Technological advances incorporated into the design of the twin Gemini telescopes optimize their imaging capabilities and infrared performance as well as their ability to quickly swap instruments in response to changing atmospheric conditions. Gemini's flexible observing modes also make it ideal for reacting rapidly to opportunities that arise in the new era of MMA. The Lab is developing software and hardware aimed at enhancing Gemini's ability to respond to transient and MMA phenomena discovered by NSF facilities such as the Vera C. Rubin Observatory, the Laser Interferometer Gravitational-Wave Observatory (LIGO), and the IceCube Neutrino Observatory. NSF also funded the development of a new adaptive optics system for Gemini-North in FY 2018 and FY 2019 as part of the Gemini in the Era of Multi-Messenger Astronomy (GEMMA) project.

Vera C. Rubin Observatory

Since 2014, NSF, in partnership with the Department of Energy (DOE), has been constructing the Vera C. Rubin Observatory (formerly known as the Large Synoptic Survey Telescope), an 8.4-meter wide-field optical survey telescope located near Gemini-South in Chile. With its 3.2 billion pixel camera and 10-square degree field of view, the Vera C. Rubin Observatory will rapidly survey the southern sky with a cadence enabling repeat observation of each survey field approximately twice weekly, and will produce a long-lived data set of unprecedented utility. Once complete, it will be the U.S. flagship ground-based OIR observatory, producing the deepest, widest-field sky image ever and issuing alerts for changing and transient objects within 60 seconds of their discovery. Commencement of the initial 10-year survey is planned for FY 2023. NSF funding of activities associated with operations planning and preparation began in FY 2019. For more information on the construction project, see the MREFC chapter.

Mid-Scale Observatories (MSO)

The Lab's 4-meter class telescopes at Kitt Peak National Observatory (KPNO) in Arizona and Cerro Tololo Inter-American Observatory (CTIO) in Chile (see table below), formerly operated by NOAO, have been a critical resource for research in OIR astronomy for several decades. KPNO and CTIO, now collectively known as the Mid-Scale Observatories, have been revitalized in recent years through the development of new instruments and observing modes. The Dark Energy Camera (DECam) on the Blanco telescope recently completed the very productive Dark Energy Survey and is now being used for other frontier scientific surveys. The NASA-NSF Exoplanet Observational Research (NN-EXPLORE) program's Doppler spectroscopy instrument (NEID) and the Dark Energy Spectroscopic Instrument (DESI), at the WIYN and Mayall telescopes respectively, will be commissioned in FY 2020, providing powerful new capabilities in exoplanet research and cosmology. The SOuthern Astronomical Research (SOAR) telescope, while continuing to serve its diverse, international community, is developing its role as an important mid-sized facility for follow-up of transients identified by the Vera C. Rubin Observatory as well as time-domain astronomy in general over the coming decade.

Primary Telescopes Comprising the Mid-Scale Observatories Program				
	WIYN	**Mayall**	**Blanco**	**SOAR**
Location	KPNO, Arizona	KPNO, Arizona	Cerro Tololo, Chile	Cerro Pachón, Chile
Diameter	3.5-m	4.0-m	4.0-m	4.1-m
Commissioned	1994	1970	1974	2005
Primary Uses	Exoplanet research with NEID and general PI-led astronomy	Dark Energy spectroscopic survey science with DESI	General PI-led astronomy with an emphasis on PI-led survey projects with DECam	General PI-led astronomy with an emphasis on time domain astronomy follow-up programs

Community Science & Data Center (CSDC)

On behalf of the U.S. astronomy community, the CSDC in Tucson develops strategies for archival data management and is building the capacity to serve as the national center for ground based OIR data archiving and utilization. CSDC has also taken a lead role in the brokering of time-domain alerts from the Vera C. Rubin Observatory through its Arizona-NOAO Temporal Analysis and Response to Events System (ANTARES) and Astronomical Event Observatory Network (AEON) collaborations with the University of Arizona, the Gemini Observatory, the Las Cumbres Observatory, and the Zwicky Transient Facility. In FY 2019, AEON was used to commission queue-based observing at SOAR.

Lab Partnerships

The Lab and its components support several important national and international partnerships on behalf of NSF.

- The Gemini Observatory is managed on behalf of the Gemini international partnership which includes NSF, the National Research Council (NRC) of Canada, the Comisión Nacional de Investigación Científica y Tecnológica (CONICYT) of Chile, the Ministério da Ciência, Tecnologia, Inovações e Comunicações (MCTIC) of Brazil, the Ministerio de Ciencia, Tecnología e Innovación Productiva (MCTIP) of Argentina, and the Korea Astronomy and Space Science Institute (KASI) of South Korea. These six agencies are signatories to the Gemini International Agreement, which the partnership is working toward renewing before the end of 2021 when the current agreement expires.
- The SOAR telescope is supported by MCTIC of Brazil, NSF’s National OIR Astronomy Research Laboratory, the University of North Carolina Chapel Hill, and Michigan State University; a new SOAR agreement will be signed in late FY 2020.
- The WIYN telescope is owned and operated by a consortium comprising the University of Wisconsin, Indiana University, NSF’s National OIR Astronomy Research Laboratory, the University of Missouri, and Purdue University. NSF’s continued participation is built around a partnership with the National Aeronautics and Space Administration (NASA), which has funded a state-of-the-art instrument for extrasolar planet studies under the NN-EXPLORE program mentioned above.
- Key agreements between NSF and DOE have supported not only the construction of the Vera C. Rubin Observatory, but also the recently completed Dark Energy Survey at the Blanco telescope and the construction and future operations of DESI on the Mayall. DOE assumed full operations funding of the Mayall telescope in FY 2019.
- Many U.S. universities support their own astronomical facilities at the KPNO and CTIO sites with reimbursed services provided by the Lab. The Lab typically receives approximately $11 million each

year from partnerships (WIYN, Mayall and SOAR), for reimbursed services provided to tenant observatories at KPNO and CTIO, from the Kitt Peak Visitors Center, and from grants from other federal agencies.

- Construction and subsequent development of the Lab's telescopes and their instrumentation has involved many industrial entities in several countries, with areas of specialization that included large and complex optical systems, engineering, electronics, electro-mechanical systems, and computing.

Education and Public Outreach

The Lab supports U.S. educational goals by promoting the public understanding of science and by providing education and training opportunities at all levels. The observatories introduce undergraduate students to scientific research by providing stimulating environments for basic astronomical research and related technologies through internship programs. The Lab maintains a diverse education program that includes teacher training programs based in Tucson, Arizona and La Serena, Chile, week-long school visit programs in Hawai'i and Chile (Gemini's *Journey Through the Universe* program in Hawai'i is now in its 16th year), visitor centers at Kitt Peak and Cerro Tololo, and a web-based information portal. With supplementary support from NSF, the Lab is also converting the recently retired McMath-Pierce Solar Telescope on Kitt Peak into a new, self-supporting astronomy visualization and presentation center with a focus on MMA. The center, to be known as the Windows on the Universe Center for Astronomy Outreach (WoUCAO), will include a Science On a Sphere (SOS) visualization system and a GeoDome Digital Planetarium, along with interactive exhibits and an astronomy classroom.

Total Obligations for NSF's National OIR Astronomy Research Laboratory

(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	ESTIMATES[1] FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Mid-Scale Observatories & CSDC	$26.66	-	$22.23	$22.10	$21.93	$20.51	$20.51	$20.51
Operations & Maintenance[2]	*25.48*	-	*20.51*	*20.51*	*20.51*	*20.51*	*20.51*	*20.51*
Special Projects[3]	*1.18*	-	*1.72*	*1.59*	*1.42*	-	-	-
Gemini Observatory	34.65	-	20.89	23.67	23.67	23.67	23.67	23.67
Operations & Maintenance	*21.66*	-	*20.89*	*23.67*	*23.67*	*23.67*	*23.67*	*23.67*
Facility Upgrades[4]	*12.99*	-	-	-	-	-	-	-
Vera C. Rubin Observatory Operations[5]	-	-	5.00	14.32	26.85	29.64	30.93	28.62
Lab Transition[6]	2.50	-	-	-	-	-	-	-
Total	**$63.81**	**-**	**$48.12**	**$60.09**	**$72.45**	**$73.82**	**$75.11**	**$72.80**

[1] Outyear funding estimates are for planning purposes only.

[2] Reflects O&M funding for the Mid-Scale Observatories (including KPNO and CTIO) and the CSDC in Tucson, which formerly comprised the National Optical Astronomy Observatory through the end of FY 2019. Included in the FY 2019 total is $5.73 million for continuity of funding into FY 2020 and approximately $412,000 in supplemental funding for U.S. Extremely Large Telescope

[3] Includes funding for the WIYN telescope and the Windows on the Universe Center for Astronomy Outreach (WoUCAO); both cooperative agreements end in FY 2023. NSF support for the Mayall concluded in FY 2018 and operations are now fully funded by DOE. Excludes $3.32 million of FY 2019 and FY 2020 design and development costs for WoUCAO obligated in FY 2018.

[4] Reflects $12.99 million in additional funding to enhance Gemini's adaptive optics system, software capabilities, and public information and outreach activities in the era of multi-messenger astronomy.

[5] A new cooperative agreement for O&M of the Vera C. Rubin Observatory for FY 2022 to FY 2026 is anticipated in FY 2021; outyear funding represents preliminary estimates. Excluded is $11.10 million in FY 2019 - FY 2021 pre-operations ramp up costs obligated in FY 2018. The funding amounts shown represent NSF support only and amount to about 50 percent of the total operations cost. Other Support from DOE and non-federal contributors provides the balance.

[6] NSF transition activities associated with the creation of the Lab are funded in FY 2019 and FY 2020.

For information on continuity of operations funding, see the opening narrative of this chapter.

Management and Oversight

MSO and CSDC O&M
MSO and CSDC base funding supports all Lab directorate-level activities and the administrative offices in Tucson and La Serena, together with operations and maintenance of the astronomical facilities and infrastructure at KPNO and CTIO, user support services, data archiving, and software development activities at CSDC.

Special Projects
In FY 2021 special projects include $1.14 million for continuing operational support of the NN-EXPLORE program on the WIYN 3.5-m Telescope on Kitt Peak, and $580,000 toward the development of the WoUCAO.

Gemini Operations, O&M
NSF is currently a partner in the Gemini Observatory. The FY 2021 Request provides funding for facility operations and maintenance costs that will maintain this partner share (the other international participants intend to contribute a further $10.08 million in FY 2021 for operations).

Vera C. Rubin Observatory Operations
NSF made an initial award of $11.10 million in FY 2018 to cover expected pre-operations costs through FY 2021. Due to changes in the Observatory's operations model,[2] additional pre-operations funding of $5.0 million is now anticipated for FY 2021 to support the ramp-up of activities associated with observatory operations.

The Lab is managed for NSF by the Association of Universities for Research in Astronomy, Inc. (AURA), which is comprised of 47 U.S. institutions and three international affiliates.

- NSF Structure: In consultation with community representatives, three AST Program Officers, working as a team, carry out continuing oversight and assessment of the Lab and its component programs, MSO, CSDC, Gemini, and Vera C. Rubin Observatory operations, by making use of detailed annual program plans, long-range plans, quarterly finance and technical reports, and retrospective annual reports. A set of pre-defined Key Performance Indicators have been established to measure performance; these are defined in a Performance Evaluation and Measurement Plan. To address issues as they arise, AST also leads an Integrated Program Team (IPT) for the Lab, which includes representatives from AST as well as other NSF offices, including the Office of General Counsel, the Division of Acquisition and Cooperative Support, and the Large Facilities Office. The MPS facilities team and the NSF Chief Officer for Research Facilities also provide high-level guidance, support, and oversight.
- Gemini Governance Structure: The Gemini Observatory is governed by the Gemini Board, the roles and responsibilities of which are codified in the Gemini International Agreement. This board meets at least twice a year and acts as the primary forum for interactions and decisions among the participants in the Gemini Agreement; it ensures that Gemini is managed and operated in accordance with the Agreement and is the body with overall budgetary and policy control over the observatory. The Gemini Board has two standing subcommittees, the Gemini Finance Committee (GFC) and the Gemini Science and Technology Advisory Committee (STAC), which provide support and input to the Board. NSF serves as the Executive Agency for the partnership, carrying out the project on their behalf. An AST Program Officer holds a seat on the Gemini Board and acts as the chair of the GFC.
- Vera C. Rubin Observatory Governance Structure: The operation of this new observatory includes a management board with members from the NSF and DOE managing organizations, AURA and the SLAC National Accelerator Laboratory, respectively. The board approves new observing modes, capabilities, and on-line services as needed to ensure that the facility and its data products meet

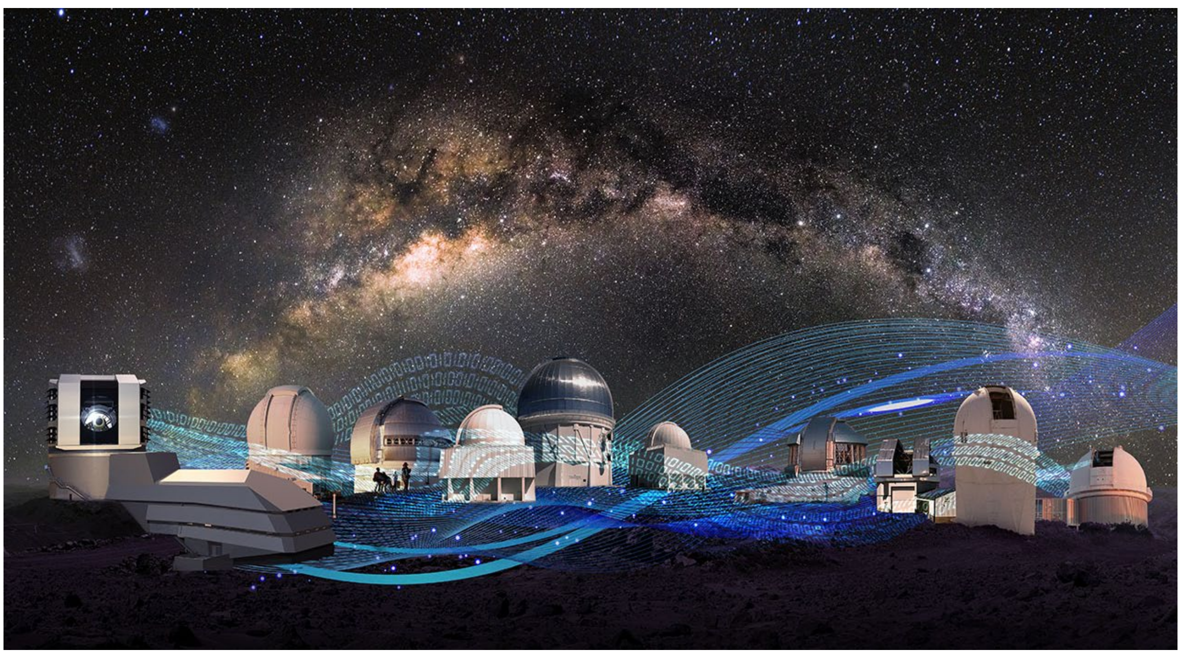
[2] See the MREFC chapter for more information on Vera C. Rubin Observatory operations planning.

community expectations for the Vera C. Rubin Observatory's key 10-year survey initiative.

- Managing Organization and External Oversight: All Lab activities associated with MSO, CSDC, Gemini, and Vera C. Rubin Observatory operations are currently managed by AURA through cooperative agreement with NSF. AURA receives management advice from a Lab-wide oversight council which meets three times a year and is composed of members of its scientific and management communities. MSO and Gemini also use Users' Committees, comprised of community scientists, to advise the observatory directors on all aspects of the user experience at each corresponding facility.
- Reviews: NSF has in the past conducted annual reviews of program operating plans, progress reports, and strategic planning documents, and will continue to do so for the entire Lab enterprise in the future. Within the last 24 months, detailed communications, staffing, risk management and change management plans that describe the transition to the Lab have been reviewed either internally by the Lab IPT, or by external panels of experts.

Renewal/Recompetition/Termination

NSF is planning for a recompetition/renewal decision for the Lab in FY 2023. This requires the synchronization of the agreements that fund all Lab activities (Gemini, MSO, CSDC and Vera C. Rubin Observatory operations), expected to be accomplished over the period FY 2021-FY 2023.



A montage showing the telescope facilities that have become part of NSF's National Optical-Infrared Astronomy Research Laboratory. From left: the Vera C. Rubin Observatory (artist's impression), SOAR, Gemini-South, CTIO 1.5-m, Blanco, CTIO 0.9-m, Gemini-North, WIYN, Mayall, and the KPNO 2.1-m. *Credit: NSF's National Optical-Infrared Astronomy Research Laboratory/AURA/NSF/P. Marenfeld.*

OTHER FACILITIES FUNDING

Major Research Equipment and Facilities Construction Account Projects

The MREFC account supports the acquisition, construction, and commissioning of major facilities and larger mid-scale research infrastructure that provide unique capabilities at the frontiers of science and engineering. Projects supported by this account are intended to extend the boundaries of technology and open new avenues for discovery for the science and engineering community. Initial planning and design, and follow-on operations and maintenance costs of the facilities and infrastructure are provided through the Research and Related Activities (R&RA) account.

For information on projects funded through this account, refer to the MREFC chapter of this Budget Request.

Preconstruction Planning

Within the R&RA account, funds are provided for preconstruction studies for prospective major facility projects. This funding generally supports such activities as design, cost estimates, and other actions that prepare potential projects for oversight review, agency decision milestones, and potential implementation.

NSF-WIDE INVESTMENTS

NSF CONVERGENCE ACCELERATOR (CA)

CA Funding
(Dollars in Millions)

FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
$41.39	**-**	**$70.00**

Overview

CA seeks to transform how NSF supports innovative science, reflecting its commitment to foundational research, while also encouraging rapid advances through partnerships between academic and non-academic stakeholders. CA makes timely investments that (1) initiate new capabilities to accelerate convergence research in areas of national importance, and (2) build capacity in multi-stakeholder convergence teams to address these critical challenges. Focusing on use-inspired, convergence research, with directed deliverables and using an approach that rewards innovation, risk-taking, and transition to use, CA has customized various models and techniques of acceleration and innovation activities that have proven successful outside the federal government. For more information on convergence research, see the Growing Convergence Research narrative in this chapter.

NSF is well positioned to implement an acceleration of convergence research. CA complements NSF's existing programs and enhances NSF's capacity to move ideas from discovery into practice. NSF has a unique role with colleges and universities, which are critical participants in this activity, as well as with other stakeholders, such as other federal agencies, industry, non-profits, foundations, and funding agencies around the world. The CA is aligned with, builds upon, and stimulates new directions for NSF directorates' foundational research investments. Therefore, the CA will complement NSF's portfolio of funding mechanisms to accelerate research.

To surface grand challenge research ideas/themes that are of mutual interest to academia, government, and industry, CA uses a variety of methods, such as multi-stakeholder roundtables and workshops. These themes are referred to as "tracks" with anticipated time horizons for each track of up to three years. Each track will comprise a number of multi-stakeholder teams that will work collaboratively to accelerate science and engineering for that particular research theme.

The initial CA pilot in FY 2019 focused on two of NSF's research Big Ideas: HDR and FW-HTF. Tracks that come from these particular research areas have been identified by the cross-agency CA Working Group and aligned with Administration R&D Priorities,[1] the President's Management Agenda,[2] and the U.S. Five-Year STEM Education Strategic Plan.[3] The HDR track focuses on advancing data-driven discovery using artificial intelligence (AI) and machine learning, through research on the components necessary to create early prototypes of an open knowledge network. The FW-HTF tracks focuses on: (1) team building and creating R&D plans addressing multiple components of AI for connecting workers with jobs of the future, such as predictive AI tools, economic and labor market analyses of needed skills for future workplaces, and AI-assisted educational technologies needed for adult learning; and (2) innovative approaches toward re-envisioning the concepts, structures, and technologies needed for employers to support continuous learning for dynamic, digitally-intensive work, and to provide access to skilled talent pathways, mentors, and

[1] www.whitehouse.gov/wp-content/uploads/2019/08/FY-21-RD-Budget-Priorities.pdf
[2] www.whitehouse.gov/wp-content/uploads/2018/03/The-President%E2%80%99s-Management-Agenda.pdf
[3] Charting a Course for Success: America's Strategy for STEM Education" National Science and Technology Council (2018), www.whitehouse.gov/wp-content/uploads/2018/12/STEM-Education-Strategic-Plan-2018.pdf.

authentic workplace experiences.

The CA track investments are distinguished from the corresponding Big Ideas by the nature of the research, the time scale of the activities supported, and the more hands-on, agile approach to project management and support that is envisioned.

Goals

1. *Accelerate the progress of use-inspired convergence research*: Accelerate scientific discovery and innovation by applying more agile team identification, funding, and project management mechanisms to use-inspired, convergence research that requires the integration of knowledge, skills, and methodologies from multiple disciplines and stakeholders.
2. *Harness partnerships to design and enable convergence research*: Assist academic researchers to engage with non-NSF partners—such as commercial entities, non-profits, foundations, philanthropies, other state or federal agencies, and international funders—to create partnerships that identify high-impact research directions and collaborate to achieve specific research goals.
3. *Focus cohorts of teams around broad national goals*: Support activities that bring together the range of expertise needed to tackle pressing, transdisciplinary research challenges and enable the formation of advanced research teams. Use competition mechanisms to enable cohorts of teams to progress towards research goals more rapidly than single teams alone.

FY 2021 Investments

NSF's FY 2021 Request for CA funding is $70.0 million, which will support the following activities:

- continuing support of the HDR and FW-HTF related CA tracks and see these projects to completion;
- continuation of the FY 2020 CA tracks that will transition from Phase I to Phase II;
- initiation of new FY 2021 CA track projects; and
- community workshops, roundtables, and analysis.

The new research tracks for FY 2020 and FY 2021 will be stimulated by research in NSF's Big Ideas and other research areas based on mutual interest of the partners and readiness of the research community to respond. New tracks will be developed through community workshops, roundtables (e.g., with industry, non-profits, and foundations), and analysis of emerging foundational advances in NSF's Big Ideas. Each track will address all three CA goals.

NSF anticipates that external partners will begin contributing financially to the effort in FY 2021. For the partners, this is a new avenue for R&D, allowing access to academic researchers working at the forefront of knowledge. For the academic researchers, this allows access to partners who are interested in contributing to research projects and the broader themes/tracks. Potential partners will be identified in two different ways: (1) by principal investigators, who understand the key stakeholders for their particular research projects; and (2) by NSF, as it develops new tracks through convenings with industry, foundations, and government agencies and workshops with the relevant research communities. For more information about CA, see the IA narrative in the R&RA chapter.

HARNESSING THE DATA REVOLUTION FOR 21ST-CENTURY SCIENCE AND ENGINEERING (HDR)

HDR Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
Stewardship Activities (CISE)	**$30.01**	**-**	**$45.00**
Foundational Activities	**$144.39**	**-**	**$112.11**
BIO	7.80	-	7.41
CISE	64.60	-	52.49
EHR	5.15	-	2.50
ENG	21.87	-	11.97
GEO	5.60	-	2.85
MPS	32.16	-	19.10
SBE	7.21	-	5.79
IA	-	-	10.00
Total	**$174.40**	**-**	**$157.11**

Overview

NSF's HDR Big Idea is a national-scale activity to enable novel modes of data-driven discovery that will allow new fundamental questions to be asked and answered at the frontiers of science and engineering. HDR will generate new knowledge and understanding, and accelerate innovation. Access to the next level of discovery relies on translating complex data from observations, experiments, and simulations into knowledge. To help close the loop from data generation to analysis, simulation, and finally discovery and decision making, the HDR Big Idea will support fundamental research in data science and engineering; development of a cohesive, federated approach to the research data infrastructure needed to power the data revolution; and development of a 21st-century data-capable workforce. HDR will enable mutually beneficial interactions between data scientists and communities—supporting transfer of data science techniques to local communities, while providing insights and practical experience to participating data scientists and data science students in real-world settings. Importantly, HDR investments in FY 2021 will allow NSF to fund critical new methods and advances in artificial intelligence (AI), notably in machine/deep learning. The development and application of AI methods will further accelerate data-driven discovery in all fields of science, engineering, and education.

Goals

The HDR vision is realized through a set of interrelated goals:
1. *The foundations of data science*: Develop the theoretical foundations of data science and its applications through integrated research and training activities.
2. *Algorithms and systems for data science*: Support the development and use of novel algorithms and systems to support data science as well as data-driven science and engineering.
3. *Data-intensive science and engineering*: Stimulate advances in multiple areas of science and engineering through data-intensive research that harnesses diverse data sources and applies new methodologies, technologies, and infrastructure for data generation, collection, modeling, and analysis.
4. *Data cyberinfrastructure*: Foster the creation of robust, trustworthy, and performant data cyberinfrastructure and services that can support data-driven research and discovery in multiple areas of science and engineering.
5. *Education and workforce development*: Develop coordinated activities in data science education,

researcher training, and knowledge transfer, and harness the power of data at the local, state, national, and international levels in the service of science and society.

FY 2021 Investments

Stewardship Investments

Foundations of Data Science ($6.0 million)
HDR will continue to support research in data science and data-enabled science and engineering primarily through the Transdisciplinary Research In Principles Of Data Science (HDR TRIPODS) program. HDR TRIPODS will bring together the electrical engineering, mathematics, statistics, and theoretical computer science communities. Through integrated research and training activities, these communities will collaborate to develop the theoretical foundations of data science. In FY 2019, Phase I HDR TRIPODS awards (spanning 15 projects) were made to support the development of small, collaborative "data science institutes". Subsequent Phase II awards, planned for FY 2022, will enable a subset of the most successful of these smaller institutes to expand in scope and impact into larger-sized data science institutes.

Data-Intensive Research in Science and Engineering ($33.0 million)
HDR will support Institutes for Data-Intensive Research in Science and Engineering (DIRSE). The DIRSE institutes will complement the HDR TRIPODS institutes described above and will harness diverse data sources and develop new algorithms, methodologies, systems, technologies, and infrastructure for data management and analysis to address critical science and engineering problems. In FY 2021, investments in HDR DIRSE institutes will emphasize fundamental research and education in AI, focused on machine/deep learning, that will accelerate data-driven discovery in all fields of science and engineering. The DIRSE institutes program constitutes a two-phase process involving conceptualization followed by convergence. In FY 2019, NSF issued more than 100 conceptualization awards spanning 28 projects supporting interdisciplinary teams that are conceptualizing and piloting new modalities for collaboration and convergence that go beyond traditional disciplinary and organizational boundaries. These projects will pave the way to the DIRSE convergence institutes planned for FY 2021. Furthermore, a coordination hub will be established in FY 2021 to support interaction, coordination, and sharing across the DIRSE institutes. By creating a portfolio of interrelated DIRSE institutes, NSF aims to accelerate discovery and innovation in multiple areas of data-intensive science and engineering.

Education and Workforce Development ($6.0 million)
HDR will continue to support data science education and workforce development through the Data Science Corps (DSC) program. NSF funded 22 DSC awards spanning nine projects in FY 2019. These awards are helping to build the data science workforce by engaging data science students and professionals in real-world data science projects that will help bridge the data-to-knowledge gap in organizations and communities at local, state, national, and international levels. In FY 2021, the DSC program will continue to provide data science students and professionals with practical experiences, new skills, and teaching opportunities across multiple learning environments; promote data literacy, including its ethical usage; and provide basic training in data science to the existing workforce across communities throughout the United States. Furthermore, in FY 2021, investments in HDR DSC will enable education and workforce development of next-generation data scientists proficient in state-of-the-art AI systems and techniques.

Foundational Activities
These activities comprise ongoing investments by NSF directorates and offices in programs that laid the initial foundations for the HDR Big Idea and HDR Track in the Convergence Accelerator (CA). These activities will continue to be supported and aligned with the overall HDR strategic goals. These foundational activities are currently managed by NSF's directorates and offices and will continue to remain within the directorates and offices with respect to their funding and management.

HDR engagement with the Convergence Accelerator (CA)

In FY 2021, although not presented in the table above, the CA seeks to transform how the agency supports the most innovative science and engineering, reflecting its commitment to be at the cutting-edge, supporting foundational research, while also encouraging rapid advances through partnerships between academic and non-academic stakeholders. Tracks within the CA focus on grand challenge themes that would benefit from acceleration. HDR will continue its cooperation with the CA by building on the projects funded in FY 2019 as part of the HDR Open Knowledge Network track as well as through collaboration on awards funded through new tracks. For more information, refer to the CA narrative in this chapter.

THE FUTURE OF WORK AT THE HUMAN-TECHNOLOGY FRONTIER (FW-HTF)

FW-HTF Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
Stewardship Activities (ENG)	**$29.96**	**-**	**$45.00**
Foundational Activities	**$123.52**	**-**	**$116.68**
BIO	0.68	-	-
CISE	83.00	-	81.67
EHR	10.36	-	10.30
ENG	16.97	-	13.78
MPS	1.09	-	-
SBE	11.43	-	10.93
Total	**$153.49**	**-**	**$161.68**

Overview

The FW-HTF Big Idea supports convergence research to develop new human-technology partnerships leading to increased worker productivity and innovation. This research will prepare the workforce for human-technology partnerships by combining the benefits of new technologies, such as artificial intelligence (AI) and virtual environments, with increased understanding of value-based social, economic, and educational opportunities and impacts.

The landscape of jobs and work is changing with unprecedented speed, driven by the development of new technologies that have moved from the factory floor to an expanding array of knowledge and service occupations. These changes, while promising benefits to the Nation in the creation of new industries of the future and related occupations, increased productivity, enhanced innovation, and sustained U.S. global leadership, come with risks for workers as technology may substantially alter, and in some cases, eliminate jobs.

The FW-HTF Big Idea started in FY 2018 and responds to the challenges and opportunities associated with the changing landscape of jobs and work. FW-HTF is supporting new convergent research to understand and advance the human-technology partnership, design new technologies to augment human performance, illuminate the emerging socio-technological landscape, and foster lifelong and pervasive learning with technology. Investments in research and development at the human-technology frontier are enabling technologies that amplify and augment human capabilities to learn, adapt, make decisions, and make sense of complex patterns and situations in the work context. It is necessary to fund interdisciplinary research at the intersection of computer and information science, engineering, social, behavioral, and economic sciences, and education. Increasing human capabilities is the result of the incorporation of advances in AI, data science, and closely related technologies for sensing, actuation, coordination, communication, and control with humans in the loop; and depends upon understanding human communication, thinking, and action. These advances will underpin the creation of systems that are adaptive, human-centered, and capable of collaborative interactions with humans. By evaluating the aspects of work that humans do most effectively and the complementary aspects of work that emerging technologies can improve, FW-HTF research will support advances that improve work quality, increase worker productivity, and make work more meaningful. Additionally, these research investments will enable an understanding of how these changes will affect society and what new approaches to education and training will be required. Moreover, NSF investments will explore the ethical and societal implications of emerging technologies, such as AI, and advance the pursuit and adoption of responsible and ethical approaches to using data and furthering data science for work and workers. These research investments will accelerate progress and enable the Nation's workforce and economy to lead in a future that is increasingly and unavoidably driven by technology and knowledge.

Goals

The FW-HTF Big Idea seeks to maximize benefits and minimize risks of the changing technological environment, to foster support of the workforce in increasing productivity and innovation, and to lay the foundation for new knowledge and developments in science and engineering through the following four strategic goals:

1. *Understand and build the human-technology partnership*: Research on the future of work will identify how new technologies affect jobs, the workplace, organizations, and society, as well as how these technologies can be designed and built to increase national productivity, job opportunities, and worker satisfaction, while enabling worker creativity.
2. *Design and develop new technologies to augment human performance*: By augmenting the physical and mental capabilities of humans, new technology can open new job opportunities. For example, using AI-based, real-time, adaptive physical and cognitive prosthetics can increase job opportunities for those with disabilities and enhance capabilities in all individuals in manufacturing settings.
3. *Illuminate the emerging socio-technological landscape*: As technology becomes increasingly capable, companies and organizations will be transformed, as will society, the economy, and relevant laws. Research will clarify the benefits and risks of such change and help inform ethical and value-based design of new technology and software in support of a diverse workforce.
4. *Foster lifelong and pervasive learning through technology*: Design of training, including novel AI-based approaches, will support both the training and reskilling that the workforce needs to work with new technology and to enable workers to migrate from old jobs to new ones. Adaptive, pervasive training systems will depend on new research in cyberlearning systems, as well as the integration of training into task performance and management.

FY 2021 Investments

Stewardship Activities

FY 2021 activities will leverage the investments made through the FY 2018 and FY 2019 FW-HTF solicitations[1] that support research on advancing cognitive and physical capabilities in the context of human-technology interactions, the evolving symbiosis of human and AI in work, and the understanding and explanation of productivity, innovation, and learning in the workplace. In addition, these activities will leverage new funding opportunities released in FY 2020 that continue to emphasize the four FW-HTF strategic goals listed above. FY 2021 catalytic activities will include standard research grants, workshops, and grants for planning and coordination. These funding opportunities will set the foundation for future integrative activities such as collaboration hubs, center-scale institutes, and larger-scale grants in FY 2021 and beyond. During FY 2020 and 2021, FW-HTF will also develop synergies with other NSF Big Ideas and NSF-wide efforts, including GCR, HDR, Mid-scale RI, NSF INCLUDES, and NRT.

Foundational Activities

Foundational activities comprise continued investments by participating directorates and offices in existing (ongoing) NSF programs that have laid the foundation for the FW-HTF Big Idea. Also, FW-HTF tracks within the Convergence Accelerator will continue to be aligned with FW-HTF goals. These foundational programs are currently managed by NSF's directorates and offices and will remain within the directorates and offices with respect to their funding and management.

[1] www.nsf.gov/pubs/2019/nsf19541/nsf19541.htm

The FW-HTF Track within the NSF Convergence Accelerator (CA)

In FY 2021, although not presented in the table above, the CA seeks to transform how the agency supports the most innovative science, reflecting its commitment to be at the cutting edge, by supporting foundational research while encouraging rapid advances through partnerships between academic and non-academic stakeholders. CA tracks focus on grand challenge themes that would benefit from acceleration. FW-HTF activities within the CA aim to strengthen the U.S. economy, improve worker performance and job satisfaction, and facilitate lifelong learning. Example projects include efforts to match workers with jobs of the future and to develop living laboratories, such as in classrooms and manufacturing environments, where hypotheses about learning and productivity will be tested. FW-HTF activities within the CA will be informed by analysis of emerging foundational advances in FW-HTF research and input from stakeholders. These activities will align with, build upon, and help reshape directorates' foundational research investments. For more information, refer to the CA narrative in this chapter.

NAVIGATING THE NEW ARCTIC (NNA)

NNA Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
Stewardship Activities (GEO)	**$30.00**	**-**	**$30.00**
Foundational Activities	**$14.47**	**-**	**$10.75**
BIO	1.50	-	1.43
EHR	1.49	-	1.19
ENG	4.78	-	1.90
SBE	0.64	-	0.48
OISE	1.00	-	1.00
OPP	5.06	-	4.75
Total	**$44.47**	**-**	**$40.75**

Overview

Arctic temperatures are rising faster than nearly everywhere else on Earth. The rapid and wide-scale changes occurring in response to this warming portend new opportunities and risks to natural systems; social and cultural systems; economic, political, and legal systems; and infrastructure and other engineered systems of the Arctic and across the globe. Gaps in scientific observations and the prevalence of interdependent social, natural, and built systems in the Arctic make it challenging to predict the region's future. Understanding and adapting to a changing Arctic will require creative new directions for Arctic-specific research, education, workforce development, and leveraging of science, engineering, and technology advances from outside the Arctic.

NNA, one of NSF's Big Ideas, embodies the Foundation's forward-looking response to these profound challenges. NNA seeks innovations in Arctic observational networks and fundamental convergence research across engineering and the social, natural, environmental, and computing and information sciences, that address the interactions or connections between natural and built environments and social systems and how these connections inform our understanding of Arctic change and its local and global effects. NNA empowers new research communities; diversifies the next generation of Arctic researchers; integrates the co-production of knowledge with local and Indigenous people and organizations; and engages with interdisciplinary, interagency, and international partners to further pan-Arctic and Arctic-global perspectives.

With respect to observational research, NNA will address key gaps in the existing array of observation, communication, computation and data systems. Strong coupling of observation, communication, and computation and data, including the theoretical foundations underlying these, will be supported to ensure progress. NNA will leverage resources with the Mid-scale RI and HDR Big Ideas as appropriate.

NNA also strongly encourages projects with components that advance STEM education; that deepen public understanding of the changing Arctic to benefit both citizens and policy makers; and that advance workforce-development objectives. NNA will build on NSF's STEM investments and the NSF INCLUDES Big Idea to encourage innovative and appropriately evaluated education and public engagement efforts that leverage exciting NNA science and inspire diverse participation in STEM.

By drawing upon expertise from across the agency, NNA investments will accelerate research needed to inform decisions regarding the national security, economic development, and societal well-being of the

U.S. as an Arctic nation and enable resilient, sustainable Arctic communities. NSF plans to invest in NNA through FY 2023.

Goals

1. Improved understanding of Arctic change and its local and global effects that capitalizes on: innovative and optimized observation infrastructure; advances in understanding of fundamental processes; and new approaches to modeling interactions among the natural environment, built environment, and social systems.
2. New and enhanced research communities that are diverse, integrative, and well-positioned to carry out productive research on the interactions or connections between Arctic natural and built environments and social systems and how these connections inform our understanding of Arctic change and its local and global effects.
3. Research outcomes that inform U.S. national security, economic development, and societal well-being and enable resilient, sustainable Arctic communities.
4. Enhanced efforts in formal and informal education that focus on the multi-scale impacts of Arctic change on natural and built environments and social systems and broadly disseminate research outcomes.

In FY 2017, NSF issued a Dear Colleague letter (DCL) on the Growing Convergence Research Big Idea (NSF 17-065)[1] to explore convergence approaches within four of the research-focused NSF Big Ideas, including NNA. This DCL requested proposals for Research Coordination Networks (RCNs), workshops, and activities to enhance Arctic observational systems. In FY 2018, NSF issued a DCL on Stimulating Research Related to NNA (NSF 18-048),[2] requesting research proposals building on the FY 2017 awards, as well as proposals for workshops and RCNs. NSF awarded 25 new projects under these two DCLs and related opportunities with budgets ranging from $50,000 to $1.50 million lasting up to 60 months. In FY 2019, NSF issued a solicitation for NNA (NSF 19-511)[3] and made 13 awards to support research projects, and eight awards to support planning projects that will develop convergence research teams, with budgets ranging from $13,000 to $3.0 million lasting up to 60 months.

FY 2021 Investments

NSF's NNA activities in FY 2021 will focus on enabling advances in priority areas, which will be developed by building on outcomes from FY 2017 to FY 2020 activities. In FY 2020, NNA is focusing on convergent social/built/natural environment systems science; advances in observation, communication, and computation and data systems; and community-coordination activities. In FY 2021, NSF will continue support for NNA, and expects to issue another solicitation.

NSF will continue to coordinate and leverage NNA-related activities with external stakeholders, including:

- other federal agencies through the Interagency Arctic Research Policy Committee chaired by the NSF Director;
- local residents and indigenous peoples through state and local governance structures of Alaska; and
- international partners through fora such as the biannual International Arctic Science Ministerial.

The portfolio of FY 2021 NNA activities will support the goals listed above.

[1] www.nsf.gov/pubs/2017/nsf17065/nsf17065.jsp
[2] www.nsf.gov/pubs/2018/nsf18048/nsf18048.jsp
[3] www.nsf.gov/pubs/2019/nsf19511/nsf19511.htm

THE QUANTUM LEAP (QL)

QL Funding[1]
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
Stewardship Activities (MPS)	**$30.02**	**-**	**$50.00**
Foundational Activities	**$28.42**	**-**	**$34.36**
BIO	-	-	0.95
CISE	1.87	-	2.00
ENG	4.15	-	1.90
MPS	21.40	-	28.51
OISE	1.00	-	1.00
Total	**$58.44**	**-**	**$84.36**

[1] Funding for QL and QIS overlaps in some areas. Thus, it should not be summed across presentations.

Overview

The QL Big Idea builds upon and extends existing knowledge of the quantum world to observe, interact with, and control, from first principles, the behavior of particles at atomic and subatomic scales. It enables discoveries in both naturally occurring and engineered quantum systems and will develop next generation quantum technologies and devices for sensing, information processing, communications, and computing. These advances will unleash the potential of the Nation's quantum-based scientific enterprise to enhance the Nation's well-being, economy, and security. NSF's investment in QL is aligned with the Administration's Quantum Information Science (QIS) effort as well as Congressional priorities as noted in the National Quantum Initiative (NQI) Act, P.L. 115-368.[1]

In its third year of investment in QL, NSF envisions continuing to advance fundamental understanding of how quantum phenomena at the subatomic scale are manifested at the macroscopic scale. Discovery will lead to new methods of characterization and control, enhance predictive and modeling capabilities, and catalyze new computing, networking, and measurement paradigms. Cross-disciplinary approaches, combining experimentation, computation, and theory, will help to identify the knowledge and skills necessary for the responsible conduct of quantum research to make fundamental advances in quantum science.

Educational research on the learning and teaching of quantum concepts will contribute to the development of the future quantum workforce. QL investments will empower U.S. scientists and engineers to advance quantum technologies and understanding, which will in turn lead to the discovery of novel materials, tools, devices, algorithms, simulations, systems, and programming paradigms, as well as new and creative application domains, along with a quantum-capable workforce. NSF will also broadly engage scientific, engineering, and educational communities to build a human capital foundation in pursuit of a better understanding of quantum phenomena.

Consistent with and crucial to its mission, NSF will form partnerships with other federal agencies, industry, private foundations, national laboratories, and existing centers in order to leverage NSF's investments in QL. NSF coordinates QL activities with other federal agencies through the National Science and

[1] www.congress.gov/115/bills/hr6227/BILLS-115hr6227enr.pdf

Technology Council Subcommittee on Quantum Information Science (SCQIS). NSF also seeks to increase international cooperation with like-minded partners consistent with the SCQIS National Strategic Overview for QIS.[2]

Goals

1. Understand fundamental limitations in time, distance, and scale for entanglement and coherence of quantum states.
2. Learn from quantum phenomena in naturally occurring and engineered quantum systems, including emergent behavior, complexity, the quantum-classical boundary, and theoretical foundations.
3. Galvanize the science and engineering community to enable quantum discoveries, devices, systems, and technologies that surpass classical capabilities.
4. Prepare an effective and diverse workforce to participate in and lead further advancements in quantum science and engineering.

FY 2021 Investments

In FY 2021, QL activities will focus on enabling advances in selected priority areas, building on outcomes from FY 2019 and FY 2020 activities, and adjusting emphases, as warranted, to address new emerging areas. In FY 2019, NSF initiated two center-scale, cross-directorate activities resulting in awards that will continue to receive funding in FY 2021. Awards made through the solicitation, "Enabling Quantum Leap: Convergent Accelerated Discovery Foundries for Quantum Materials Science, Engineering, and Information,"[3] will provide support for accelerated quantum materials design, synthesis, characterization, and translation for quantum devices, systems, and networks. The "Quantum Leap Challenge Institutes (QLCI)"[4] solicitation called for proposals for quantum institutes that will receive the first year of funding in FY 2020. As part of the QLCI solicitation, in FY 2019, NSF also supported conceptualization grants for workshops and related activities that are helping teams to coalesce and develop institute proposals for competition in a second round of review; the institutes selected from the second round will receive the first year of funding in FY 2021. QLCI research will identify and address science and engineering challenges in fundamental at-scale problems in quantum communication, quantum computing, quantum sensing, and quantum simulations.

[2] www.whitehouse.gov/wp-content/uploads/2018/09/National-Strategic-Overview-for-Quantum-Information-Science.pdf
[3] www.nsf.gov/funding/pgm_summ.jsp?pims_id=505504
[4] www.nsf.gov/publications/pub_summ.jsp?org=NSF&ods_key=nsf19559

UNDERSTANDING THE RULES OF LIFE: PREDICTING PHENOTYPE (UROL)

URoL Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
Stewardship Activities (BIO)	**$30.00**	**-**	**$30.00**
Foundational Activities	**$108.24**	**-**	**$109.26**
BIO	58.80	-	57.00
CISE	7.66	-	4.75
ENG	5.63	-	2.85
GEO	4.00	-	3.80
MPS	27.30	-	37.06
SBE	4.85	-	3.80
Total	**$138.24**	**-**	**$139.26**

Overview

The URoL NSF Big Idea aims to create a new paradigm at the convergence of science, engineering, and technology that will elucidate theoretical frameworks, or rules, to enable prediction of the diversity of solutions that biological systems use to support life processes. Advances in understanding life at the fundamental level of the genome will enable re-engineering of cells, organisms, and ecosystems, and innovative biochemicals and biomaterials that sustain a vibrant bioeconomy and strengthen society. URoL also aims to train the next generation of researchers capable of using those rules and theories not only to predict the behavior of living systems, but to design them to benefit humankind.

Associated with URoL, NSF funds convergent research across the Foundation that addresses questions from the molecular to the ecosystem scale, and across biological diversity. These include foundational research on genetic variation and phenotypic emergence; the ethical and social implications and societal acceptance of new biotechnologies, such as tools for genetic engineering and synthetic biology; ecological forecasting; and machine learning to predict phenotype. In addition, in FY 2021, NSF will fund new awards in mathematical and physical sciences that utilize theory and novel experimental tools to address fundamental problems in biological systems and build capacity in a convergent research domain; new programs in synthetic biology that enable creation of novel chemicals, materials, and engineered systems; and infrastructure that further enables URoL research. These associated activities align with the Administration's R&D budgetary priorities and are expected to continue in FY 2022.

In FY 2018, NSF released several Dear Colleague Letters to announce URoL opportunities for catalytic activities. Building on those, in FY 2019, NSF made 38 new awards for 14 collaborative projects in response to two Foundation-wide URoL solicitations: *Understanding the Rules of Life: Building a Synthetic Cell: An Ideas Lab Activity*[1] and *Understanding the Rules of Life: Epigenetics*.[2] The awards, totaling $36 million, demonstrate NSF's commitment to applying interdisciplinary approaches to uncovering the rules, and their exceptions, that govern the essential features of life at all scales, from cells to ecosystems. In FY 2020 NSF anticipates funding projects in response to the re-issued *Understanding the Rules of Life: Epigenetics* solicitation*,* and in response to a new NSF-wide solicitation, *Understanding the Rules of Life: Microbiome Theory and Mechanisms*.[3] Also in FY 2020, NSF will invite proposals for research networks to build

[1] www.nsf.gov/funding/pgm_summ.jsp?pims_id=505600
[2] www.nsf.gov/funding/pgm_summ.jsp?pims_id=505582
[3] www.nsf.gov/funding/prgm_summ.jsp?pims_id=505694

capacity in URoL research domains. NSF anticipates that URoL will run through FY 2023.

Goals

1. To support a convergence of science, engineering, and technology in discovery of rules governing the emergence of robust, resilient, and adaptable phenotypes at three levels of biological organization, across the tree of life: (1) cells and cell systems; (2) multi-cellular organisms and their co-dependent microbial associations; and (3) complex networks of organisms and species involving social, ecological, and population dynamics. These rule sets are referred to as, respectively, minimal rules, interaction rules, and complexity rules. Understanding the rules at these three different scales should enable the prediction of the behavior of living systems and how those systems interact with, respond to, and modify the environment, and will facilitate the engineering of biological systems and enable new forms of bio-manufacturing that are ethically sound, societally acceptable, and that can benefit humankind.
2. To support the discovery of scale-invariant rules that govern living systems. These theories will begin to explain the existence of a diversity of solutions that biology creates and uses to solve the essential problems of living systems at all scales: maintenance and transmission of information (genome); capture and conversion of raw materials to make biochemicals and biomaterials that make up a living system; capture and conversion of energy to support all life processes; and reproduction to perpetuate the species. These universal, scale-invariant rules will serve to help improve human health and safety (e.g., agricultural adaptability, food safety, environmental sustainability, and disease prevention).
3. To support networks of researchers, technology developers, and educators engaged in URoL activities and thereby further the development of a robust community, with an impact that is sustained beyond the five-year investment in the URoL Big Idea. The convergent nature of research addressing emergent properties of life should stimulate technological innovation that feeds back to drive the science forward. This includes development of: new and improved techniques in molecular, genomic, and cellular examination and manipulation; improved technologies for the capture of biological, behavioral, and social phenotypic data in free-living organisms, including new sensors and observing capabilities from nano- to macro-spatial and temporal scales; advances in data analysis, such as machine learning, as well as computation and complex modeling to support learning and simulation-driven URoL investigations; more capable cyberinfrastructure to support robust, data- and computational-enabled URoL discovery and sharing of research results; and advances in theory coming from all of these sciences and engineering. The predictive goals of URoL also guide investments in training and workforce development to produce scientists that have a firm grounding in the life sciences as well as the mathematical, physical, computational, behavioral and/or social sciences and engineering that enable them to work collaboratively across disciplinary boundaries. Finally, URoL provides a rich context in which to expand science-literacy efforts, in both formal and informal learning environments, aimed at diverse communities across the nation. Research networks provide a mechanism for sustained support of distributed groups of investigators working to achieve URoL goals.

FY 2021 Investments

URoL activities in FY 2021 will build upon the investments made in FY 2019 and FY 2020. The FY 2020 solicitation supporting microbiome research will continue in FY 2021, enabling deeper exploration of interaction rules (Goal 1). A new solicitation will be developed to support research that addresses convergence approaches for the discovery of scale-invariant rules that govern living systems (Goal 2). The URoL: Research Networks solicitation that will be released in FY 2020 will also continue in FY 2021, supporting networks of researchers, technology developers, and educators in different URoL domains (Goal 3). URoL-associated activities include continued support of convergent programs initiated in FY 2019 and planned for FY 2021 across all directorates, most of which address Goals 1 and 3.

WINDOWS ON THE UNIVERSE (WOU)

WoU Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
Stewardship Activities (MPS)	**$30.00**	**-**	**$30.00**
Foundational Activities	**$17.68**	**-**	**$22.90**
MPS	17.68	-	21.00
OPP	-	-	1.90
Total	**$47.68**	**-**	**$52.90**

Overview

For millennia, humankind has viewed the universe through the optical part of the electromagnetic spectrum to which human eyes are sensitive. Over the last half century, this range has been extended to observe electromagnetic radiation across the full spectrum from radio waves to X-rays and gamma rays. Observatories constructed and operated over the past two decades have extended this view to include high-energy particles such as neutrinos and cosmic rays. Most recently, with LIGO, NSF has established the ability to view the universe through gravitational waves. This ushers in the era of multi-messenger astrophysics. The three messengers—electromagnetic radiation, high-energy astrophysical particles, and gravitational waves—each provide unique information. Together, they provide a detailed picture of the Universe that allows scientists to study matter, energy, and the cosmos in fundamentally new ways—through several powerful and diverse "windows". WoU builds these capabilities and accelerates the synergy and interoperability of the three messengers to realize integrated, multi-messenger astrophysical exploration of the Universe.

Prior investments have led to important recent discoveries that demonstrate the power of WoU. The coincident detection of gravitational waves and electromagnetic radiation identified a merging binary neutron star system, confirmed Einstein's theory of General Relativity, and revealed critical information on the origin of heavy elements. Recent observations of high energy neutrino emission coincident with gamma-ray flares from the nucleus of an active galaxy have revealed for the first time an astrophysical source of high energy cosmic rays. These discoveries, along with others, have heralded the era of multi-messenger astrophysics.

WoU is anticipated to be a 10-year effort and builds upon decades of prior investments in individual and large-scale efforts. These include both presently operating observatories such as IceCube (for the detection of high-energy neutrinos) and LIGO (for the detection of gravitational waves) as well as development efforts for future experiments. In the FY 2019 Request, stewardship funding for WoU was first introduced and was complemented by the ongoing investments in foundational activities aimed at building capabilities for each of the three messengers. This funding strategy (stewardship funding supplemented with investments in foundational activities) will continue in FY 2021. These investments will also serve to grow the workforce not only for multi-messenger astrophysics but also for engineering, data science, and many other areas.

Goals

1. *Enhancing and accelerating the theoretical, computational, and observational activities within the scientific community*: Support efforts within the scientific community to build the observational and analysis capabilities in each of the three window areas, integrate the different research communities to

develop full interoperability between the three windows, and develop a new workforce that is skilled in this new paradigm.

2. *Building dedicated instrumentation and capabilities*: Construct experiments and instrumentation or develop cyberinfrastructure that will make critical contributions to the multi-messenger research infrastructure by enabling new capabilities in energy range or sky coverage, improved sensitivity, or new experimental or computational capabilities. The Big Idea: Mid-scale Research Infrastructure program, described elsewhere in this chapter, is an essential part of realizing this goal.
3. *Exploiting current facilities and developing the next generation of observatories*: Enhance infrastructure and provide modest upgrades to enable full utilization of the current generation of multi-messenger facilities, and support planning and development for the next generation of observatories to accelerate progress to realize significantly greater capabilities and extend the scientific reach.

FY 2021 Investments

WoU continues to be implemented through a dedicated program, "Windows on the Universe: The Era of Multi-Messenger Astrophysics (WoU-MMA)."[1] The WoU-MMA program includes the Division of Astronomical Sciences and the Division of Physics within MPS, and OPP within GEO. The WoU-MMA program will address all of the WoU goals. Stewardship funding ($30.0 million) resides in the MPS Office of Multidisciplinary Activities but will be allocated to awards from all participating divisions and directorates on the basis of merit and portfolio balance. Participating divisions and offices may elect to supplement this allocation through foundational activities in core research programs in order to advance particularly compelling scientific opportunities related to WoU. For MPS this is expected to be primarily through research grants in astronomy, particle astrophysics, and gravitational physics. OPP will supplement the WoU allocation with grants from the Antarctic Astrophysics and Geospace Sciences program. Other NSF divisions may participate where activities originating in their divisions meet the WoU criteria.

[1] PD 18-5115: www.nsf.gov/funding/pgm_summ.jsp?pims_id=505593

GROWING CONVERGENCE RESEARCH (GCR)

GCR Funding
(Dollars in Millions)

FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
$15.80	**-**	**$15.20**

Overview

Growing Convergence Research (GCR) is an enabling idea within NSF's Big Ideas that empowers the U.S. research community to leverage multiple scientific and engineering (S&E) disciplines and develop novel research strategies to address extremely challenging and complex problems. GCR research challenges are inspired by deep scientific questions or pressing societal needs and require the integration of multi-disciplinary perspectives.

The grand challenges of today—such as exploring the universe at all scales; developing infrastructure resilient to extreme events and geo-hazards; combining biology, physical sciences, engineering, computer and cognitive science to produce the machines and materials of the future; and creating the breakthroughs that will enable the industries of the future—will not be solved by one discipline alone. They require convergence: the merging of ideas, approaches, tools, and technologies from widely diverse fields of knowledge to stimulate innovation and discovery. Convergence research is a means of solving complex research problems that have two unifying characteristics: (1) they have the potential to make a significant impact, either on fundamental understanding in S&E or on the Nation's ability to meet pressing societal challenges, or both; and (2) they require the integration of knowledge, tools, and ways of thinking from multiple disciplines.

NSF's GCR responds in part to recommendations from major reports describing the importance of convergence for the research ecosystem. Key reports include National Academies of Science, Engineering, and Medicine reports from 2014[1] and 2017,[2] Massachusetts Institute of Technology (MIT) reports from 2011[3] and 2016,[4] and a 2013 report published by Springer.[5] These reports emphasize the importance of convergence approaches to S&E research to address grand challenges and underline the importance of team science to such efforts. These reports also emphasize the role of federal funding agencies in realizing the benefits of convergence by expanding mechanisms for funding convergence research.

Goals

Since the GCR Big Idea began in FY 2017, the goals of GCR are to:
1. Catalyze convergence approaches to solve compelling scientific and engineering research problems at the intersection of existing disciplines; and
2. Enhance NSF's review process to more effectively assess the merit of convergence research proposals.

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[1] Convergence: Facilitating Transdisciplinary Integration of Life Sciences, Physical Sciences, Engineering, and Beyond. Washington, D.C.: The National Academies Press. www.nap.edu/catalog/18722/convergence-facilitating-transdisciplinary-integration-of-life-sciences-physical-sciences-engineering
[2] *A New Vision for Center-Based Engineering Research*. Washington, DC: The National Academies Press. www.nap.edu/catalog/24767/a-new-vision-for-center-based-engineering-research
[3] The Third Revolution: The Convergence of the Life Sciences Physical Sciences, and Engineering. Cambridge, MA: MIT www.aplu.org/projects-and-initiatives/research-science-and-technology/hibar/resources/MITwhitepaper.pdf
[4] Convergence: The Future of Health. Cambridge, MA: MIT. www.convergencerevolution.net/s/Convergence-The-Future-of-Health-2016-Report-55pf.pdf
[5] Convergence of Knowledge, Technology, and Society. www.springer.com/us/book/9783319022031

Approach

GCR will strengthen the global competitiveness of the U.S. S&E enterprise by growing a new generation of convergence researchers skilled at working in teams and able to respond rapidly to new research challenges. To support convergence research, NSF is enhancing its review processes to address the key technical, organizational, and logistical challenges that hinder the evaluation of truly integrative research. GCR's strategic investments in emerging convergence research themes will support the development of new fields of inquiry, discovery of the knowledge necessary for society to develop solutions or technologies to address important societal challenges, and training in convergence research.

GCR uses several mechanisms to accomplish programmatic goals, including:

- *Capacity-Building Activities*: GCR seeks to broaden the range of those engaged in convergence efforts. A portion of GCR funds is invested in capacity-building activities, such as workshops, Ideas Labs, and Research Coordination Networks (RCNs). NSF remains open to novel approaches to capacity-building that may be suggested by researchers and other stakeholders. One goal of capacity-building is to foster new partnerships between U.S. academic researchers and other sectors such as industry, federal laboratories, non-profit research organizations, and the international research community. Another emphasis is to broaden demographic diversity of teams participating in convergence research. GCR began by funding capacity-building activities to address grand challenges within NSF's Big Ideas.
- *Exploratory Grants*: GCR exploratory research grants enable research teams to: demonstrate their ability to collaborate effectively; resolve epistemological and ontological differences between disciplines; integrate conceptual models, tools, methodologies, and infrastructure; and show progress on their convergence research projects. Exploratory grants are expected to have budgets of up to $3.60 million and durations of up to five years. Exploratory grants will prepare research teams for larger scale convergence research awards through programs such as Science and Technology Centers, Engineering Research Centers, and NSF Research Traineeships. NSF announced the first exploratory grant opportunity in FY 2018.[6] In February 2019, NSF released a GCR solicitation, NSF 19-551,[7] which announced funding opportunities for FY 2019 and FY 2020.
- *Enhanced Merit Review Process*: An enhanced merit review process is employed for convergence research projects. NSF identified a cadre of experienced convergence researchers using data-mining tools, the knowledge of program staff, and suggestions from learned societies to evaluate GCR research projects. A diverse pool of researchers to participate were then invited in a College of Reviewers (CoR), which is a group of about 100 distinguished researchers that enables NSF staff to recruit appropriate reviewers for convergence research and was used to review proposals submitted in response to the FY 2019 GCR solicitation.

FY 2021 Investments

- *Capacity-Building Activities:* As part of catalyzing convergence, up to four capacity-building activities in emerging convergence research themes are anticipated, each at up to $150,000.
- *Exploratory Grants*: Investments will focus on two phases: (1) catalyzing convergence of new teams at the intersection of existing disciplines (six to eight new research collaborations, each funded at up to $600,000 per year for the first two years); and (2) continuing support of teams funded in 2019 who have demonstrated significant progress on their convergence research projects.[8]
- *Enhanced Merit Review Process*: Additional experts will be recruited to expand the Convergence CoR.

[6] "Dear Colleague Letter: Growing Convergence Research," (NSF 18-058) www.nsf.gov/pubs/2018/nsf18058/nsf18058.jsp. This resulted in seven awards in FY 2018 and three in FY 2019.

[7] www.nsf.gov/publications/pub_summ.jsp?WT.z_pims_id=505637&ods_key=nsf19551. In FY 2019, this led to 11 collaborative research project awards.

[8] The second phase of projects will be funded up to $800,000 per year and may continue for up to three years pending successful yearly progress.

INCLUSION ACROSS THE NATION OF COMMUNITIES OF LEARNERS OF UNDERREPRESENTED DISCOVERERS IN ENGINEERING AND SCIENCE (NSF INCLUDES)

NSF INCLUDES Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
EHR	$20.01	-	$18.92
ENG	0.20	-	-
Total	**$20.20**	**-**	**$18.92**

Overview

The NSF INCLUDES Big Idea aims to develop a talented, innovative, and capable STEM workforce that reflects the diversity of the Nation. For the United States to remain the world leader in STEM innovation and discovery, it must identify and develop talent from all sectors to become tomorrow's STEM professionals. Providing opportunities and support for members of all communities and sectors across the Nation reflects NSF's commitment to broadening participation and is vital for the Nation's economic welfare, which aligns with the Administration's priority crosscutting action to build and leverage a diverse, highly skilled American workforce.

NSF INCLUDES is NSF's response to the Committee on Equal Opportunities in Science and Engineering's (CEOSE) 2011-2012 Biennial Report to Congress.[1] CEOSE recommended that NSF develop "a bold new initiative focused on broadening participation of underrepresented groups in STEM, similar in concept and scale to NSF's centers." As part of NSF's continuing response to CEOSE's recommendation, NSF is investing in developing and sustaining the NSF INCLUDES National Network, a multifaced collaboration of agencies, organizations, and individuals working collectively to scale innovations in pursuit of broadening participation in STEM. The NSF INCLUDES National Network is comprised of NSF INCLUDES Design and Development Launch Pilots,[2] NSF INCLUDES Alliances,[3] and an NSF INCLUDES Coordination Hub.[4] NSF INCLUDES Alliances will serve as test beds for designing, implementing, studying, and refining change models that are based on collective impact-style approaches.[5] Thus, the NSF INCLUDES investment will provide valuable research and evaluation knowledge that will strengthen this initiative and contribute to NSF's understanding of strategies for addressing the Nation's most challenging diversity and inclusion issues. Opportunities to join the NSF INCLUDES National Network have been extended through dear colleague letters and language in multiple program solicitations. Other organizations with an interest in broadening participation in STEM are invited to join and support the goals of the NSF INCLUDES National Network via the Coordination Hub website.[6] The NSF

[1] www.nsf.gov/od/oia/activities/ceose/reports/Full_2011-2012_CEOSE_Report_to_Congress_Final_03-04-2014.pdf
[2] NSF INCLUDES Design and Development Launch Pilots—pilot to address broadening participation planning activities and laying the foundations for potential partners to share common goals and purposes
[3] NSF INCLUDES Alliances: collaborators or partners working to scale best practices in broadening participation
[4] NSF INCLUDES Coordination Hub: collaboration of multiple institutions facilitating activities needed to build and maintain the network
[5] Kania, J., & Kramer, M. (Winter 2011). Collective impact. Stanford Social Innovation Review. Retrieved from: http://ssir.org/articles/entry/collective_impact. Kania and Kramer note that collective impact "requires a systematic approach to social impact that focuses on relationships between organizations and the progress toward shared objectives," p. 5.
[6] www.includesnetwork.org/home

INCLUDES National Network has expanded through the addition of federal agencies that pledged to join following the 2018 release of *Charting a Course for Success: America's Strategy for STEM Education.*[7]

Goals

NSF INCLUDES investments target the following three strategies:

1. *Broadening Participation (BP) in STEM Research*: Synthesize and build the research base for broadening participation in STEM and foster the spread and adaptation of proven effective practices.
2. *Shared Goals and Objectives*: Support stakeholders as they identify shared goals and objectives, including those from specific STEM disciplines.
3. *NSF INCLUDES National Network*: Support local and regional, discipline-specific, and crosscutting, multi-stakeholder partnerships and networks as part of the NSF INCLUDES National Network.

FY 2021 Investments

In FY 2021, NSF plans to invest $18.92 million in NSF INCLUDES, all funded within EHR.

<u>Goal 1: Broadening Participation in STEM Research</u>

- NSF INCLUDES will continue to fund BP projects and related research through NSF INCLUDES Alliances and NSF's existing BP portfolio,[8] such as pilot projects, planning grants, supplements, and starter networks (e.g., research coordination networks) that serve as on-ramps to NSF INCLUDES Alliances and the NSF INCLUDES National Network. NSF INCLUDES also supports the dissemination and adaptation of proven strategies for expanding the use of innovative BP practices.

<u>Goal 2: Shared Goals and Objectives</u>

- NSF will provide ongoing funding to the NSF INCLUDES Coordination Hub to oversee the implementation of a system of measurement, communication, and mutually reinforcing activities across the NSF INCLUDES National Network.
- NSF will support connections of existing NSF BP programs and other NSF-funded projects that support the NSF INCLUDES vision through the NSF INCLUDES National Network.
- NSF will develop a comprehensive evaluation, monitoring, and feedback framework implemented with the NSF INCLUDES Coordination Hub, with indicators and measures for tracking progress towards the achievement of the goals of the NSF INCLUDES National Network and the NSF BP portfolio.

<u>Goal 3: NSF INCLUDES National Network</u>

- NSF will fund NSF INCLUDES Alliances, which are five-year, center-scale projects committed to solving a specific set of objectives. FY 2021 funding will also provide ongoing support to the eight NSF INCLUDES Alliances funded in prior years.
- NSF will regularly convene principal investigators of NSF INCLUDES projects (virtually and face-to-face) to discuss BP challenges, proposed strategies, scaling mechanisms, common metrics, and the feasibility of sustaining projects.

[7] NSTC (2018). Charting a Course for Success: America's Strategy for STEM Education. www.whitehouse.gov/wp-content/uploads/2018/12/STEM-Education-Strategic-Plan-2018.pdf
[8] www.nsf.gov/od/broadeningparticipation/bp_portfolio_dynamic.jsp

MID-SCALE RESEARCH INFRASTRUCTURE (MID-SCALE RI)

Mid-scale RI Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
R&RA (IA/Mid-scale RI-1)[1]	$60.04	-	$32.67
MREFC	-	-	65.00
Total	**$60.04**	**-**	**$97.67**

[1] In FY 2021, The EPSCoR program will invest no less than an additional $20.0 million in Mid-scale RI within EPSCoR jurisdictions

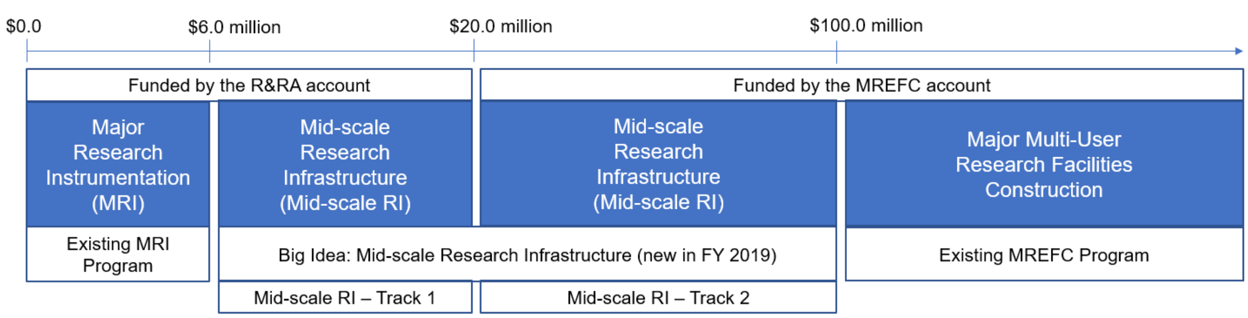
Overview

The Mid-scale RI program is an NSF-wide effort to meet the research community's needs for modern research infrastructure to support priority science and engineering research. Mid-scale RI is an "enabling" Big Idea that implements agile mechanisms for funding experimental research capabilities costing between $6.0 million and $100.0 million.[1] The objective is to transform scientific and engineering research fields with new infrastructure, while simultaneously training early-career researchers in the development, design, construction, and use of cutting-edge infrastructure.

The scientific importance of mid-scale research infrastructure is reflected in the 2017 American Innovation and Competitiveness Act (AICA), which directed NSF to "evaluate the existing and future needs, across all disciplines supported by the Foundation, for mid-scale projects." NSF issued a Request for Information in late 2017 that resulted in nearly 200 ideas for research infrastructure within a project cost range of $20 million to $100 million. Subsequently, FY 2018 appropriations report language directed the NSB to "consider steps to bridge the gap between the NSF's Major Research Instrumentation (MRI) program and the agency's Major Research Equipment and Facility Construction (MREFC) account." Responding to this direction, the NSB report, "Bridging the Gap: Building a Sustained Approach to Mid-scale Research Infrastructure and Cyberinfrastructure at NSF",[2] highlights that:

> "The research community has identified mid-scale research infrastructure as a key enabler of scientific advances on shorter timescales than required for the larger projects funded within the MREFC account. ... Infrastructure investments at the required mid-level can also help maintain the United States' standing among global partners and competitors."

NSF Portfolio of Central Instrumentation and Infrastructure Implementation Programs



[1] The NSF-established thresholds for Mid-scale Track-2 projects have been updated from prior presentations to align with the definitions in AICA.
[2] www.nsf.gov/nsb/publications/2018/NSB-2018-40-Midscale-Research-Infrastructure-Report-to-Congress-Oct2018.pdf

The graphic above shows NSF-wide instrumentation and infrastructure programs. Information presented in this narrative focuses on the Mid-scale RI components, Mid-scale RI - Track 1 (Mid-scale RI-1) and Mid-scale RI - Track 2 (Mid-scale RI-2), which constitute the Mid-scale RI Big Idea. Information on the complementary MRI program may be found in the IA narrative, while information on major multi-user research facility construction projects may be found in the MREFC chapter. The Mid-scale RI program supports the implementation of research infrastructure at scales that are above what is possible through the MRI program and below what has previously been funded through the MREFC account. Mid-scale RI-2 awards will be funded by the MREFC account and are distinguished from Mid-scale RI-1 awards by their scale, potential risks, and the resulting NSF oversight.

In FY 2019, NSF received proposals in response to two Mid-scale RI funding opportunities. One (Mid-scale RI-1, NSF-19-537[3]) included an opportunity to propose Mid-scale RI implementation projects with a total NSF project cost between $6.0 million[4] and $20.0 million, as well as infrastructure design projects with costs between $600,000 and $20.0 million, while a second (Mid-scale RI-2, NSF-19-542[5]) included an opportunity to implement projects with a total NSF cost between $20.0 million and $70.0 million. NSF made ten Mid-scale RI-1 awards, including the development of the first 1.2GHz nuclear magnetic resonance (NMR) facility in the U.S., extremely fast and powerful lasers, a neutron spin echo spectrometer to be deployed at National Institute of Standards and Technology, and a testbed for experiments for future internet designs, as well as support for the design of a future experiment to study the cosmic microwave background. The first awards for Mid-scale RI-2 will be made in FY 2020. The anticipated total number of Mid-scale RI-2 awards made as a result of the first competition is three to six.

Goals

1. Provide access to cutting-edge mid-scale research infrastructure, including instrumentation.
2. Enable agile development and implementation of frontier scientific and engineering research infrastructure with a high potential to significantly advance the Nation's research capabilities.
3. Train early-career scientists and engineers in the development and use of advanced research infrastructure.

FY 2021 Investments

In FY 2021, NSF will invest a total of $117.67 million in Mid-scale RI, split between two separate tracks, Mid-scale RI-1 ($52.67 million) and Mid-scale RI-2 ($65.0 million). Track 1 will be funded through the R&RA account, and Track 2 will be funded through the MREFC account. For Track 1, $32.67 million will be available for investment in projects in any jurisdiction, while no less than $20.0 million will be invested in EPSCoR jurisdictions. Subject to availability of funding in FY 2022, Mid-scale RI-1 funding will support an estimated seven to nine new awards in a funding cycle that will span FY 2021 and FY 2022. It is anticipated that Mid-scale RI-2 funding will provide support for projects funded as a result of the first Mid-scale RI-2 competition that will conclude during FY 2020.

[3] www.nsf.gov/pubs/2019/nsf19537/nsf19537.htm
[4] Design activities to bring Mid-scale or larger projects to readiness for implementation may request a minimum of $600,000.
[5] www.nsf.gov/pubs/2019/nsf19542/nsf19542.htm

ADVANCED MANUFACTURING

Advanced Manufacturing Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
BIO	$4.50	-	$7.16
CISE	41.27	-	39.41
EHR	-	-	2.00
ENG	138.14	-	140.00
MPS	113.94	-	113.78
OISE	-	-	0.50
Total	**$297.85**	**-**	**$302.85**

Overview

Manufacturing is essential to almost every sector of the U.S. economy, from medicine to information technology to transportation. Breakthroughs in manufacturing spur the economy by increasing productivity, enabling new products, and opening new industries. Advanced manufacturing uses innovative technologies to create products and processes with higher performance, fewer resources, and/or new capabilities. NSF programs accelerate breakthroughs in manufacturing materials, technologies and systems through fundamental, multidisciplinary research that transforms manufacturing capabilities, methods and practices.

NSF invests in the Administration's Industry of the Future research and development priority area, advanced manufacturing, to increase U.S. prosperity, as well as our competitiveness, security, and quality of life. Specifically, NSF support will:

- Advance competitiveness through groundbreaking discoveries that lead to manufacturing innovations,
- Secure the supply chain by growing and maximizing the use of U.S. resources (including raw materials, knowledge, and workforce),
- Grow the manufacturing workforce by broadening pathways and fostering communities, and
- Rapidly translate discoveries into useful products and create jobs through collaborations between researchers, entrepreneurs, and industry.

Since its founding in 1950, NSF has pushed the frontiers of manufacturing, sparking breakthroughs from nanomaterials and computer-aided design, to 3D printing and blockchain, as well as tools for real-time, *in situ* feedback and remote sensing.

Today, NSF invests in fundamental research to create new capabilities for chemical and materials synthesis and processing; advanced semiconductors, quantum and optical device design, fabrication and manufacturing; smart manufacturing systems; safe, productive, and collaborative worker-technology interactions; and many other areas of advanced manufacturing. NSF invests in communities and experiential programs to grow and nurture a STEM-enabled manufacturing workforce. NSF also invests in industry partnerships and entrepreneurship to speed manufacturing innovations to the marketplace.

NSF's advanced manufacturing research intersects, builds upon, and contributes to related investments such as biotechnology, synthetic biology, sustainability, artificial intelligence, robotics, sensing, internet of things, data science, and computer modeling. NSF's Big Idea investments in FW-HTF, HDR, and URoL also contribute to advanced manufacturing.

In FY 2020, NSF begins a new effort to enable leadership in future manufacturing by creating knowledge in new sectors based on emerging areas—such as biomanufacturing, cybermanufacturing, and ecomanufacturing—and enable a new generation of manufacturing industries.

Goals

1. Support groundbreaking discoveries for advanced manufacturing that lead to products and processes with higher performance, fewer resources, and/or new capabilities.
2. Create knowledge based on emerging areas to enable a new generation of manufacturing industries that do not exist today, will be compatible with human needs, and will make U.S. manufacturing competitive far into the future.
3. Attract, educate, train and reskill/upskill workers, from K-12 to college and industry, for the manufacturing workforce of the future.
4. Leverage industry partnerships to advance research, transition it to practice, develop the workforce, and create and maintain research infrastructure.

FY 2021 Investments

NSF research accelerates advances in manufacturing with emphasis on multidisciplinary research that fundamentally alters and transforms manufacturing capabilities, methods, and practices. NSF investments will make producing next-generation products and services more efficient and sustainable, and they will lead to advantages such as less time to market, new performance attributes, cost savings, energy savings, and/or reduced environmental impact.

- *Advanced Manufacturing research*: Continued investments in advanced manufacturing include fundamental research on highly connected cyber-physical systems and activities that develop new methods, processes, analyses, tools, or equipment for new or existing manufacturing products, supply chain components, or chemicals and materials. In FY 2020 and FY 2021, the Emerging Frontiers in Research and Innovation program plans to support two areas of advanced manufacturing research: Distributed Chemical Manufacturing (DCheM) and Engineering the Elimination of End-of-Life Plastics (E3P).
- *Future Manufacturing research*: Initiated in FY 2020, the Future Manufacturing investment is fundamental research to enable manufacturing that (a) does not exist or is not possible today, or (b) exists or is possible only at such small scales that it is not yet viable for mass production.
- *Workforce*: To prepare the advanced manufacturing workforce, NSF invests in the Advanced Technological Education, Faculty Early Career Development Program, Grant Opportunities for Academic Liaison with Industry, Research Experiences for Undergraduates, and Research Experiences for Teachers programs, as well as manufacturing engineering education in research projects. NSF support for Non-Academic Research Internships for Graduate Students and I-Corps™ provides students with industrial and entrepreneurship experience.
- *Translation*: NSF speeds translation of fundamental discoveries in advanced manufacturing into products and processes through its Engineering Research Center, Industry–University Cooperative Research Center, and Partnerships for Innovation programs, as well as through NSF Small Business Innovation Research and Small Business Technology Transfer programs. In addition, NSF coordinates with other agencies and participates in the Manufacturing Innovation Institutes, particularly by connecting them to universities and community colleges.

ARTIFICIAL INTELLIGENCE (AI)

Artificial Intelliegence Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request[1]
BIO	$12.53	-	$38.09
CISE	297.00	-	525.44
EHR	-	-	37.59
ENG	119.92	-	159.19
MPS	23.52	-	87.34
SBE	12.25	-	20.44
Total	**$465.21**	**-**	**$868.09**

[1]Includes $30.0 million, split evenly between CISE and ENG, for AI-related research activities in the HDR and FW-HTF Big Ideas. For more information, see the individual Big Idea narratives in this chapter.

Overview

AI is advancing rapidly and holds the potential to vastly transform our lives. NSF has a long and rich history of supporting transformative research in AI, along with the closely related areas of data science and robotics. For example, NSF-funded researchers in the 1990s began working on what is now known as collaborative filtering. Today, collaborative filtering fuels the recommender engines on popular websites like Netflix and Amazon – the "you might also like" suggestions that propel a significant proportion of e-commerce activity. Similarly, NSF investments in understanding learning across the lifespan, in different species and contexts, have contributed to today's deep learning systems.

Today, NSF supports fundamental research, education and workforce development, and access to data and advanced computing research infrastructure that collectively enhance AI. NSF's ability to bring together numerous fields of scientific inquiry—including computer and information science; cognitive science and psychology; economics and game theory; engineering and control theory; ethics; linguistics; mathematics; and philosophy—uniquely positions the agency to lead the Nation in expanding the frontiers of AI. In FY 2021, NSF will increase support for foundational research in AI, including machine learning (ML) and deep learning, natural language technologies, knowledge representation and reasoning, and computer vision, along with the safety, security, robustness, and explainability of AI systems. In addition to foundational research in these areas, NSF also supports translational research that links AI innovation with science and the economy, including agriculture, manufacturing, transportation, and health. Equally important is NSF's investment in education and learning, which grows the human capital and institutional capacity needed to nurture the next generation of AI researchers and practitioners. Finally, advances in AI rely upon access to data as well as NSF-funded advanced computing research infrastructure.

Through collaboration and coordination with the Office of Science and Technology Policy, NSF leadership is helping to drive and coordinate AI R&D efforts across the federal government. For example, the NSF Director co-chairs the National Science and Technology Council's Select Committee on AI, which advises the White House on interagency AI R&D priorities and establishes structures to improve government planning and coordination. In June 2019, the Select Committee issued an update to the 2016 *National Artificial Intelligence Research and Development Strategic Plan*[1] that identified eight strategic priorities and provided a coordinated federal strategy for AI R&D that will help the United States continue to lead

[1] www.nitrd.gov/pubs/National-AI-RD-Strategy-2019.pdf

the world in cutting-edge advances in AI that will grow the economy, increase our national security, and improve quality of life. The goals outlined below directly address many of these strategic priorities.

Goals

1. *Fundamental AI Research:* Invest in fundamental AI research that will give rise to transformational technologies and, in turn, breakthroughs across all areas of science and engineering and across all sectors of society. This includes research investments in:
   - Knowledge representation, planning, human language technologies, ML and deep learning, multi-agent systems, and computer vision;
   - Human-AI collaboration, including the development of AI systems that complement and augment human capabilities, with increasing focus on the future of work;
   - Explainability, fairness, and transparency of AI systems to provide the ability to ensure, assess, and ultimately demonstrate these traits in AI systems; and
   - AI safety and security to develop systems whose decisions are well understood and whose trustworthiness can be measured.
2. *Education and Workforce Development*: Develop AI systems that enhance learning for all and grow the next generation of talent to advance the U.S. AI R&D workforce, including those working on AI systems and those working alongside them.
3. *Access to Data and Advanced Computing Research Infrastructure:* Provide access to advanced, scalable computing resources and enhance the availability of deep, high-quality, and accurate training datasets in order to advance AI research and education.
4. *Public-Private Partnerships:* Continue to pursue collaborations with other federal agencies, industry, and nonprofits to coordinate and accelerate advances in AI research and education.

FY 2021 Investments

<u>Goal 1: Fundamental AI Research</u>
In FY 2021, NSF will build on prior year investments and increase funding for fundamental AI research:
- In FY 2019, NSF and DARPA partnered on the Real-Time Machine Learning (RTML) program to explore high-performance, energy-efficient hardware and machine-learning architectures that can learn from a continuous stream of new data in real time. The NSF-DARPA collaboration on RTML will enable cross-pollination of ideas and co-design of RTML algorithms and hardware through FY 2021.
- In FY 2019, NSF and Amazon began a collaboration to jointly support research focused on AI fairness with the goal of jointly contributing $20.0 million ($10.0 million each) over three years to trustworthy AI systems that are readily accepted and deployed to tackle grand challenges facing society. Specific topics of interest include, but are not limited to, transparency, explainability, accountability, potential adverse biases and effects, mitigation strategies, validation of fairness, and considerations of inclusivity.
- In FY 2020, NSF is partnering with four other federal agencies, the U.S. Department of Agriculture's National Institute of Food and Agriculture, Department of Homeland Security's Science & Technology Directorate, Department of Transportation's Federal Highway Administration, and the U.S Department of Veterans Affairs, on the new National AI Research Institutes program. In FY 2020, NSF plans to fund up to six multidisciplinary, multi-institutional research institutes—at up to $20.0 million each over five years—that will serve as national hubs for universities, federal agencies, industry, and nonprofits to advance AI research and workforce development in key areas while addressing grand challenges. Key foci for the FY 2020 AI Institutes include foundations of ML; trustworthy AI; AI-driven innovation in agriculture and food systems; AI-augmented learning; AI for accelerating molecular synthesis and manufacturing; and AI for discovery in physics. In FY 2021, NSF plans to fund additional AI Institutes.

- Through the HDR Big Idea, NSF will continue to support fundamental research in data science and engineering and with increased support for research on critical new methods and advances in AI, notably in ML and deep learning. In addition, through the FW-HTF Big Idea, NSF will continue to support socio-technical research enabling a future where intelligent technologies collaborate synergistically with humans to achieve broad participation in the workforce and improve the social, economic, and educational benefits across a range of work settings.
- NSF will continue investments in robotics and autonomous systems that exhibit significant levels of both computational capability and physical complexity, including research related to the design, application, and use of robotics to augment human function, promote human-robot interaction, and increase robot autonomy.

<u>Goal 2: Education and Workforce Development</u>

- As part of the National AI Research Institutes program as discussed above, NSF plans to fund an AI Research Institute in Augmented Learning in FY 2020 at up to $20.0 million over five years. AI-Augmented Learning includes AI-driven innovations to radically improve human learning and education writ large—in formal settings (e.g., preK-12, undergraduate, graduate, vocational education); training, on-the-job and across the lifespan; as well as informal settings (e.g., museums, nature centers, libraries; TV/film; crowd-sourcing and citizen science; on-line experiences).
- In support of the 2019 *Federal Cybersecurity Research and Development Strategic Plan*,[2] and the Presidential Executive Order on *America's Cybersecurity Workforce*,[3] NSF will address a critical shortage of cybersecurity educators and researchers in priority areas including the cybersecurity aspects of AI, through the NSF CyberCorps®: Scholarship for Service program.
- In FY 2021, the NSF Graduate Research Fellowship Program (GRFP) will encourage applications from students wanting to conduct AI-related research. The NSF GRFP recognizes and supports outstanding graduate students in NSF-supported STEM disciplines who are pursuing research-based master's and doctoral degrees at accredited United States institutions.
- The NSF Research Traineeship (NRT) program advances graduate education by combining interdisciplinary training with innovative professional development activities to educate the next generation of scientists and engineers capable of solving convergent research problems in areas of national need. In FY 2021, NRT will expand to include a special focus on traineeships in AI.
- In FY 2021, NSF will continue support at the K-12 and undergraduate levels for enhancing the core computer science (CS) and computational thinking (CT) competencies necessary for the next generation of AI researchers and practitioners. For example, NSF's Computer Science for All: Researcher Practitioner Partnerships program will support research and partnership efforts to provide all U.S. students the opportunity to participate in CS and CT education in their schools at the preK-12 levels. Likewise, the Improving Undergraduate STEM Education: Computing in Undergraduate Education program will support teams of Institutions of Higher Education (IHEs) in re-envisioning the role of computing in interdisciplinary collaboration within their institutions. NSF will also encourage partnering IHEs to integrate the study of ethics into their efforts.

<u>Goal 3: Access to Data and Advanced Computing Research Infrastructure</u>

- NSF supports a range of advanced computing systems and services for the full range of computational- and data-intensive research across all areas of science and engineering, including AI. For example, in September 2019, Frontera, the largest and most powerful supercomputer NSF has ever supported, came online to serve the Nation's science and engineering research community. The system, located at the University of Texas at Austin's Texas Advanced Computing Center and named the fifth fastest supercomputer in the world, will enable access to advanced computing resources for AI research. NSF will continue these investments in FY 2021.

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[2] www.nitrd.gov/pubs/Federal-Cybersecurity-RD-Strategic-Plan-2019.pdf

[3] www.whitehouse.gov/presidential-actions/executive-order-americas-cybersecurity-workforce/

- In FY 2019, NSF put in place a five-year cooperative agreement for $5.0 million with the University of California-San Diego, University of California-Berkeley, and University of Washington for the establishment and operation of CloudBank, an entity that will help the computer science community access and use public clouds for research and education by delivering a set of managed services designed to simplify access to public clouds. CloudBank will specifically enable new research in AI by broadening the access and impact of cloud computing across the many fields of computer science research and education.
- For FY 2021, NSF will continue to collaborate with other federal agencies to enable researcher access to deep, high-quality, and accurate federal training datasets.

Goal 4: Public-Private Partnerships

- In FY 2021, pursuant to the other three goals described above, NSF will continue to engage other stakeholders in its portfolio of AI research, education, and infrastructure investments. Specifically, NSF will place a priority on developing partnerships with other federal agencies, like-minded international funders, and especially the private sector, including private industry, foundations, and nonprofits, as an increasingly important means to maximize the scientific, economic, and societal impacts of its investments. A key focal point of the public-private partnerships in AI research, education, and research infrastructure will be via the National AI Research Institutes program, enabling large-scale, long-time-horizon challenges in areas of national importance.

QUANTUM INFORMATION SCIENCE (QIS)

Quantum Information Science Funding[1]
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
BIO	$1.05	-	$3.12
CISE	12.10	-	14.60
ENG	10.19	-	27.84
GEO	-	-	-
MPS	82.50	-	180.80
SBE	0.30	-	-
Total	**$106.14**	**-**	**$226.36**

[1] Funding for QIS and QL overlaps in some areas. Thus, it should not be summed across presentations.

Overview

Research in Quantum Information Science (QIS) will advance fundamental understanding of uniquely quantum phenomena that can be harnessed to promote information processing, transmission, and measurement in ways that classical approaches do less efficiently, or not at all. Current and future QIS applications differ from prior applications of quantum mechanics, such as lasers, transistors, and magnetic resonance imaging, by using distinct quantum phenomena—superposition and entanglement—that do not have classical counterparts. The development of these new applications will form the basis of one of the major technological revolutions of the 21st century. Building upon more than two decades of exploratory discovery, NSF investment in QIS will help propel the Nation forward as a leading developer of quantum technology. These investments are a key component of the Administration's National Quantum Initiative (NQI) to coordinate and expand America's world-leading position in fundamental quantum research.

An effective national strategy for QIS requires use of the full spectrum of talent cross the Nation. In addition, international cooperation with like-minded countries is critical to ensure that discoveries, and their resulting technologies, provide for economic growth and national security. Foundational activities that serve as idea factories will continue to be supported. There will also be special stewardship activities targeting all major areas of computers, communications, sensors, and networking. Special attention as to how these areas connect with each other will accelerate development in all of them and lead to advances in quantum computers, quantum communications networks, quantum sensors that enhance resolution and detection capabilities significantly, and networks that can connect components of quantum systems without loss of fidelity. Continued investments will be made to leverage our understanding of quantum phenomena observed in nature to enable bioinspired design of novel sensing and computing devices. Outreach to fields beyond the core of QIS will identify end users of this new technology and help establish the market for new tools and applications from security to biomedical. Ultimately, this work will allow quantum technology to become established on a sound footing and play a recognizable role in the US economy.

Goals

1. Answer key science and engineering questions in order to facilitate the translation of fundamental knowledge into technological applications.
2. Deliver proof-of-concept devices, applications, tools, or systems with a demonstrable quantum advantage over their classical counterparts that will form the basis of a revolutionary 21st century technology.

3. Empower the full spectrum of talent to which NSF has access to build the capacity necessary to achieve goals one and two and generate the quantum-literate workforce that will implement the results of these breakthroughs.

FY 2021 Investments

Workforce Development: The development of a broad-based, diverse workforce is a primary. Proposed activities include: (1) expansion of the highly successful joint industry-academia graduate program to additional hubs; (2) support for Research Experience for Undergraduates sites and supplements to existing awards dedicated to quantum; (3) support for summer schools and targeted programs to expand participation across the Nation, especially to groups and geographic locations that are not currently heavily involved; (4) support for a faculty fellows program to grow capacity in the computer science community related to quantum computing; and (5) support for personnel exchange with international partners.

Centers: NSF will continue its investment in the quantum foundries and Quantum Leap Challenge Institutes initiated in FY 2020 and add additional Quantum Leap Challenge Institutes following a second round of competition in FY 2021. Institutes will seek industry partnerships as well as like-minded international partners whose investments complement our own.

Quantum Simulators: Development and use of quantum simulators has promise for connecting quantum developers with communities that have extensive computational needs. Earlier NSF investment in quantum simulators has resulted in several promising directions that are ready for further exploitation. NSF would enable this through a meta-program, a convergent approach that has proven to have enhanced flexibility in making real-time adjustments to accommodate new areas of science.

Quantum Sensors: Quantum sensors offer the most recognized near-term end-user applications of second-generation quantum technologies. Potential users cover the scientific spectrum, from precision measurements in physics to high-resolution imaging in biology to seismology in earth sciences. Exploiting the potential offered by quantum-based sensors relies on establishing close connections between the builders and the users. NSF would achieve this through a series of Research Coordination Networks and "Dear Colleague" letters emphasizing areas of mutual interest.

Quantum Interconnects: While the exact implementation of quantum processing nodes and qubits is still the topic of research and debate, the information between the quantum processing nodes will most likely be carried by photons. Therefore, interfacing different types of qubits with photons is critical for the realization of scalable distributed quantum computational systems as well as for coherent connections between quantum platforms dedicated to computing, communication, and/or sensing. NSF will support convergent and cross-disciplinary teams of engineers, computer scientists, and physical scientists to develop basic research results that enable emerging quantum computing systems to interface with each other as well as with existing traditional computing systems.

Quantum Computing: Much progress has been made in superconducting and ion-trap quantum computing architectures, and NSF continues to invest in ways to scale these by at least a factor of ten or more. However, there is yet no single platform that has emerged as the leading contender, and multiple architectures might simultaneously co-exist to support distinct types of quantum computations enabled by each. NSF will continue exploring alternative quantum computing architectures that could emerge as viable options in the future as well as the basic underpinnings and limits of quantum computing as defined by the underlying physical processes and architectures. At the same time, in collaboration with industry, NSF will support researcher access to quantum systems and platforms to experiment in specific domains.

SPECTRUM INNOVATION INITIATIVE (SII)

SII Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
Stewardship Activities (MPS)	**-**	**-**	**$17.00**

Overview

The electromagnetic spectrum plays a crucial role in many ways for the United States, including scientific investigation of the world around us, public safety and security, and the provision of a tremendous range of commercial services and products. The objective of the SII is to expand upon NSF's portfolio in this area to promote dynamic and agile electromagnetic spectrum utilization, while ensuring innovation and security for all users, including for both new active spectrum applications and for spectrum used for non-communication purposes. Reaching this objective will require basic research, infrastructure development, new collaborations, public outreach, education and workforce development.

Goals

As demands for spectrum availability have increased, the need to more efficiently and robustly use this limited natural resource to meet multiple goals has also increased. An increasing demand for broadband services, such as the coming 5G and beyond networks, and the need for a spectrum supply necessary for scientific research, such as atmospheric modeling, are two of the major sources of demand for spectrum availability, and innovation is required to solve the challenge of achieving the most efficient spectrum utilization for these and other purposes. While NSF has supported successful spectrum research activities for many years, the SII represents an increased and sustained commitment on a larger and more interdisciplinary scale. This initiative will result in increased industry, research, and societal capabilities through more efficient use of the electromagnetic frequency spectrum. Enhancing efficient spectrum utilization and access is vital to the national interest, including both the scientific enterprise and industries of the future.

The primary goals of the SII include the following:
1. Develop the concept and infrastructure for National Radio Dynamic Zones, which can be used for testing of dynamic spectrum utilization techniques while minimizing regulatory hurdles that slow innovation.
2. Establish and sustain an interdisciplinary National Center for Wireless Spectrum Research, which will bring teams of scientists, engineers, computer scientists, and social scientists together to innovate, developing new solutions that enable more efficient use of the electromagnetic spectrum.
3. Integrate the National Radio Dynamic Zones and the National Center for Wireless Spectrum Research with the frontier research currently being conducted through other NSF programs and facilities. Those programs include the NSF-industry partnership in Platforms for Advanced Wireless Research (PAWR), the Spectrum and Wireless Innovation enabled by Future Technologies (SWIFT) program, and NSF facilities performing cutting edge scientific research such as the Green Bank Observatory, the National Radio Astronomy Observatory, and the National Center for Atmospheric Research.
4. Develop the workforce needed to research and implement the dynamic and agile spectrum utilization techniques that will secure access to the spectrum for receive-only systems and enable the broadband applications of the future.
5. Develop increased public awareness of the scarcity of the electromagnetic spectrum resource, and the challenges associated with its scarcity and its efficient use.

FY 2021 Investments

Investments in FY 2021 include the following:

- *National Radio Dynamic Zones ($9.40 million)*: This investment includes enhancements in active electromagnetic spectrum management efforts at NSF's major research facilities ($1.40 million) as well as computing infrastructure and hardware research and development to support the National Radio Dynamic Zones ($8.0 million).
- *National Center for Wireless Spectrum Research ($5.0 million)*: This investment creates and sustains an interdisciplinary SII-Center that will bring together a diverse group of researchers that serve as a hub to develop, innovate and sustain new solutions that enable more efficient use of the electromagnetic spectrum.
- *Integration activities ($1.60 million)*: This investment will integrate ongoing NSF activities, including SWIFT research and the support of national and international spectrum regulatory efforts, with the National Radio Dynamic Zones and the National Center for Wireless Spectrum Research.
- *Workforce development and public outreach ($1.0 million)*: The investment in workforce development will include fellowships associated with the above efforts and research funded through SWIFT and PAWR, as well as Research Experiences for Undergraduates. The public outreach efforts will include supplements to existing awards that enable enhanced public awareness of the electromagnetic spectrum and the challenges associated with its scarcity and its efficient use.

These investments represent a new cross-disciplinary, NSF-wide focus on spectrum innovation.

NSF INNOVATION CORPS (I-CORPS™)

I-Corps™ Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
BIO	$1.00	-	$1.00
CISE	11.70	-	13.11
ENG	17.33	-	14.63
GEO	0.60	-	0.60
MPS	1.70	-	1.61
SBE	0.50	-	0.47
Total	**$32.82**	**-**	**$31.42**

Overview

The NSF Innovation Corps (I-Corps™) program connects NSF-funded science and engineering research with the technological, entrepreneurial, and business communities, fostering a national innovation ecosystem that links scientific discovery with technology development, societal needs, and economic opportunities. The goal of the I-Corps™ program, created in 2011 by NSF, is to reduce the time and risk associated with translating promising ideas and technologies from the laboratory to the marketplace. The I-Corps™ curriculum uses experiential learning of customer and industry discovery, coupled with first-hand investigation of industrial processes, to quickly assess the translational potential of inventions. The program is designed to support the commercialization of deep technologies, or those revolving around fundamental discoveries in science and engineering. The I-Corps™ program addresses the skill and knowledge gap associated with the transformation of basic research into deep technology ventures.

In 2017, the *American Innovation and Competitiveness Act* (AICA, Public Law 114-329, Sec. 601) formally authorized NSF to carry out, further develop, and expand the I-Corps™ program and other training programs that focus on education in entrepreneurship and commercialization. In the program's initial phase, I-Corps™ Nodes and Sites were funded separately to serve as the backbone of the National Innovation Network (NIN). Informed by community feedback and lessons learned over its first eight years, the I-Corps™ program is creating a new phase of the NIN anchored by I-Corps™ Hubs that will begin in FY 2020.[1] Hubs are designed to be capable of more integrated, sustained operation at the scope and scale required to support the expansion of the NSF I-Corps™ program as directed by AICA. This new model will fund Hubs that are envisioned as centers of I-Corps™ entrepreneurial training and research activities and that represent integration of the existing Nodes and Sites. Any college or university in the country will be able to engage with I-Corps™ activities through one of these Hubs, expanding access to NIN for teams throughout the country.

In alignment with the Administration's priority crosscutting action to build, strengthen, and expand strategic multisector partnerships, the NIN supports innovation research and education, and enhances the development of technologies, products, and processes that benefit society. NIN participants are diverse in research areas, resources, tools, programs, capabilities, and geographic locations, and the network has the flexibility to grow or reconfigure as needs evolve. These components contribute to enhancing and enlarging the NIN's community of mentors, researchers, entrepreneurs, and investors.

[1] www.nsf.gov/funding/pgm_summ.jsp?pims_id=505760&org=NSF

The I-Corps™ program supports NSF's strategic vision of "a Nation that is the global leader in research and innovation." Specifically, I-Corps™ contributes directly to strategic objectives in NSF's FY 2018-FY 2022 Strategic Plan, including Objective 1.1, to "advance knowledge through investments in ideas, people, and infrastructure"; Objective 2.1, to "support research and promote partnerships to accelerate innovation and to provide new capabilities to meet pressing societal needs"; and Objective 2.2, to "foster the growth of a more capable and diverse research workforce and advance the scientific and innovation skills of the Nation."

Goals

The specific goals of the I-Corps™ program are to:
1. Capitalize on NSF's investment in fundamental research and identify, develop, and support promising ideas with commercial potential.
2. Create and implement tools, resources, and training activities that offer academic researchers an opportunity to learn first-hand about technology-based innovation and entrepreneurship.
3. Connect academic researchers with entrepreneurship resources, industrial mentors, startup investors, and peers conducting translational research and commercialization.
4. Provide diverse communities of student innovators with real-world knowledge through curriculum and first-hand participation in transforming scientific and engineering discoveries to meet societal needs.
5. Share and leverage effective innovation practices on a national scale to improve the quality of life for all Americans.

FY 2021 Investments

The new phase of the I-Corps™ program has two components:
- I-Corps™ Teams are funded at $50,000 per Team with a duration of six months. NSF currently funds approximately 240 teams per year. NSF will grow the number of Teams trained through partnerships with other federal agencies and programs, states, and regional organizations.
- New I-Corps™ Hubs will be supported for up to five years, funded at up to $3.0 million per year.

NSF will continue to pursue potential scaling, through the I-Corps™ Hubs introduced in FY 2020 and other means. This strategy calls for new mechanisms to provide I-Corps™ curriculum and experience to a much larger community of technology innovators and entrepreneurs, particularly those without prior connections with NSF and who may not otherwise have access to the I-Corps™ curriculum. The expanded community will include local and regional entrepreneurs, university spinoffs, and awardees of other federal agencies, state governments, and non-profit organizations. By leveraging existing entrepreneurial and innovation capacities in universities and tapping into federal, state, and regional resources, the I-Corps™ NIN holds significant potential to reach a larger number of budding and existing innovators and entrepreneurs.

NSF will continue to build NIN partnerships with stakeholders, including federal agencies, state governments, universities, and non-profit organizations. Current partnerships with the Department of Energy and the National Institutes of Health are outlined in the first AICA I-Corps™ report.[2] NSF also has Memoranda of Understanding in place with the U.S. Department of Agriculture, Department of Defense, Advanced Research Projects Agency-Energy, Department of Homeland Security, and National Aeronautics and Space Administration. Each of these agencies supports the participation of its researchers in the NSF-operated I-Corps™ Teams training program. In FY 2019, NSF entered into a cooperative agreement with the National GEM Consortium[3] to promote inclusive and diverse participation in I-Corps™.

[2] www.nsf.gov/news/special_reports/i-corps/pdf/I-CorpsReport--6_4_19FINAL_508.pdf
[3] www.gemfellowship.org/

SECURE AND TRUSTWORTHY CYBERSPACE (SaTC)

SaTC Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
CISE	$70.22	-	$65.00
EHR	55.33	-	52.13
ENG	3.25	-	3.03
MPS	1.70	-	0.95
SBE	4.00	-	3.80
Total	**$134.50**	**-**	**$124.91**

Overview

In today's increasingly networked, distributed, and asynchronous world, society is deeply reliant on the smooth functioning of its digital infrastructure—and the security of that infrastructure (also known as cybersecurity) involves hardware, software, networks, data, people, and integration with the physical world. Recent events have exposed the dual nature of cyberspace: while it is an unprecedented source of innovation, efficiency, and growth, it also brings the potential for attacks on enterprises, loss of privacy, and even erosion of trust in democratic institutions. Indeed, key components of the digital infrastructure were not designed to operate in a hostile environment with intentional adversaries. Achieving a truly secure and trustworthy cyberspace therefore requires addressing not only challenging scientific and engineering problems involving many components of a complex system, but also issues that arise from human behaviors and choices. Examining the fundamental principles of security and privacy as a multidisciplinary subject constitutes a promising approach to develop better ways to design, build, and operate cyber systems; to protect existing and future infrastructure; and to motivate and educate individuals about cybersecurity. Achieving these goals not only requires expertise in computer science, engineering, statistics, mathematics, social, behavioral, and economic sciences, and education research, but also the translation of new concepts and technologies into practice.

SaTC is a multi-year investment area that began in FY 2012 and continuously evolves to address new threats. SaTC is aligned with the 2019 *Federal Cybersecurity Research and Development Strategic Plan*,[1] which was developed pursuant to the Cybersecurity Enhancement Act of 2014 (P.L. 113-274), and the Presidential Executive Order on *Strengthening the Cybersecurity of Federal Networks and Critical Infrastructure*.[2] Outcomes from SaTC include an organized scientific body of knowledge that informs the theory and practice of cybersecurity and privacy and an improved understanding of the causes of and mitigations for current threats. SaTC contributes to the development of foundational countermeasure techniques leveraging sound mathematical and scientific foundations, principled design methodologies, and socio-technical approaches that consider human, social, organizational, economic, and technical factors, as well as design metrics for evaluating success or failure of these approaches. In the space of training and education, SaTC makes recommendations for new instructional materials, degree programs, and educational pathways. Ultimately, through SaTC, NSF funds a broad and deep multidisciplinary research and education portfolio spanning cybersecurity and privacy, whose results underlie methods for securing critical infrastructure. Further, NSF expects to produce an innovation ecosystem that ensures (a) new and existing technologies are secure from both current threats and potential future threats as technologies evolve, and (b) users' information is protected from violations of privacy despite new attack surfaces that

[1] www.nitrd.gov/cybersecurity/index.aspx - FedCyberR&DStratPlan2019
[2] www.whitehouse.gov/the-press-office/2017/05/11/presidential-executive-order-strengthening-cybersecurity-federal

these technologies may present. Similarly, the development of an American workforce and citizenry with an understanding of cybersecurity and privacy issues is a key benefit of NSF's support in this area. As the goals of SaTC contribute to national security, NSF plans to continue investments in this area for the foreseeable future.

Importantly, SaTC also supports cybersecurity and privacy for the Industries of the Future (IoTF) through research investments, for example, in threats and countermeasures in the context of advanced wireless networks; artificial intelligence (AI) as a tool for cybersecurity; security of AI and machine learning (ML) systems, including adversarial ML; and the implications of quantum computing for security, including post-quantum cryptography.

Goals

1. *Foundational Research*: Develop the scientific theory, methodologies, and tools necessary for the development of trustworthy and usably secure systems and appropriate privacy safeguards that account for the role of human behavior and decision-making.
2. *Accelerating Transition to Practice (TTP)*: Transition successful fundamental research results and innovations into early adoption and use, and allow NSF cyberinfrastructure to serve as a premier proving ground and state-of-the-art environment for advancing cybersecurity solutions and moving them into technical and organizational practice.
3. *Education and Preparation of Cybersecurity Researchers and Professionals*: Increase the number of qualified American students who pursue degrees in cybersecurity and privacy, and enhance the capacity of institutions of higher education to produce professionals in these fields to meet the needs of our increasingly digital society. This goal also includes NSF's investment in the CyberCorps®: Scholarship for Service (SFS) program.

FY 2021 Investments

<u>Goal 1: Foundational Research</u>
- NSF will issue a revised SaTC solicitation for FY 2021 that is aligned with the 2019 *Federal Cybersecurity Research and Development Strategic Plan*. Through this revised solicitation, NSF will continue to fund innovative projects that advance the science of cybersecurity and privacy, with emphases on: architectures and technologies for protecting cyberspace from increasingly sophisticated connected devices; security and privacy aspects of smart infrastructure including the Internet of Things, and security and privacy for IoTF as described above.
- NSF will continue its efforts to grow the cybersecurity research community to include more researchers who cross the boundaries between computer and information science, engineering, the social, behavioral, and economic sciences, mathematics, statistics, and education research. In support of this specific aim, NSF will hold a range of workshops on cutting-edge topics. For example, NSF plans to develop a series of workshops and summer schools that will explore the role of security in the quantum computing era.
- In FY 2021, NSF plans to fund a SaTC Research Coordination Network (RCN) on propagation of information in cyberspace and methods of reliably detecting "deep fakes" and inferring provenance of such misinformation, especially in the context of images, audio, and video.

<u>Goal 2: Accelerating Transition to Practice</u>
- NSF will continue its focus on transitioning to practice research results that are ready for experimental deployment, early adoption, commercial innovation, and/or implementation in cyberinfrastructure. NSF will also continue to support research infrastructure in security and privacy in conjunction with the CISE Community Research Infrastructure program.

- In FY 2021, NSF plans to develop an industry-academia RCN, separate from the one described above, to foster stronger collaboration between academic researchers and industry.

Goal 3: Education and Preparation of Cybersecurity Researchers and Professionals

- In alignment with the Presidential Executive Order on *Strengthening the Cybersecurity of Federal Networks and Critical Infrastructure*, NSF will continue the focus on cybersecurity education in FY 2021, with the aims of building and sustaining an American cybersecurity workforce that is unrivaled in its ability to develop secure cyberinfrastructure components and systems, and raising the awareness of cybersecurity challenges across the entire American population.
- CyberCorps®: SFS will prioritize investments in K-12 education with the aim of growing interest in cybersecurity careers, promoting foundational cybersecurity principles and safe online behavior, improving teaching methods for delivering cybersecurity topics within computer science curricula, and promoting teacher recruitment in the field of cybersecurity. NSF will encourage and incentivize SFS institutions to participate in task forces on the cybersecurity workforce at the state level and explore possible private-public partnerships. SFS will support innovative approaches to workforce re-skilling, apprenticeships, cooperative learning opportunities, and practice-oriented models for training.
- In support of the 2019 *Federal Cybersecurity Research and Development Strategic Plan* and the Presidential Executive Order on *America's Cybersecurity Workforce*,[3] SFS will address a critical shortage of cybersecurity educators and researchers including in priority areas such as the cybersecurity aspects of AI, quantum information science, and advanced wireless networks.

[3] www.whitehouse.gov/presidential-actions/executive-order-americas-cybersecurity-workforce/

IMPROVING UNDERGRADUATE STEM EDUCATION (IUSE)

IUSE Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
BIO	$2.68	-	$1.81
CISE	2.74	-	2.00
EHR	89.99	-	74.09
ENG	0.53	-	4.43
GEO	6.00	-	5.42
OPP	-	-	0.46
Total	**$101.94**	**-**	**$88.21**

Overview

High-quality undergraduate STEM education is essential for preparing the diverse STEM workforce needed to sustain U.S. leadership in innovation.[1,2] It is also essential for producing STEM-knowledgeable workers who can use STEM skills in business and industry, as well as a STEM-literate public that understands and benefits from STEM.[3] Thus, the Improving Undergraduate STEM Education (IUSE) program aims to ensure that every college student in the United States has exceptional STEM learning opportunities.

To achieve this goal, the NSF-wide IUSE initiative supports research and development projects to improve undergraduate STEM education at multiple scales, ranging from individual STEM classrooms to nationwide efforts. IUSE also supports innovative undergraduate STEM education to prepare the STEM workforce in emerging and interdisciplinary areas, such as computational and data-enabled science and engineering. All IUSE projects include research and assessment components, and thus also contribute new knowledge about effective teaching and learning practices in undergraduate STEM education that can guide future innovations.

IUSE is one of NSF's most flexible funding programs, which continues to support Administration priorities to build and leverage a diverse, highly skilled workforce. In addition to supporting projects that have specific relevance to any NSF-supported discipline, it also supports projects that span all STEM disciplines. Examples of such cross-cutting efforts include incorporating active learning, increasing access to undergraduate research experiences, and developing cyberlearning courses and curricula. This flexibility enables IUSE to respond rapidly to emerging areas and priorities. For example, IUSE contributes to the Data Science Corps (DSC) program within the HDR Big Idea. HDR-DSC supports projects that engage students in solving data science challenges faced by communities, organizations, and governmental agencies. Thus, DSC leverages undergraduate data science education in service to science and society, contributing to a strong national data science infrastructure and workforce.

[1] National Science Board (2018). Our Nation's Future Competitiveness Relies on Building a STEM-Capable U. S. Workforce. www.nsf.gov/nsb/sei/companion-brief/NSB-2018-7.pdf
[2] Hulten, C. (2017). The Importance of Education and Skill Development for Economic Growth in the Information Era. In Education, Skills, and Technical Change: Implications for Future US GDP Growth. University of Chicago Press. Retrieved from: www.nber.org/chapters/c13937
[3] National Academies of Sciences, Engineering, and Medicine. (2016). Science literacy: Concepts, contexts, and consequences. National Academies Press. Retrieved from: www.nap.edu/catalog/23595/science-literacy-concepts-contexts-and-consequences

IUSE was initiated as a multi-year, NSF-wide priority investment area, spanning FY 2014 to FY 2020. The NSF 2018-2022 Strategic Plan extended the initiative through FY 2022, thus enabling NSF to support ongoing innovations that will ensure that the undergraduate STEM education enterprise in the United States remains current with advances in STEM and STEM education. Assessment of the IUSE portfolio will inform decisions about continuing the program beyond FY 2022. However, we anticipate that IUSE will continue as the principal component of NSF's undergraduate education strategies for the foreseeable future.

Goals

IUSE aims to support improvements in undergraduate STEM education across the Nation by funding research, development, and implementation efforts that will:

1. *Improve undergraduate STEM learning and learning environment*—Investments will improve the knowledge base for innovative undergraduate STEM instruction;
2. *Broaden participation and institutional capacity for undergraduate STEM learning*—Investments will increase the number and diversity of undergraduate students in STEM majors and career pathways; and
3. *Build the STEM workforce for tomorrow*—Investments will advance the preparation of undergraduate students to be productive members of the future STEM and STEM-capable workforce.

FY 2021 Investments

As part of its mission to advance STEM, NSF plans to invest $88.21 million in FY 2021. The IUSE initiative's anchor investment is made by IUSE/EHR, a solicitation-based program in EHR's Division of Undergraduate Education. IUSE/EHR supports research-based activities such as the use of inquiry-based and active learning approaches in undergraduate instruction, increasing undergraduate research experiences and courses, and research on the persistence and graduation of students in STEM programs. IUSE/EHR is complemented by five additional IUSE core programs, which share the three common IUSE goals listed in the previous section but have a narrower funding focus than IUSE/EHR:

- *EHR/IUSE: Hispanic Serving Institutions (HSI) Program*: Supports improvements in retention and graduation rates at HSIs that have not received high levels of NSF support; approximately 15 awards.
- *BIO/IUSE: Research Coordination Networks/Undergraduate Biology Education (RCN-UBE)*: Supports collaborative networks to improve undergraduate biology education; approximately 10 awards.
- *ENG/IUSE: Professional Formation of Engineers (IUSE/PFE:RED)*: Supports organizational change strategies to transform undergraduate engineering education; approximately six awards.
- *CISE/IUSE: Computing in Undergraduate Education (IISE:CUE)*: Supports multi-institution teams to re-envision the role of computer science in undergraduate education to better prepare a wider, more diverse range of students and to integrate the study of ethics into computer science curricula; approximately 14 awards.
- *GEO/IUSE: Pathways into the Earth, Ocean, Polar, and Atmospheric & Geospace Sciences (IUSE:GEOPATHS)*: GEO supports strategies to increase the number and diversity of undergraduate students pursuing geoscience degrees; approximately 20 awards.

IUSE funding is intended to help move the Nation forward in achieving the vision of an undergraduate STEM education enterprise in which every undergraduate becomes STEM knowledgeable and every student who desires to do so can pursue a STEM education that maximizes their full potential for a STEM career.

MAJOR INVESTMENTS IN SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS (STEM) GRADUATE STUDENTS AND GRADUATE EDUCATION

Overview

A U.S. science, technology, engineering, and mathematics workforce with advanced preparation in research and innovation, and in professional fields such as cybersecurity and STEM teaching, is essential for the progress of science and engineering (S&E). Today, emerging fields of S&E increasingly demand collaborations that span institutions, disciplines, and national boundaries, and require the use of sophisticated data infrastructure, instruments, and networks of researchers. Computationally intensive and data-enabled science in areas such as artificial intelligence and quantum information science is dramatically changing the knowledge and experience required of researchers and other STEM professionals across all fields. Thus, the preparation of graduate students in STEM must continue to evolve to provide a supply of scientists and engineers who not only meet the needs of the STEM enterprise, but who also have the knowledge, skills, and preparation to advance it and lead innovation in academia and the private and public sectors.

Investing in discoverers—that is, building a diverse and talented next-generation of STEM research leaders and professionals in leading-edge scientific areas, across sectors and through inclusive processes—is an important NSF focus and aligns with Administration and Congressional priorities. A major portion of NSF's overall investment in graduate education and graduate students supports research assistants funded through research grants. The Division of Graduate Education (DGE) also supports graduate students through other mechanisms such as traineeships, scholarships and fellowships.

Goals

The goal of NSF's investments in STEM graduate education and STEM graduate students is to prepare a diverse workforce with advanced research training that is equipped to transform the frontiers of S&E, and to prepare professionals to participate and innovate in STEM intensive careers. This goal is based on the following framework[1] to:

1. *Advance Science and Engineering Research*: Support graduate students and graduate education to enable long-term contributions of new knowledge at the frontiers of science and engineering.
2. *Broaden Participation to Promote Excellence in Research and Build the Next Generation STEM Workforce*: Recruit graduate students from a variety of geographic, demographic, social, and educational backgrounds to promote the advancement of science and a highly qualified professional workforce.
3. *Build Effective Models of Graduate Education and Workforce Development*: Support the development and use of innovative models and evidence-based approaches in graduate education, including education and research about promising practices and program effectiveness.

FY 2021 Investments

NSF's two major agency-wide programs in graduate education are the NSF Research Traineeship (NRT) program and the Graduate Research Fellowship Program (GRFP). EHR's Division of Graduate Education leads management for both programs. NSF-wide working groups guide the administration of these programs. Both programs contain design elements recommended in major national reports[2] as ways to

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[1] National Science Foundation (2016). NSF Strategic Framework for Investments in Graduate Education. National Science Foundation, Alexandria, VA. Retrieved from: www.nsf.gov/pubs/2016/nsf16074/nsf16074.pdf.
[2] National Academy of Sciences, Engineering, and Medicine. 2018. Graduate STEM Education in the 21st Century. Washington,

better prepare graduates for a broad range of careers. The NRT has two complementary components: (1) training grants that focus on developing researchers in high priority interdisciplinary research areas; and 2) the Innovations in Graduate Education (IGE) research program through the initiation of research on the development and implementation of bold, new, and potentially transformative approaches to STEM graduate education and training. GRFP identifies and supports the next generation of outstanding STEM researchers. Both programs provide professional development opportunities for graduate students, including internships and international research experiences. Ongoing evaluation and monitoring of the programs and students involved in NRT and GRFP provide rich data that will be used for gaining a better understanding of graduate program experiences and interventions, monitoring career outcomes longitudinally, and contributing to improving the understanding of STEM professional workforce development.

There are several other programs at NSF that focus on developing sectors of the STEM workforce and provide support to students in testing new models and approaches to graduate education. For example, the CyberCorps®: Scholarship for Service (SFS) program, led by EHR, addresses the national need for a cybersecurity workforce. The Robert Noyce Teacher Scholarship program (Noyce) provides fellowship support to members of the master teacher cohort at the graduate level and funds innovation and development in STEM teacher education approaches. The Louis Stokes Alliances for Minority Participation's Bridge to the Doctorate (LSAMP-BD) track and NSF Scholarships in Science, Technology, Engineering, and Mathematics (S-STEM) support the successful entry and transition of underrepresented and underserved populations into STEM graduate education and into the STEM workforce. This broad suite of programs contributes substantially to the NSF investment in graduate education of the STEM research and education workforce of the future.

<u>NSF Research Traineeship</u>

The goals of NRT are to support highly effective training of STEM graduate students in interdisciplinary research areas of national priority, as well as to create and promote innovative, effective, and scalable models for STEM graduate student training. In FY 2021, NRT will expand to include a special focus on traineeships in artificial intelligence and artificial intelligence engineering.

The NRT program is distinguished by its emphasis on training for multiple career pathways, rotating priority research themes with an emphasis on future scientific challenges, inclusion of both masters and doctoral students, and availability of the training components to both NRT-funded students and other graduate students who may want to take advantage of these training opportunities. NRT addresses interdisciplinary graduate education through two approaches: traineeships and fundamental education research. Traineeships are dedicated to effective training of STEM graduate students in high-priority interdisciplinary research areas using a comprehensive training model that is innovative, evidence-based, and aligned with changing workforce and research needs. This training includes development of technical and professional skills for both research and research-related careers within and outside academia. Fundamental education research is addressed through the Innovations in Graduate Education (IGE) component of NRT, which focuses on test-bed projects aimed at piloting, testing, and validating innovative and potentially transformative approaches to graduate education, including activities such as career preparation, mentoring, partnerships, and internships. NSF expects to fund about 17-20 traineeships and up to $8.0 million in fundamental research in graduate education.

DC: The National Academies Press. Retrieved from: www.nap.edu/catalog/25038/graduate-stem-education-for-the-21st-century; American Chemical Society Presidential Commission (2012). Advancing graduate education in the chemical sciences. American Chemical Society, Washington, DC. Retrieved from: www.acs.org/content/dam/acsorg/about/governance/acs-presidential-graduate-education-commission-full-report.pdf; Biomedical Research Workforce Working Group (2012). Biomedical Research Workforce Working Group Draft Report. National Institutes of Health, Bethesda. Retrieved from https://acd.od.nih.gov/documents/reports/bmw_report.pdf

NRT Funding
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
BIO	$3.32	-	-
CISE	7.20	-	-
EHR	33.04	-	61.87
ENG	2.50	-	-
GEO	2.77	-	-
MPS	4.54	-	-
OPP	0.72	-	-
Total	**$54.09**	**-**	**$61.87**

In FY 2020, NRT funding is consolidated into EHR.

Graduate Research Fellowship Program
The goal of GRFP is to help build the STEM human capital necessary to ensure the Nation's leadership in advancing innovations in S&E. GRFP selects, recognizes, and financially supports graduate students with demonstrated high potential for excellence in STEM careers. Applications are welcome from students in disciplines supported by NSF, including STEM, STEM education, or STEM interdisciplinary areas. In FY 2021, GRFP will be funded at $275.28 million. This will support 1,600 new fellows with a cost of education allowance of $12,000 and a stipend of $34,000. The GRFP program will continue to align awards with NSF and Administration research priorities, including AI, QIS, and other industries of the future.

GRFP Funding by Account
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
Education and Human Resources	$142.26	-	$137.64
Research and Related Activities	142.29	-	137.64
Total	**$284.55**	**-**	**$275.28**
Number of New Fellows	1,976		1,600
Projected Fellows on Tenure[1]	5,705		5,800

[1] Fellowship tenure status is the period of time during which fellows actively use the fellowship award to pursue an advanced degree in a STEM or STEM education field.

CyberCorps®: Scholarship for Service
The SFS program addresses cybersecurity education and workforce development by providing funding to institutions for developing educational programs and interventions in cybersecurity and for awarding scholarships to undergraduate and graduate students in those programs. In return for their scholarships, tuition, fees, health insurance, travel, and book allowances, recipients work after graduation for a federal, state, local, or tribal government organization in a position related to cybersecurity for a period equal to the length of the scholarship. The SFS program also supports research to improve cybersecurity education through the Secure and Trustworthy Cyberspace: Education program (SaTC-EDU).

SFS Funding
(Dollars in Millions)

FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
$55.00	-	$52.13

Additional Programs and Activities Supporting STEM Graduate Education and Workforce Development

Louis Stokes Alliances for Minority Participation-Bridge to the Doctorate (LSAMP-BD)
The LSAMP program assists universities and colleges in diversifying the STEM workforce by increasing the number of STEM baccalaureate and graduate degrees awarded to populations historically under-represented in STEM disciplines: African Americans, Alaska Natives, American Indians, Hispanic Americans, Native Hawaiians, and Native Pacific Islanders. The LSAMP program provides funding to alliances comprised of multiple degree-granting organizations that can implement comprehensive and sustained strategies that result in the graduation of well-prepared, highly qualified students from underrepresented groups. The LSAMP-BD is a targeted activity where established alliances provide post-baccalaureate fellowships for students to successfully transition from master's degrees and/or earn STEM doctoral degrees and be competitive in the STEM workforce.

In FY 2021 LSAMP will focus largely on undergraduate students and the competition for the LSAMP BD activity will be on hold to review the different tracks of LSAMP and anticipate having a revised solicitation by FY 2021.

NSF Scholarships in Science, Technology, Engineering, and Mathematics (S-STEM)
NSF established the S-STEM program in accordance with the American Competitiveness and Workforce Improvement Act of 1998 (P.L. 105-277), as modified by P.L. 106-313 and P.L. 108-447 in 2005. The Act reflects the national need to increase substantially the number of American scientists and engineers. The S-STEM program provides institutions with funds for student scholarships to encourage and enable low-income, academically talented U.S. students with demonstrable financial need to enter the STEM workforce or STEM graduate school following completion of an associate, baccalaureate, or graduate degree in STEM fields. The program emphasizes the importance of recruiting students to STEM disciplines, mentoring and supporting students through degree completion, and partnering with employers to facilitate student career placement in the STEM workforce. S-STEM provides individual scholarships of up to $10,000 per year, depending on cost of attendance and unmet financial need. S-STEM expects to fund about 300 Masters or PhD students in FY 2021.

In addition to the long-standing scholarship support, S-STEM projects contribute to the knowledge base of research in education by carrying out research on factors such as recruitment and retention of STEM students. S-STEM is funded through H-1B Nonimmigrant Petitioner Account receipts.

Robert Noyce Teacher Scholarship (Noyce)
The Noyce program supports talented STEM professionals to become K-12 STEM teachers. It also supports experienced, exemplary K-12 STEM teachers to become leaders and innovators in STEM education at their school or district.

Categories of Noyce Support for Graduate Education

Track	Outcome	Eligible Individuals	Support	Length of Commitment to Teach in High-need Schools
Scholarships and Stipends	Highly effective K-12 STEM teachers in high need schools/districts	STEM professionals	One-year scholarship to become certified/licensed teacher	2 years
Teaching Fellowship			One-year Scholarship to complete a master's degree in education and salary supplement* during teaching commitment	4 years
Master Teaching Fellowships	Highly effective K-12 teacher leaders in STEM education in high need schools/districts	K-12 STEM Teachers without a master's degree	One-year Scholarship to complete a master's degree and salary supplement during teaching commitment	5 years**

**The salary supplements support participation in mentoring and professional development to increase the Fellow's effectiveness in the classroom and/or as teacher leaders.*
***The Master Teaching Fellows continue teaching in a high need school and/or school district while they are pursuing their master's degree.*

The Noyce Teaching Fellowships and Master Teaching Fellowships track expects to fund about 160 fellows in FY 2021.

Additional Programs Supporting STEM Graduate Education and Workforce Development
(Dollars in Millions)

Program	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
LSAMP-BD	$8.60	-	-
S-STEM	5.00	-	2.00
Noyce Teaching and Master Teaching Fellows	22.83	-	3.78
Total	**$36.43**	**-**	**$5.78**

NATIONAL SCIENCE FOUNDATION CENTERS

NSF supports a variety of centers programs that contribute to the Foundation's mission and vision. Centers exploit opportunities in science, engineering, and technology in which the complexity of the research program or the resources needed to solve the problem require the advantages of scope, scale, duration, equipment, facilities, and students. Centers are a principal means by which NSF fosters interdisciplinary research. NSF is also funding AI and Quantum center-like institutes in FY 2021. See the NSF-Wide Investments chapter for more information on these two efforts.

NSF Centers
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request	Change over FY 2019 Actual Amount	Change over FY 2019 Actual Percent
Centers for Analysis & Synthesis	$0.05		-	-$0.05	-100.0%
Centers for Chemical Innovation	19.10		21.00	1.90	9.9%
Engineering Research Centers	58.95		50.92	-8.03	-13.6%
Materials Centers	52.51		52.51	-	-
Science & Technology Centers	53.58		57.95	4.37	8.2%
Total	**$184.19**	**-**	**$182.38**	**-$1.81**	**-1.0%**

Description of Major Changes

Centers for Analysis and Synthesis (BIO)
There is no funding for the FY 2021 Request for Centers for Analysis and Synthesis as the National Social-Environmental Synthesis Center (SESYNC) has sunset as planned. Preparation for a new competition is underway.

Centers for Chemical Innovation (MPS)
The FY 2021 Request of $21.0 million is expected to fund up to six Phase II Centers for Chemical Innovation (CCI). This includes up to five continuing centers and one new center.

The CCI program makes awards at two levels: smaller Phase I awards (three-year) for center development, and larger Phase II awards (five-year awards with potential for renewal up to a total of ten years) for full centers. In FY 2021, up to five continuing Phase II CCIs will be funded. In addition, two FY 2018 Phase I CCIs will be eligible to compete for Phase II in FY 2021; up to one new Phase II CCI is anticipated. A Phase I CCI competition will be held in FY 2021, supporting up to three new developmental awards.

The themes of the new Phase I and II CCIs are varied and include Artificial Intelligence (AI); the Big Ideas: QL, URoL, and HDR; and sustainable chemistry, synthetic biology, clean energy technologies, and other topics in Advanced Manufacturing. The CCI Program supports research centers focused on major, long-term fundamental chemical research challenges. CCIs address these challenges by producing transformative research leading to innovation and attracting broad scientific and public interest that lead to better lives for all Americans. For example, the Center for Sustainable Polymers initiated an exploratory project that uses complex molecules formed from sugars to remove trace impurities and emerging contaminants from water, which affects drinking water systems used by about 15 million people in 27 states in the United States.

CCIs are agile, collaborative entities that respond rapidly to emerging opportunities by integrating research with innovation, higher education, broadening participation, and informal science communication. A broad range of chemical research is currently represented at CCIs advancing fundamental understanding in:

chemical synthesis and catalysis; characterization, theory, computation, and modeling; data science, machine learning, and AI for molecular synthesis; and advanced manufacturing of nanomaterials; along with training for students at all levels. CCIs are also actively engaged in knowledge transfer to industry and the commercialization of their discoveries and new technologies.

Each year, CCIs include nearly 100 participating academic institutions, 74 non-academic partner institutions, and over 175 Senior Personnel, 100 Postdoctoral Associates, 255 Graduate Students, and 60 Undergraduate Students.

Engineering Research Centers (ENG)

The FY 2021 Request is $50.92 million. This funding level supports 13 NSF Engineering Research Centers (ERC). The total includes funding for three 4th-generation ERCs, funded as part of the Class of 2020 that will advance convergent engineering research to tackle high-impact challenges that have the potential to benefit U.S. security, prosperity, health, and society. The new ERCs will implement new strategies for effective team formation and engagement with stakeholder communities to maximize their impacts. Four centers from the Class of 2010 received final year NSF funding in FY 2020 as planned.

All NSF ERCs enable innovation, combining the energy and intellectual curiosity of university research focused on discovery with real-world engineered systems and technology opportunities through partnerships with industry. Since the program began in 1985, products of ERC innovation include more than 2,440 inventions disclosures, approximately 2,100 patent applications filed, 850 patents awarded, and 1,360 licenses. ERCs also have a successful track record for educating a technology-enabled workforce with hands-on, real-world experience. Together, NSF ERC's have graduated annually, on average, 134 Bachelor's, 128 Master's, and 150 Doctoral degree students for the past 33 years. Over that time, they have also impacted, on average, over 2,120 K-12 teachers and students annually. NSF ERCs are also effective at broadening participation from underrepresented groups. For example, across currently active ERCs, women comprise approximately 35 percent of those involved in center activities, in comparison to the national average of 24 percent across engineering. Also, the percentage of people from underrepresented groups participating is more than double that of engineering's national average.

The ERC program periodically commissions studies by external evaluators to examine aspects of the program, such as the effectiveness of ERC graduates in industry and the benefits of ERC membership to industry. In FY 2015, NSF funded the National Academies of Sciences, Engineering, and Medicine to study the future of center-based, multidisciplinary engineering research. The study report, delivered May 2, 2017, articulates a vision for the future of NSF-supported center-scale, multidisciplinary engineering research.[1] After careful consideration, in FY 2018 ENG sparked new convergent engineering research collaborations through planning grants, providing 60 awards to build capacity for a new generation of ERCs. In October 2018, ENG released a solicitation (NSF 19-503)[2] for the 4th-generation of ERCs and anticipates awards in FY 2020.

The program also commissioned a study on the sustainability of ERCs once NSF funding has ended. The 2010 report[3] "Post-Graduation Status of National Science Foundation Engineering Research Centers" (SciTech Communications), augmented by a 2015 update, found that 29 of the 35 centers (83 percent) that graduated after 10 years of NSF support are self-sustaining, with most NSF ERC features in place and strong financial support from other government sources and industry partners. NSF plans to commission a new study in FY 2020 that is expected to be completed in late FY 2021.

[1] www.nap.edu/catalog/24767/a-new-vision-for-center-based-engineering-research
[2] www.nsf.gov/pubs/2019/nsf19503/nsf19503.htm
[3] http://erc-assoc.org/sites/default/files/topics/Grad_ERC_Report-Final.pdf

Materials Centers (MPS)
The FY 2021 Request of $52.51 million is expected to support 17 to 18 continuing Materials Research Science and Engineering Centers (MRSEC). A MRSEC competition is not planned for FY 2021 as this long-standing, flagship program will complete its triennial competition in FY 2020, funding up to nine new centers.

MRSECs function as hubs to solve complex grand challenge materials problems requiring broad multidisciplinary expertise within the physical sciences and engineering to understand materials phenomena, exploit materials behavior, and to create and discover new materials. Research in materials science is inherently interdisciplinary and the MRSEC program is a prime example of convergent research encompassing physics, chemistry, mathematics, biology, and engineering. Through collaborative efforts involving academics, industry, national laboratories experts, and international and educational partners, MRSECs advance materials research and education in the U.S., and in many cases are international leaders.

MRSECs have five major components: (1) interdisciplinary research thrusts, (2) education and outreach, (3) industrial outreach/partnerships, (4) the materials research facilities network—providing access to more than 1,250 state-of-the art equipment instrumentation to materials researchers across the Nation—and (5) the SEED program, which enables MRSECs to rapidly react/move into new high risk and potentially transformative areas not yet fully explored. FY 2019 seeding efforts were built within each MRSEC to start addressing emerging research areas relevant to the Division of Materials Research. These areas include NSF's Big Ideas QL, FW-HTF, URoL, and HDR, as well as recyclable plastics and alternative materials for sustainable development, synthetic materials biology, structural materials under extreme conditions, and the use of machine learning to accelerate materials discovery.

Each year, MRSECs produce over 200 Ph.Ds. in STEM fields, mentor nearly 500 Research Experiences for Undergraduate students and 70 Research Experiences for Teachers participants, and impact over 1 million students and parents through outreach activities such as summer camps, K-12 science curriculum development, K-12 in-school science demonstrations, development and deployment of science kits, and partnering with the Nation's top museums to create STEM-related exhibits that impact the public. Since 1994, the program has created over 172 startups and annually produces about 50 awarded patents and 30 patent licensures. MRSECs engage and assist about 250 industrial partners per year in advancing fundamental materials research that can be translated into the marketplace.

Science and Technology Centers: Integrative Partnerships (multi-directorate)
The FY 2021 Request of $57.95 million will support a total of 12 Science and Technology Centers (STC) and the administrative costs associated with program management and oversight. Of the twelve centers, seven are continuing STCs from the FY 2013 and FY 2016 cohorts, and five will be new centers starting in FY 2021. In FY 2019, a solicitation for a new STC class was issued to replace the sunsetting 2010 cohort. The program received 188 preliminary proposals with the expectation of making five new awards in FY 2021 for a total of $25.0 million. Currently, full STC awards are for five years, with possible renewal for an additional five years, or 10 years total. The award sizes of the existing STCs are approximately $5.0 million per year with ramp down in years nine and ten.

The STC program advances interdisciplinary discovery and innovation in science and engineering through the integration of cutting-edge research, excellence in education, targeted knowledge transfer, and the development of a diverse workforce. The STC portfolio reflects NSF-supported disciplines; examples include: creation of atomic-scale devices and systems based on quantum materials; elucidating the mechanisms and architecture of intelligence in the human brain; studying mechanical forces in molecules, cells, and tissues of plants and animals; and developing atomic scale imaging. STCs engage the Nation's intellectual talent and collaborate with partners in academia, industry, national laboratories, and government. STCs strengthen the caliber of the Nation's science, technology, engineering, and mathematics workforce through intellectually challenging research experiences for students, postdoctoral fellows, researchers, and educators; they advance public scientific understanding through partnerships with K-12 and informal education communities. The knowledge transfer activities focus on engaging stakeholders with the intent of supporting innovation, providing information to policy-makers, and disseminating knowledge across scientific disciplines. For example, the Sustainability of semi-Arid Hydrology and Riparian Areas (SAHRA) STC disseminated knowledge to the community of water professionals and elected officials to help them make more scientifically informed decisions on water policy and management. The STC program also uses a network of evaluators working with the centers to share information and lessons learned about the most effective way to measure progress.

Estimates for Centers Participation in 2019

	Number of Participating Institutions[1]	Number of Partners[2]	Total FY 2019 NSF Support ($ in millions)	Total Leveraged Support ($ in millions)[3]	Number of Participants[4]
Centers for Analysis & Synthesis	239	127	$0.05	$1.37	955
Centers for Chemical Innovation	82	74	19.10	4.17	696
Engineering Research Centers	640	215	58.95	3.00	2,953
Materials Centers	291	236	52.51	53.00	4,556
Science & Technology Centers	164	212	53.58	30.40	2,230

[1] All academic institutions participating in activities at the centers.

[2] The total number of non-academic participants, including industry, states, and other federal agencies at the centers.

[3] Funding for centers from sources other than NSF.

[4] The total number of people who use center facilities, not just persons directly support by NSF.

Centers Supported by NSF in FY 2019

Center	Institution	State
Centers for Analysis and Synthesis		
National Institute for Mathematical & Biological Synthesis	U of Tennessee	TN
CyVERSE (formerly iPlant)	U of Arizona	AZ
Socio-Environmental Synthesis Center	U of Maryland	MD
Centers for Chemical Innovation (Phase II awards only)[4]		
Center for Chemical Evolution	Georgia Institute of Tech	GA
Center for Chemical Innovation in Solar Fuels	California Institute of Tech	CA
Center for Chemistry at the Space-Time Limit	U of California-Irvine	CA
Center for Sustainable Materials Chemistry	Oregon State	OR
Center for Sustainable Nanotechnology	U of Wisconsin	WI
Center for Sustainable Polymers	U of Minnesota	MN
NSF Center for Aerosol Impacts on Chemistry and the Environment	U of California-San Diego	CA
NSF Center for Selective C-H Functionalization	Emory	GA
Engineering Research Centers		
Advanced Self-Powered Systems of Integrated Sensors and Technologies (ASSIST)	North Carolina State	NC
Bio-mediated and Bio-inspired Geotechnics (CBBG)	Arizona State	AZ
Center for Ultra-wide-area Resilient Electric Energy Transmission Network (CURENT)	U of Tennessee	TN
Engineering Research Center for Innovative and Strategic Transformation of Alkane Resources (CISTAR)	Purdue	IN
Engineering Research Center for Precise Advanced Technologies and Health Systems for Underserved Populations (PATHS-UP)	Texas A&M	TX
Future Renewable Electric Energy Delivery and Management Systems (FREEDM)	North Carolina State	NC
Integrated Access Networks (CIAN)	U of Arizona	AZ
Nanomanufacturing Systems for Mobile Computing and Mobile Energy Technologies (NASCENT)	U of Texas	TX
Nanosystems Engineering Research Center for Directed Multiscale Assembly of Cellular Metamaterials with	Boston College	MA

[4] Smaller, developmental Phase I awards do not meet the criteria as formal NSF Centers and so are not captured here.

Nanoscale Precision (CELL-MET)		
Nanotechnology Enabled-Water Treatment Systems (NEWT)	Rice University	TX
NSF Engineering Research Center for Cell Manufacturing Technologies (CMaT)	Georgia Institute of Tech	GA
Optimization for Electro-thermal Systems (POETS)	U of Illinois	IL
Quantum Energy and Sustainable Solar Technologies (QESST)	Arizona State	AZ
Sensorimotor Neural Engineering (CSNE)	U of Washington	WA
Translational Applications of Nanoscale Multiferroic Systems (TANMS)	U of California-Los Angeles	CA
Materials Centers		
Brandeis Bioinspired Soft Materials Center	Brandeis	MA
Center for Dynamics and Control of Materials	U of Texas at Austin	TX
Center for Emergent Materials	Ohio State	OH
Center for Multifunctional Materials	Northwestern	IL
Center for Nanoscale Science	Pennsylvania State	PA
Center for Polarization and Spin Phenomena in Nanoferroic Structures	U of Nebraska	NE
Chicago Materials Research Centers	U of Chicago	IL
Columbia Center for Precision Assembly of Superstratic and Superatomic Solids	Columbia	NY
Cornell Center for Materials Research	Cornell	NY
Harvard Materials Research Center	Harvard	MA
Illinois Materials Research Center	U of Illinois at Urbana-Champaign	IL
Laboratory for Research on the Structure of Matter	U of Pennsylvania	PA
Materials Research Science and Engineering Center at UCSB	U of California-Santa Barbara	CA
Materials Research Science and Engineering Center	U of Minnesota	MN
MIT Center for Materials Science and Engineering	Massachusetts Institute of Tech	MA
NYU Materials Research Science and Engineering Center	New York U	NY
Princeton Center for Complex Materials	Princeton	NJ
Soft Materials Research Center	U of Colorado	CO
UW Molecular Engineering Materials Center	U of Washington	WA
Wisconsin Materials Research Center	U of Wisconsin	WI
Nanoscale Science and Engineering Centers		
Center for the Environmental Implications of Nanotechnology (CEINT)[5]	Duke	NC
Predictive Toxicology Assessment & Safe Implementation of Nanotechnology in the Environment (CEIN)[5]	U of California-Los Angeles	CA
Science and Technology Centers		
BEACON: An NSF Center for the Study of Evolution in Action	Michigan State	MI
Biology with X-Ray Free Electron Lasers	SUNY Buffalo	NY
Center for Brains, Minds, and Machines: The Science and the Technology of Intelligence	Massachusetts Institute of Tech	MA
Center for Bright Beams	Cornell	NY
Center for Cellular Construction	U of California-San Francisco	CA
Center for Dark Energy Biosphere Investigations	U of Southern California	CA
Center for Emergent Behaviors of Integrated Cellular Systems	Massachusetts Institute of Tech	MA
Center for Energy Efficient Electronics Science	U of California-Berkeley	CA
Center for Engineering MechanoBiology	U of Pennsylvania	PA
Center for Integrated Quantum Materials	Harvard	MA
Science and Technology Center on Real-Time Functional Imaging	University of Colorado	CO
Center for Science of Information	Purdue	IN

[5] CEINT and CEIN are operating on no-cost extensions. No funds were obligated for the centers in FY 2019.

SELECTED CROSS-CUTTING PROGRAMS

Many investments at NSF draw on interdisciplinary teams from across the Foundation and are supported by multiple directorates. Other parts of this chapter, NSF-Wide Investments, provide narratives for NSF-wide priority investments such as NSF's Big Ideas and SaTC. Additional cross-cutting programs at NSF are selected for presentation in the narrative below. Full funding data for these programs are provided in the Summary Tables chapter.

ADVANCE

In FY 2021, $17.03 million in funding is requested for the ADVANCE program to encourage institutions of higher education and the broader science, technology, engineering and mathematics (STEM) community, including professional societies and other STEM-related not-for-profit organizations, to address various aspects of STEM academic culture and institutional structure that may differentially affect women faculty and academic administrators. As such, ADVANCE is an integral part of the NSF's multifaceted strategy to broaden participation in the STEM workforce and supports the critical role of the Foundation in advancing the status of women in academic science and engineering. EHR stewards funding for ADVANCE in FY 2021 in order to support projects in all areas of NSF STEM disciplines.

Faculty Early Career Development (CAREER)

The CAREER program offers NSF's most prestigious awards in support of early-career faculty and is designed to provide stable support at a sufficient level and duration to enable awardees to develop careers not only as outstanding researchers but also as educators demonstrating commitment to teaching, learning, and dissemination of knowledge. The FY 2021 Request provides $254.22 million for the CAREER program, funding approximately 200 new CAREER awards, which support exceptionally promising college and university junior faculty who are committed to the integration of research and education and who are most likely to become the leaders in their fields. BIO, CISE, ENG, GEO, MPS, and SBE provide funding for CAREER.

Long-Term Ecological Research (LTER)

The FY 2021 Request provides $27.96 million for LTER, which supports fundamental research that requires data collection over long time periods to unravel the principles and processes of ecological science, which frequently involves long-lived species, legacy influences, and rare events. This program supports a loosely coordinated network of 29 field sites that focus on: (1) understanding ecological phenomena that occur over long temporal and broad spatial scales; (2) creating a legacy of well-designed, long-term ecological experiments; (3) conducting major syntheses and theoretical efforts; and (4) providing information to identify and to address environmental challenges. LTER projects represent a diversity of habitats in continental North America, the Caribbean, Pacific Ocean, Arctic, and the Antarctic; including coral reefs, arid grasslands, estuaries, lakes, prairies, forests, alpine and Arctic tundra, urban areas, and agroecosystems. The support for LTER in FY 2021 will be used to sustain site-specific research activities examining ecological and evolutionary dynamics in natural populations, communities, and ecosystems, some of which have been studied for over 30 years, and conducting syntheses of long-term data using contemporary modeling methods. BIO and GEO provide funding for LTER.

The National Ecological Observatory Network (NEON) infrastructure is co-located at eight LTER sites. NEON is a continental-scale infrastructure facility providing standardized physical and data resources to researchers and educators. LTER is a network of long-term research projects aimed at understanding ecological processes in a wide range of ecosystems. Ongoing research at LTER sites may take advantage of data generated using NEON infrastructure. In addition, the co-location of NEON infrastructure at LTER sites will stimulate new research that builds on the long history of LTER research by enhancing the ability to extend site-based knowledge to regional and continental scales. For more information on NEON, see the NEON narrative in the Major Multi-User Research Facilities chapter.

National Nanotechnology Coordinated Infrastructure (NNCI)

In FY 2021, $13.71 million in funding is requested for NNCI, which supports 16 user facility sites, their affiliated partners, and a coordinating office. 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 nanoscience, engineering, and technology. With ENG leading, all NSF R&RA directorates provide funding for NNCI.

Research Experiences for Undergraduates (REU)

In FY 2021, $73.60 million in funding is requested for the REU Sites and Supplements program. NSF's ongoing support for REU reflects the importance of undergraduate research experiences in building students' interest and competence in STEM disciplines. REU grants involve students at all stages of undergraduate education. REU Supplements allow students to join research projects that are supported by NSF research grants. REU Sites support cohorts of students to conduct research within STEM disciplines or on topics that cut across disciplines. Most of the students in an REU Site come from outside the host institution. This feature enables the program to involve students in research who might not otherwise have the opportunity, particularly students from institutions where faculty research activities are limited. The REU program encourages partnerships between community colleges and baccalaureate degree-granting institutions to provide research opportunities for community college STEM students and faculty. NSF's REU Sites and Supplements programs fall within the Improving Undergraduate STEM Education framework as affiliated programs, with budget and award decisions remaining within individual directorates. BIO, CISE, ENG, GEO, MPS, and SBE provide funding for REU.

Research in Disabilities Education (RDE)

The FY 2021 Request for NSF's RDE program totals $6.50 million. RDE helps increase participation in STEM for postsecondary students with disabilities. RDE proposals are accepted in all fields of science and engineering supported by NSF, particularly research on learning and education. Planned funding for RDE is provided through EHR's Division on Research on Learning in Formal and Informal Settings, with additional funding potentially provided by other EHR divisions and R&RA directorates for meritorious projects relevant to their communities. The FY 2019 Actual includes $5.44 million from EHR and $8.33 million from other directorates and EHR divisions.

Research in Undergraduate Institutions (RUI)

The FY 2021 Request for NSF's RUI program totals $33.20 million. The RUI activity seeks to support high quality research by faculty members of predominantly undergraduate institutions, strengthen the research environment in academic departments that are primarily oriented toward undergraduate instruction, and promote the integration of research and education of undergraduate students. RUI proposals are accepted in all fields of science and engineering supported by NSF, including research on learning and education. BIO, CISE, MPS, and SBE providing funding for RUI.

NATIONAL NANOTECHNOLOGY INITIATIVE (NNI)

Total Funding for NNI
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
BIO	$42.50	-	$39.95
CISE	13.50	-	13.08
EHR	2.53	-	2.50
ENG	218.35	-	199.00
MPS	243.34	-	199.00
SBE	0.40	-	-
IA	0.10	-	-
Total	**$520.72**	**-**	**$453.53**

Overview

NSF's contribution to the multiagency NNI encompasses the systematic understanding, organization, manipulation, and control of matter at the atomic, molecular, and supramolecular levels in the size range of about 1 nanometer to 100 nanometers. Novel materials, devices, and systems—with their building blocks designed on the scale of nanometers—open new directions in science, engineering, and technology with potentially profound implications for society. With the capacity to interact with and control matter at this scale, science, engineering, and technology researchers are realizing revolutionary advances in areas such as order-of-magnitude faster computers with less energy consumption; catalysts for industry; molecular medicine; imaging and understanding of the brain; quantum qubits and systems; nanosensors to monitor health, the environment, human-machine interactions, and input to artificial intelligent (AI) systems; efficient and large-scale nanomanufacturing; more resilient materials and system architectures; and sustainable development for water, energy, and food resource utilization. NSF contributes to the NNI goals and five Program Component Areas (PCAs) outlined in the 2016 NNI Strategic Plan and the NNI Supplement to the President's Budget for Fiscal Year 2019.[1] Funding by PCA is shown at the end of this discussion. Funding for the Nanotechnology Signature Initiative (NSI) on Nanotechnology Knowledge Infrastructure continued through the end of FY 2019, without additional funding for FY 2021.

FY 2021 NNI Funding

NSF supports nanoscale science and engineering throughout all the research and education directorates as a means to advance discovery, invention, and innovation and to integrate various fields of research. NNI enables increased interdisciplinarity in areas of atomic and molecular research in about 6,000 active awards with full or partial contents on nanoscale science and engineering (NSE). Approximately 10,000 students and teachers will be educated and trained in NSE in FY 2021.

Overall, NSF's total NNI funding in the FY 2021 Request is $453.53 million. Several new directions planned for FY 2021 include research connected to advanced manufacturing, AI, the bioeconomy, sustainability, and quantum information science and engineering. Nanotechnology research will contribute and synergize in the future with NSF's Big Ideas, particularly with QL, URoL, FW-HTF, HDR, and GCR. NSF sponsors an annual NSE grantee conference to assess the progress in nanotechnology and facilitate

[1] www.nano.gov

identification of new research directions.[2]

In FY 2021, NSF support will increasingly focus on convergence research and education activities in confluence with other priority areas. NSF will strengthen partnerships of the Nanoscale Engineering Research Centers (NERCs) with small businesses in the areas of nanomanufacturing and commercialization, and will support an industrial internship program (INTERN) in emerging areas. NSF will continue its contributions to translational innovation programs, including Grant Opportunities for Academic Liaison with Industry (GOALI); Industry-University Cooperative Research Centers (IUCRC); the NSF Innovation Corps (I-Corps™) program; and the Partnerships for Innovation (PFI). The NSF Small Business Innovation Research (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.

Various assessments and reports have assisted with informing plans for NNI going into the future. NSF sponsored an international study on long-term research entitled *Nanotechnology Research Directions for Societal Needs in 2020*,[3] which provides a vision of the field to 2020 and beyond. With the National Institutes of Health (NIH), National Aeronautics and Space Administration (NASA), Environmental Protection Agency (EPA), Office of Naval Research (ONR), and the U.S. Department of Agriculture (USDA), NSF co-sponsored the study entitled *Converging Knowledge, Technology, and Society*[4] evaluating the convergence of nanotechnology with other emerging areas by 2030. Other reports address aspects of fundamental research for energy-efficient sensing and computing, data storage, real-time communication ecosystem, multi-level and scalable security, a new fabrication paradigm, and insight computing.[5,6,7]

PCAs are the major subject areas of relevance to the NNI agencies, where progress is critical to achieving NNI's goals and to realizing its vision.[8] NSF supports funding in all five PCAs.

PCA 1: Nanotechnology Signature Initiatives (NSIs) and Grand Challenges (GCs)
The first PCA, which encompasses the four NSIs, will be funded at a total of $100.42 million. The Water Sustainability through Nanotechnology NSI began in FY 2016 and will continue in FY 2021. The Nanotechnology-Inspired Grand Challenge for Future Computing began in FY 2017. Special emphasis will be on:

- *Sustainable Nanomanufacturing ($32.0 million)*: 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 hierarchical nanomanufacturing, high-performance structural carbon-based nanomaterials, optical metamaterials, cellulosic nanomaterials, nanobiomanufacturing and nanomodular systems. Engineering biology at the nanoscale for advanced manufacturing activities in BIO, ENG, and MPS are being organized for 2021. Methods for nanomanufacturing design are in synergy with the Materials Genome Initiative. A new direction is manufacturing of quantum systems, nanomachines and nano biostructures.
- *Nanoelectronics for 2020 and Beyond ($34.0 million)* : 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.

[2] 2019 Nanoscale Science and Engineering Grantees Conference: www.nsf.gov/nano and www.nseresearch.org/2019/
[3] NSF/WTEC 2010, Springer, available on www.nsf.gov/nano and www.wtec.org/nano2/
[4] NSF/WTEC 2013, Springer, available on www.nsf.gov/nano and www.wtec.org/NBIC2-Report/
[5] www.nsf.gov/nano
[6] 1.usa.gov/1Fg90Dw; www.src.org/nri/energy-efficient-computing-workshop.pdf
[7] www.semiconductors.org/issues/research/research/
[8] www.nano.gov/about-nni/what/vision-goals

Collaboration with SRC (n-CORE, STARnet, nanobio) and the National Institute of Standards and Technology (NIST) is planned to continue in 2021 with a focus on new concepts for *energy-efficient devices and architectures and Semiconductor Synthetic Biology for Information Processing and Storage Technologies (SemiSynBio)*. NSF will increase coordinated research on QL and the FW-HTF.

- *Nanotechnology for Sensors and Sensors for Nanotechnology ($8.50 million)*: This initiative funds the 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. This initiative supports materials and technologies that enable new sensing of biological, chemical, and nanoscale materials, including sensors for nano environment, health, and safety (nano-EHS). Dedicated programs on biosensing and biophotonics in ENG's Division of Chemical, Bioengineering, Environmental, and Transport Systems (CBET) will support this effort.
- *Water Sustainability through Nanotechnology ($13.0 million)*: This initiative 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. Besides core nanoscience-related programs on water filtration and applications, the NERC for Nanotechnology Enabled Water Treatment Systems (NEWT) led by Rice University, funded between 2015 and 2025, 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 ($12.92 million)*: Research is planned on the NNI Grand Challenge related research on "Brain-like Computing" and "Intelligent Cognitive Assistants" (ICA). Two examples of active centers are the Science and Technology Center (STC) on Integrated Quantum Materials 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. NSF plans to sponsor research on ICA as part of program announcements for two NSF Big Ideas: FW-HTF and GCR. 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 implementing in various applications. The research will be conducted in collaboration with other agencies (NIH, Defense Advanced Research Projects Agency (DARPA)).

<u>PCA 2: Foundational Research</u>

The FY 2021 Request includes $258.44 million 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. It will support activities surrounding the fundamental, interconnected elements of collaborative modeling and computer simulation, an interacting cyber-toolbox, and data infrastructure for nanotechnology. The Network for Computational Nanotechnology (NCN) conducts key activities in support to this PCA with about 1.4 million users per year and has been awarded an extension to 2022. About 60 percent of the MRSECs pursue NSE-related fundamental research.

<u>PCA 3: Nanotechnology-Enabled Applications, Devices, and Systems</u>

The FY 2021 Request includes $50.75 million 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 ENG, CISE, and MPS support development of new principles, design methods, and constructive solution for nanodevices. A special focus is on smart autonomous nanoscale-based devices and systems.

PCA 4: Research Infrastructure and Instrumentation
The FY 2021 Request includes $33.40 million 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 workforce 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 curriculum development to advanced training, are included here as resources supporting the workforce infrastructure of NNI. NSF funded an award of about $16 million per year for the National Nanotechnology Coordinated Infrastructure (NNCI) sites for 2015-2020, whose national coordination office was added in FY 2016. The FY 2021 Request for this is funded at $13.71 million. Other STC, ERC, and MRSECs have a focus supporting NNI such as the STC Center for Cellular Construction at the University of California-San Francisco (annual award since 2016 is approximately $5 million) and two NERCs, one each on nano-bio and cell technology. NSF continues to sponsor nanotechnology education and related activities, such as disseminating the NBC Learn video series *Nanotechnology: Super Small Science* or hosting a nationwide communication competition with the Boston Museum of Science for undergraduate and graduate students.[9]

PCA 5: Environment, Health, and Safety
In FY 2021, NSF will continue its funding for the Environment, Health, and Safety (EHS) PCA at $10.52 million, representing roughly three percent of its overall NNI budget. Requests for research are primarily directed at understanding nano-bio phenomena and processes, as well as environment, health, and safety implications and methods for reducing the respective risks of nanotechnology development. ENG's nano EHS program has changed to *Nanoscale Interactions*. MPS supports the Center for Chemical Innovation (CCI): Center for Sustainable Nanotechnology.

Coordination with Other Agencies

NSF's NNI program is coordinated with 32 other departments and agencies through the National Science and Technology Council subcommittee on Nanoscale Science, Engineering and Technology (NSET). These agencies also partner with NSF to sponsor joint funding activities and workshops on nanotechnology research directions and send representatives to participate in grantees conferences. Some specific coordination efforts are:

- Sustainable Nanomanufacturing—NSF, NIST, Department of Energy (DOE), EPA, NIH, National Institute for Occupational Safety and Health (NIOSH), Occupational Safety and Health Administration (OSHA), USDA/Food Safety (FS).
- Collaboration with NIST, Air Force Office of Scientific Research (AFOSR), and DARPA will continue in 2020 with a focus on "Brain-like Computing".
- Nanoelectronics—NSF, NIST, Department of Defense (DOD), DOE, Intelligence Community (IC)/Director of National Intelligence (DNI), and NASA.
- NSF collaborates with other 12 other agencies in the NNI task force on "Nanoplastics".
- NNCI and NCN centers and networks—NSF, DOD, NASA, DOE, and NIH.
- Nanosensors—NSF, NIOSH, NIH, FDA, NIST, DOD, NASA, and EPA.
- NSF collaboration with NIOSH, NIH's National Cancer Institute (NCI), NIST, Pacific Northwest National Laboratory, and DOD, and many public- and private-sector partners with the Nanoinformatics

[9] www.mos.org/quantum-matters-competition

Consortium: UCLA, the National Nanomanufacturing Network, nanoHUB, RTI International, MIT, and the NanoBusiness Commercialization Association.

- OECD (Working Group on Bio, Nano, and other Converging Technologies) and other international forum activities—participation by NSF in collaboration with State Department and other NNI agencies.

NNI Funding by Program Component Area
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
1. Nanotechnology Signature Initiatives	$150.92	-	$100.42
Sustainable Nanomanufacturing	*40.10*	-	*32.00*
Nanoelectronics for 2020 and Beyond	*51.82*	-	*34.00*
Nanotechnology Knowledge Infrastructure	*22.67*	-	-
Nanotechnology for Sensors	*11.59*	-	*8.50*
Water Sustainability through Nanotechnology	*12.76*	-	*13.00*
Nanotechnology-Inspired Grand Challenge for Future Computing	*11.98*	-	*12.92*
2. Foundational Research	271.37	-	258.44
3. Nanotechnology-Enabled Applications, Devices, and Systems	57.71	-	50.75
4. Research Infrastructure and Instrumentation	27.91	-	33.40
5. Environment, Health, and Safety	12.81	-	10.52
Total	**$520.72**	**-**	**$453.53**

NETWORKING AND INFORMATION TECHNOLOGY RESEARCH AND DEVELOPMENT (NITRD)

Total Funding for NITRD
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
BIO	$77.00	-	$90.00
CISE	980.32	-	1,062.40
EHR	9.90	-	9.50
ENG	129.45	-	142.37
GEO	20.00	-	19.00
MPS	173.71	-	213.39
SBE	26.56	-	31.67
Total	**$1,416.94**	**-**	**$1,568.33**

Overview

NSF is a primary supporter of the NITRD program, and NSF's NITRD portfolio includes all research, research infrastructure, and education investments in CISE, as well as contributions from all other directorates across the agency, enabling investments in every NITRD Program Component Area (PCA). The NSF assistant director for CISE is co-chair of the NITRD Subcommittee of the National Science and Technology Council's (NSTC) Committee on the Science and Technology Enterprise. In addition, numerous NSF staff work in close collaboration with other NITRD agencies and participate in all NITRD interagency working groups, including at the co-chair level in most. NSF also facilitates interaction between NITRD and other bodies of the NSTC as appropriate. For example, the NSF assistant director for CISE also co-chairs the Machine Learning and Artificial Intelligence (MLAI) Subcommittee, enabling close coordination between NITRD and MLAI.

NSF's FY 2021 Budget Request includes support for NITRD at a level of $1,551.33 million. NITRD activities represent approximately 20 percent of NSF's FY 2021 Budget Request to Congress. CISE's support comprises 68 percent of NSF's NITRD activities.

The PCAs are reviewed annually to ensure they remain relevant and reflect the most up-to-date R&D needs of the Nation. No major changes were made to the PCAs for FY 2021.

FY 2021 NSF Investments by Program Component Area (PCA)

The following information focuses on FY 2021 NSF investments, both new and continuing, by PCA.

AI R&D ($425.11 million): AI R&D will include investments in fundamental research advancing AI. A key focal point of the increased investment in AI R&D will be support for National AI Research Institutes. These center-scale projects will advance foundational research; leverage use-inspired research; build the next-generation of talent; mobilize multidisciplinary groups of scientists, engineers, and educators; and serve as a nexus point for multisector collaborative efforts. The National AI Research Institutes will fill a critical gap in America's AI research and education portfolio by accelerating AI innovations, training AI researchers and innovators, and transitioning outcomes across a range of sectors.

AI R&D will also include increased investments in HDR and FW-HTF stewardship funds that will allow NSF to fund critical new methods and advances in AI, notably in deep learning and machine learning (ML), as well as the evolving symbiosis of humans and AI in work.

Additionally, this PCA will include CISE investments in foundational research in AI, including knowledge representation and reasoning, multi-agent systems, planning, machine and deep learning, computer vision, and human language technologies; ENG investments in advanced manufacturing and the mind, machine, and motor nexus; SBE investments to integrate machine learning advances with learning mechanisms developed in cognitive science, develop new statistical inferences and algorithms for the analysis of large data sets, and understand the legal and ethical implications of AI; BIO investments in ML, natural language processing, computer vision, and genetic algorithms applied to solve problems such as genome sequence alignment, prediction of protein structure, reconstruction of evolutionary relationships, extraction of quantitative information from multi-media data sources, and the bioeconomy more generally; and MPS investments in ML, deep learning, and neural networks through the Condensed Matter and Materials Theory, Designing Materials to Revolutionize and Engineer our Future, and Materials Research Science and Engineering Centers programs.

Computing-Enabled Human Interaction, Communications, Augmentation (CHuman) ($92.37 million): CHuman will include investment in FW-HTF, which supports convergent research to understand and develop the human-technology partnership, design new technologies to augment human performance, illuminate the emerging socio-technological landscape, and foster lifelong and pervasive learning with technology. As part of FW-HTF, CHuman will also include investment in the Cyberlearning program, which will support educating and re-educating learners of all ages and career stages (American students, teachers, and workers) in STEM content areas through emerging technologies. CHuman will also include SBE investment on cyberinfrastructure related to its three major ongoing social science surveys (American National Election Studies, the Panel Study of Income Dynamics, and the General Social Survey), which will enable examination of American competitiveness, security, economic development, and well-being.

Computing-Enabled Networked Physical Systems (CNPS) ($82.89 million): CNPS will include CISE and ENG investments in Cyber-Physical Systems, enabling foundational interdisciplinary research and education in adaptive and pervasive smart systems supporting applications such as the smart grid, intelligent transportation systems, and medical devices. It will also include investment in the NSF-wide Smart and Connected Communities (S&CC) program, which will support interdisciplinary, integrative research that deeply engages local residents, stakeholders, and governments to improve understanding, design, and long-term sustainability of intelligent infrastructure for American communities, thereby leading to enhanced quality of life for residents. CNPS will additionally include BIO investment in expanding and enhancing access to the national resource of digital biological and paleontological data and ENG investment in advanced and future manufacturing, including cyber-manufacturing.

Cyber Security and Privacy (CSP) ($106.24 million): CSP will include investment in the NSF-wide SaTC program and other related cybersecurity and privacy research. The investment in SaTC in particular will support foundational research necessary to ensure society's ubiquitous computing and communication systems are resistant to cyber-attacks and associated vulnerabilities, while enabling and preserving privacy and trust. SaTC emphases will span AI and ML, including adversarial ML; implications of quantum computing for security, including post-quantum cryptography; architectures and technologies for protecting cyberspace from increasingly sophisticated connected devices; and security and privacy aspects of smart infrastructure including the Internet of Things.

Education and Workforce (EdW) ($61.03 million): EdW will include CISE and EHR investments in IUSE: Computing in Undergraduate Education, to support efforts to re-envision the role of computing in interdisciplinary collaboration within American institutions of higher education and in Computer Science for All: Researcher-Practitioner Partnerships, to support the R&D needed to bring computer science and computational thinking to all schools at the preK-12 levels. It will also include CISE and EHR investments supporting workforce development in cybersecurity, enabling a growing pipeline of researchers, educators, and practitioners, and allowing all Americans to understand the security and privacy of the digital systems on which their lives increasingly depend. EdW will additionally include BIO investment in advancing America's ability to incorporate and apply biological knowledge to economic development and other issues of societal importance.

Enabling-R&D for High-Capability Computing Systems (EHCS) ($162.96 million): EHCS will include investments in strategic computing activities initiated under the recently updated National Strategic Computing Initiative,[1] which will support research advances in new computing technologies, architectures, and platforms for the future, as well as the development of advanced computing systems and services, including maximizing the benefits of these systems and services through deep integration with science and engineering research. EHCS will also include CISE and MPS investments that advance computational algorithms and data analytics to address scientific and engineering opportunities presented by data emerging from digital and observational data sources. It will also include CISE and MPS investments in fundamental research on innovative materials integration and novel phenomena associated with quantum information science, optical computing, and neuro-computing.

High Capability Computing Infrastructure and Applications (HCIA) ($170.36 million): HCIA will include CISE investments on the development of software and algorithms for advanced computing systems and services. For example, HCIA will include CISE and MPS investments in new computational methods, algorithms, scientific databases, and other computational tools to support researchers in the mathematical and physical sciences as well as engineering through programs such as Computational and Data-Enabled Science and Engineering; CISE and GEO investment in EarthCube, a cyberinfrastructure investment for the geosciences; GEO investment in the operations and maintenance of the National Center for Atmospheric Research's Wyoming Supercomputer facility and associated modeling efforts; and BIO investment in the application of advanced computing to a range of grand challenge problems in the biological sciences, including the genotype-to-phenotype relationship, and the environmental sciences.

Intelligent Robotics and Autonomous Systems (IRAS) ($57.58 million): IRAS will include CISE and ENG investments in robotics and autonomous systems that exhibit significant levels of both computational capability and physical complexity, including research related to the design, application, and use of robotics to augment human function, promote human-robot interaction, and increase robot autonomy. As part of the next generation of robotics, collaborative robotics (co-robot) systems, i.e., robotic systems that work beside or cooperatively with people, will be characterized by their flexibility and resourcefulness. They will use a variety of modeling or reasoning approaches, along with real-time, real-world data, demonstrating a level of intelligence and adaptability seen in humans and animals. As development of this next generation of co-robotics proceeds in application domains such as advanced manufacturing, emergency response, and health care, complete confidence in these systems becomes increasingly important.

Large-Scale Data Management and Analysis (LSDMA) ($213.85 million): LSDMA will include investment in HDR, including foundational research in data science and engineering; the development of a cohesive, federated approach to the research data infrastructure; and development of a 21st-century data-capable workforce. As part of HDR, LSDMA will include CISE investments in the development of a comprehensive, scalable data infrastructure. LSDMA will additionally include ENG investment on cyberinfrastructure for the Natural Hazards Engineering Research Infrastructure, which provides access to and storage and analysis of massive amounts of data related to natural disasters; MPS investments in Data-Driven Discovery Science in Chemistry as well as Computational Mathematics; SBE investments in data science and associated research infrastructure; and BIO investment in integrative modeling of complex biological processes.

[1] www.whitehouse.gov/wp-content/uploads/2019/11/National-Strategic-Computing-Initiative-Update-2019.pdf

Large-Scale Networking (LSN) ($131.0 million): LSN will include CISE investment in the NSF-wide S&CC program as well as on a set of Platforms for Advanced Wireless Research that enable research on topics ranging from dynamic spectrum sharing to measurement and monitoring, thus advancing the next generation of high-performance, robust wireless networks. LSN will also include NSF investment in the Spectrum Innovation Initiative supporting foundational spectrum research in increased spectrum efficiencies, flexibility, and adaptability and leading to the creation of advanced wireless technologies and systems beyond 5G.

Software Productivity, Sustainability and Quality (SPSQ) ($64.94 million): SPSQ will include investment in the software foundations within CISE, as well as new thinking, paradigms, and practices in developing and using software that is robust, reliable, usable, and sustainable through the NSF-wide Cyberinfrastructure for Sustained Scientific Innovation (CSSI) program. SPSQ will also include investment in NSF-wide programs, such as the interagency and international Collaborative Research in Computational Neuroscience (CRCNS). For example, through CRCNS, BIO will fund research involving the development of software and other computational tools to advance biological knowledge and computational innovations.

NITRD Funding by Program Component Area
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
Artificial Intelligence R&D	$234.96	-	$425.11
Computing-Enabled Human Interaction, Communications, Augmentation	94.63	-	92.37
Computing-Enabled Networked Physical Systems	77.09	-	82.89
Cyber Security and Privacy	110.26	-	106.24
Education and Workforce	81.51	-	61.03
Enabling-R&D for High-Capability Computing Systems	178.77	-	162.96
High Capability Computing Infrastructure and Applications	196.17	-	170.36
Intelligent Robotics and Autonomous Systems	45.89	-	57.58
Large-Scale Data Management and Analysis	194.24	-	213.85
Large Scale Networking	131.31	-	131.00
Software Productivity, Sustainability and Quality	72.11	-	64.94
Total	**$1,416.94**	**-**	**$1,568.33**

U.S. GLOBAL CHANGE RESEARCH PROGRAM (USGCRP)

Total Funding for USGCRP
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
BIO	$90.00	-	$88.25
GEO	120.00	-	106.50
SBE	16.50	-	11.73
OPP	14.28	-	10.61
Total	**$240.78**	**-**	**$217.09**

Overview

NSF addresses global change issues through investments that advance frontiers of knowledge, provide state-of-the-art instrumentation and facilities, develop new analytical methods, and enable cross-disciplinary collaborations while also cultivating a diverse, highly-trained workforce and developing educational resources. NSF's global change-related programs support the research and related activities to advance fundamental understanding of physical, chemical, biological, and human systems and the interactions among them. Programs encourage interdisciplinary approaches to studying Earth system processes and the consequences of change, including how humans respond to changing environments and the impacts on ecosystems and the essential services they provide.

NSF has been investing in the fundamental research at the heart of global change issues for several decades. Long-term, continuous, and consistent observational records are essential for testing hypotheses quantitatively and are thus a cornerstone of global change research. NSF supports a variety of research observing networks that complement, and are dependent on, the climate monitoring systems maintained by its federal partners. The results of NSF investments have helped communities address challenges associated with mitigation, adaptation, and other responses to a changing and variable environment.

NSF funding for USGCRP in the FY 2021 Request is $217.09 million. NSF’s investments will continue to support research that contributes to the USGCRP Goal Areas to (1) advance scientific knowledge of the integrated natural and human components of the Earth system and (2) inform decisions by providing the scientific basis to inform and enable timely decisions on adaptation and mitigation. In FY 2021, NSF will continue to engage with other USGCRP agencies on priorities from intra-seasonal to centennial predictability, predictions, and projections; water cycle research; understanding the impacts of global change on the Arctic region and effects on global climate; and fundamental research on actionable science. In addition, NSF will further seek greater integration of social-science research, methodologies, and insights into understanding and supporting responses to global change, improving computing capacity, and maintaining needed observational capabilities over time.

Past investments have helped inform the National Climate Assessment and several other technical reports mandated by the Global Climate Research Act of 1990. Investments have also aided U.S. communities to develop mitigation and adaptation strategies to address both challenges and opportunities derived from a changing environment. The fundamental knowledge gained through NSF disciplinary and cross-cutting programs focusing on the coupled natural-human system are critical in developing effective solutions to these challenges and opportunities.

FY 2021 Investments by Program Component Area (PCA)

Goal 1: Advance scientific knowledge of the integrated natural and human components of the Earth system

Earth System Understanding: NSF participates in the Earth System Understanding PCA to improve our knowledge of the Earth's past and present climate variability and change through activities to document and understand long-term climate cycles across the globe, as well as to better understand the natural variability of climate and the processes responsible for global changes using a range of paleoclimate and instrumental data and modeling approaches. NSF also supports activities to improve our understanding of the frequency and intensity of extreme climate events, particularly wet and dry extremes of the water cycle, their causes, and how those may be manifested in the future. Upgrading and expanding critical environmental observing systems are vital to these efforts.

NSF also supports Earth System Understanding through activities spanning a broad range of disciplines and topics that seek to better understand the physical, geological, chemical, biological, and human components of the Earth system and their interactions. Examples of major foci include fundamental research on all aspects of the carbon cycle, the water cycle, atmospheric composition and greenhouse gas processes, marine and terrestrial ecosystems, and ocean and atmospheric circulations that both drive and respond to climate and global change. Human drivers of change include urbanization, population growth, and economic and technological development over a range of temporal scales and NSF has a strong commitment to fostering new interdisciplinary research approaches that allow exploration of the interdependencies across these areas.

Integrated Observations: NSF contributes to the Integrated Observations PCA through its advanced capabilities to observe the physical, chemical, biological, and human components of the Earth system over multiple space and time scales. Facilities such as the Academic Research Fleet and the National Ecological Observatory Network assist the Nation in gaining a fundamental scientific understanding of the Earth as well as monitor important variations and trends that allow the research community to examine major feedback processes between the climate and natural and human systems.

Integrated Modeling: NSF will continue to devote significant resources to advancing climate modeling capabilities from global and centennial to regional and decadal scales. Since there is increasingly deep interplay among observations and modeling at multiple spatial and temporal scales, a high priority will be given to developing more complete representations—models of coupled interactive atmospheric chemistry, terrestrial and marine ecosystems, biogeochemical cycling, and middle atmospheric processes. In addition, NSF is encouraging the development of ecosystem and water models at regional scales, as well as models that integrate human system components such as risk, vulnerability, and decision-making.

Goal 2. Inform Decisions: Provide the scientific basis to inform and enable timely decisions on adaptation and mitigation

Inform Adaptation and Mitigation: A key focus of the USGCRP is developing better means of assessing and responding to the impacts of global change as well as the vulnerability and resilience of both human and natural systems to those changes, particularly in highly sensitive regions such as the Arctic. In addition to supporting research that will inform adaptation decisions, NSF will also support fundamental research regarding the science of adaptation, defined as the adjustment in natural or human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects. This research ranges from developing the theoretical framework for evaluating adaptation options (and avoiding unintended consequences of adaptation choices) to risk assessment and decision-making. NSF will continue interdisciplinary research (including human factors) in water sustainability, resiliency, biodiversity, ocean acidification, and vulnerable areas, particularly in the rapidly changing Arctic.

USGCRP Funding

(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
Integrated Observations	$90.00	-	$84.50
Multidisciplinary Earth and Human System Understanding	113.26	-	98.07
Integrated Modeling	27.15	-	24.60
Science of Adaptation and Science to Inform Adaptation Decisions	10.36	-	9.92
Total	**$240.78**	**-**	**$217.09**

PERFORMANCE AND MANAGEMENT

NSF PERFORMANCE FRAMEWORK

Per the GPRA Modernization Act of 2010, this chapter, together with the Overview, contains basic information about NSF's mission and Strategic Plan, as well as NSF's FY 2021 Annual Performance Plan (APP), Major Management Challenges, FY 2019 Annual Performance Report (APR), and Strategic Objective Progress Update. Information about NSF's performance can also be found on the NSF website in the FY 2019 Performance and Financial Highlights Report.[1]

Strategic Plan and Strategic Objectives

In FY 2018, NSF released its Strategic Plan for FYs 2018-2022: *Building the Future: Investing in Discovery and Innovation.*[1] This Plan lays out two strategic goals that embody the dual nature of NSF's mission to advance the progress of science while benefitting the Nation: *Expand knowledge in science, engineering, and learning* and *Advance the capability of the Nation to meet current and future challenges*. A third goal, *Enhance NSF's performance of its mission*, directs NSF to hold itself accountable for achieving excellence in carrying out its mission. Each goal has two Strategic Objectives which together encompass all areas of agency activity. This goal structure enables NSF to link its investments to longer-term outcomes.

Strategic Goal		Strategic Objective
1	Expand knowledge in science, engineering, and learning.	**1.1 Knowledge** Advance knowledge through investments in ideas, people, and infrastructure.
		1.2 Practice Advance the practice of research.
2	Advance the capability of the Nation to meet current and future challenges.	**2.1 Societal Impacts** Support research and promote partnerships to accelerate innovation and to provide new capabilities to meet pressing societal needs.
		2.2 STEM Workforce Foster the growth of a more capable and diverse research workforce and advance the scientific and innovation skills of the Nation.
3	Enhance NSF's performance of its mission.	**3.1 Human Capital** Attract, retain, and empower a talented and diverse workforce.
		3.2 Processes and Operations Continually improve agency operations.

Agency Priority Goal and Performance Plan

The most prominent goal in NSF's FY 2021 APP is its Agency Priority Goal in the area of Partnerships. This is a continuation of the previous APG in this area, which expanded the number of public and private partnerships NSF entered into between FY 2017 and FY 2019. The current iteration of the Partnerships APG covers the time period of FY 2020-FY 2021 and is broader in scope, seeking to strengthen NSF's capacity to strategically engage in partnerships.

The APP also includes two goals aimed at maintaining and improving customer service: NSF's longstanding performance goal to make timely award decisions and a goal, which was new in FY 2018, that focuses on improving the quality of the reviews written by outside reviewers. The APP also continues two goals aimed at monitoring of key program and infrastructure investments. Monitoring of activities funded as Mid-scale Research Infrastructure supported by the MREFC account was added to the infrastructure investment monitoring goal in FY 2020.

[1] www.nsf.gov/about/performance

Renewing NSF

For the third year, NSF's APP supports the Renewing NSF effort, the agency-wide change initiative that arose from NSF's internal work over the summer of 2017 to implement agency reform per M-17-22. NSF wrote Renewing NSF into its annual performance plans beginning in FY 2019: the former and current APG in support of Partnerships supports one of the four pillars of Renewing NSF, and the existing goals in the Performance Plan that monitor inclusion, human resources, and information technology customer service were refocused to support Renewing NSF efforts in Workforce and IT.

FY 2019 NSF STRATEGIC OBJECTIVE PROGRESS UPDATES

In FY 2019, the National Science Foundation conducted Strategic Reviews (SRs) of the six Strategic Objectives in its 2018-2022 Strategic Plan in response to the requirement of the GPRA Modernization Act 2010 Section 1116(f). Table 1 summarizes the analyses performed and the outcomes to date of each SR. The table also provides NSF's determination as to whether performance towards an Objective is making noteworthy progress, should pursue focused improvement, or neither.

FY 2019 Process and Modifications

In FY 2019, NSF streamlined its SR process to ensure completion in a timeframe that could inform FY 2021 budget development. In an approach informed by Enterprise Risk Management (ERM) principles, topics were chosen to support and inform two areas where process improvements were immediately needed: development of the new OMB dashboard to highlight agency performance, and application of lessons learned during the lapse to our operations and towards maturation of the NSF model for major facilities oversight. NSF did not conduct a review in an area relevant to each of its Objectives, although each Review applied to more than one Objective.

For the FY 2018 Objective rankings, NSF's Performance Improvement Officer (PIO) assessed the maturation stage of each SR's implementation plans. No evidence was found that would warrant changes to those rankings in FY 2019.

Strategic Review Results

Strategic Objectives	Relevant SRs in FY 2018	Relevant SRs in 2019	Rankings
1.1 Knowledge	Streamlining, standardizing, and simplifying processes and practices*	Merit Review Report Modernization Funding Continuity for Major Facilities Portfolio	Progressing
1.2 Practice		Merit Review Report Modernization	Progressing
2.1 Societal Impacts	Expanding and deepening public and private partnerships*	No review in 2019	Noteworthy Progress
2.2 STEM Workforce	SR of NSF INCLUDES to illustrate a Learning Agenda		Progressing
3.1 Human Capital	Adapting NSF's work and workforce*		Area of Focus
3.2 Processes and Operations	Making IT work for all*	Merit Review Report Modernization Funding Continuity for Major Facilities Portfolio	Progressing

*A Renewing NSF initiative. For more information on Renewing NSF, see the Special Analyses chapter.

Strategic Review of Merit Review Report Modernization

Strategic Objective 1.1: Knowledge: Advance knowledge through investments in ideas, people, and infrastructure.
Strategic Objective 1.2: Practice: Advance the practice of research.
Strategic Objective 3.2: Processes and Operations: Continually improve agency operations.

The strategic review explored evidence to inform agency planning and decision making and a strategy to improve the Merit Review Report (MRR).[1]

To ensure the integrity, quality, accountability, and transparency of its policies and processes, NSF prepares and submits an annual MRR to the National Science Board. It contains a statistical summary of the operation of the merit review process, including information on the number of proposals submitted, funding rates, average award sizes and durations, and information about the diversity of proposers, awardees and reviewers. In July 2018, the NSB Committee on Oversight asked NSF to examine how the Merit Review Report could be made more useful with a goal of providing greater accountability, openness, and transparency about the merit review process and enabling continuous assessment and improvement of the merit review process.

Three Key Analytical Questions were posed:
1. How can we broaden understanding of the merit review process's correspondence to NSF's mission and increase the value of information about it to stakeholders?
2. How can NSF inform and empower key stakeholders by revising electronic access to Merit Review Report content?
3. How can NSF leverage existing resources to sustainably maintain an improved online version of Merit Review Report content?

The SR team consulted a broad range of internal stakeholders, examined a similar effort undertaken by the NSF National Center for Science and Engineering Statistics (NCSES), and reviewed data from existing merit review surveys of PIs and reviewers. The team found that many NSF Program Officers are unfamiliar with the Merit Review Report and its value as a resource when communicating with their PI communities. Some program officers reported using the report to disabuse communities of misconceptions about the review process. For example, a major misconception evident in recent PI surveys is that a majority of PIs believed that the proposal funding rate was 10 percent or lower, when it has historically been about 22 percent Foundation-wide.

The strategic review team concluded that a scoping feasibility study is necessary to better inform the Merit Review Report modernization effort, and that a coherent communications strategy would improve understanding and the usefulness of the Merit Review Report contents.

Activities after the SR

In response to the Strategic Review findings and recommendations, NSF is engaging in a feasibility study to inform plans for subsequent steps of the modernization activities. In consultation with key stakeholders, especially the National Science Board Committee on Oversight, NSF will develop a prioritized approach to creating a Merit Review dashboard that provides access to detailed information about NSF's merit review process. In concert with the development of the dashboard, NSF will implement a coordinated communications plan aimed at informing internal and external stakeholders about the Merit Review report and related electronic resources.

[1] Copies from 1996 forward are available online at www.nsf.gov/nsb/publications/pubmeritreview.jsp.

Strategic Review of Funding Continuity for NSF's Major Facilities Portfolio

Strategic Objective 1.1: Knowledge: Advance knowledge through investments in ideas, people, and infrastructure.
Strategic Objective 3.2: Processes and Operations: Continually improve agency operations.

This Strategic Review focused on the evaluation of agency practices in funding NSF's Major Facilities. Specifically, it incorporated lessons learned from the maturation of the recently-created Chief Officer for Research Facilities (CORF) position and from the impact of the FY 2019 lapse in appropriations on the major facilities portfolio.

NSF's portfolio of major facilities represents a substantial fraction of its total budget, including construction and operations of facilities at sites throughout the U.S. and around the world. Oversight of activities related to these facilities is led by program officers (PO) in distinct directorates, in close collaboration with multiple divisions within the Office of Budget, Finance, and Award Management (BFA). NSF has traditionally managed major facilities as discrete programs in their relevant directorates, and the divisions within those directorates, with summary data collected and presented only once a year as part of the Congressional Budget Request. Day-to-day oversight is generally provided at the division level by POs, in coordination with other members of an NSF Integrated Project Team. The distributed nature of this approach requires extensive coordination of oversight activities across the agency.

Two emerging elements in NSF's Major Facilities management inspired this review:
1. As mandated by Congress in the 2017 American Innovation and Competitiveness Act (AICA), the CORF, in the Office of the Director, is responsible for overall full life-cycle oversight of NSF's Major Facilities.
2. The lapse in appropriations from December 22, 2018 to January 25, 2019 highlighted several of the challenges involved in facilities oversight and financial management: how NSF ensures that appropriate facility funding obligations are in place throughout the fiscal year, how NSF management is able to quickly and accurately monitor the financial status of each facility to ensure that adequate funding is available, and how the funding is distributed to the facilities on a routine basis.

Following the resumption of NSF operations in January 2019, this Strategic Review analyzed lessons learned and considered potential improvements in facilities funding and oversight practices that would be applicable throughout the fiscal year to ensure funding continuity across all of NSF's Major Facilities. The team concluded that targeted improvements in NSF's financial management of its major facilities portfolio would enhance the stability of operations and decrease risks to NSF's mission. Specifically, a centralized and reliable method to provide timely and accurate financial information for all of the major facilities is needed in order to better inform agency-level decision making on a continual basis. In addition, NSF needs agency-wide guidelines for how funds should be routinely obligated to major facilities operations and maintenance (O&M) awards in order to support on-going science activities and to improve financial stability for the recipients at key operational milestones throughout the year. These guidelines must consider workload impacts and be flexible enough to address the diversity of facilities and funding circumstances across NSF divisions.

Activities after the SR

In response to the Strategic Review findings and recommendations, NSF issued a cross-directorate instruction memo on August 6th regarding the requirements for facility funding at potential discontinuity points in federal funding (e.g., end of Fiscal Year, end date of short-term Continuing Resolutions). A major facilities funding health "dashboard" for internal use is under development.

FY 2019 ANNUAL PERFORMANCE REPORT AND FY 2021 ANNUAL PERFORMANCE PLAN

This document combines NSF's FY 2019 Annual Performance Report and FY 2021 Annual Performance Plan (APP + APR = APPR). FY 2020's goals, and historical information on individual goals, are also provided when available. Results for each performance goal are presented in strategic context, with reference to strategic goals, objectives, and targets from NSF's 2018-2022 Strategic Plan. Multiple years of trend data are available for NSF's longstanding quantitative performance measures (Infrastructure Investments and Timely Proposal Decisions). Other performance goals monitor progress towards multiyear goals, such as implementation of a new process (Improve Review Quality, Culture of Inclusion), upgrades to ongoing processes (Align Job Requirements, Improve User Interactions), or strategically important investments (Key Program Investments, Expand Public and Private Partnerships).

In FY 2019, NSF tracked progress toward its three strategic goals using eight performance goals, one of which was an Agency Priority Goal. Six of the eight goals partially or fully achieved their targets in FY 2019 and two goals missed their targets.

Goal 1, Agency Priority Goal (APG): Public and Private Partnerships

Lead Organizations: Directorate for Biological Sciences, Directorate for Computer and Information Science and Engineering.

Goal Statement

Strategically engage in public and private partnerships to enhance the impact of NSF's investments and contribute to American economic competitiveness and security.

Measure, Milestone, or Deliverable

Current Year		
FY	**Target Summary**	
2020-2021	To benefit the U.S. scientific and engineering research and education enterprise, by September 30, 2021, NSF will develop and pursue an agency-wide partnerships strategy, components of which will include targeted outreach, implementation of process improvements, and improvement of internal and external communications.	
Reporting Year		
FY	**Target Summary**	**Result**
2019	Expand public and private partnerships to enhance the impact of NSF's investments and contribute to American economic competitiveness and security. By September 30, 2019, NSF's number of partnerships and award actions with other federal agencies, private industry, and foundations/philanthropies will grow by five percent, relative to the FY 2017 baseline, to make available infrastructure, expertise, and financial resources to the US scientific and engineering research and education enterprise.	Achieved. FY 2017 baseline = 57 partnerships 70 partnerships in FY 2019, an increase of 23 percent over FY 2017 baseline.
Previous Years		
FY	**Target Summary**	**Result**
2018	No FY 2018 target—first year of APG	FY 2018 = 68 partnerships

Strategic Alignment

Strategic Goal 2: Advance the capability of the Nation to meet current and future challenges. Objective 2.1, Societal Impacts: Support research and promote partnerships to accelerate innovation and to provide new capabilities to meet pressing societal needs.

About This Goal

This goal incorporates principles from Renewing NSF, the agency operational reform plan initiated in FY 2017 in response to M-17-22, "Comprehensive Plan for Reforming the Federal Government."

Private industry, foundations, and non-profits, together with other federal agencies and international funding organizations, bring additional expertise, resources, and capacity to NSF-funded research. This, in turn, accelerates discovery and translation of research to products and services, and enhances preparation of the future workforce to benefit society and grow the American economy.

Partnerships require significant time and intellectual capital, as well as strategic foresight, in their development. NSF will improve efficiencies in developing, implementing, and managing partnerships to ultimately grow the number and scope of partnerships and maximize the scientific, economic, and societal impacts of its investments.

Discussion of FY 2019 Results

As a result of this APG, NSF noted a significant year-over-year increase in number of partnership activities, defined for this APG as a formal agreement between NSF and at least one external, domestic stakeholder and for which there was investment, new commitment, or other quantifiable contribution formalized in the fiscal year. “Formal agreements” include, but are not limited to, Interagency Agreements and Memoranda of Understanding. Additionally, the Partnerships APG implementation team increased the Foundation’s awareness of partnerships, increased the attention paid to strategy and diversity of opportunity in partnership formation, and streamlined processes relating to partnerships. See performance.gov/NSF for a fuller report on these activities.

FY 2020 and Planned FY 2021 Changes

In FY 2020 and beyond, the Partnerships pillar of Renewing NSF and the APG Implementation Team will merge to strengthen NSF’s partnerships strategy. The group will focus on the strategic value of the Foundation’s partnerships, including a milestone-oriented approach to reporting and assessing progress. The group plans to continue refining the approach used in FYs 2018-2019 to quantitatively track partnerships.

<u>Goal 2, Ensure that Key Program Investments are on Track</u>
Lead Organization: Office of Budget, Finance, and Award Management.

Goal Statement
Ensure that key NSF-wide program investments are implemented and on track.

Measure, Milestone, or Deliverable

<table>
<tr><th colspan="3">Current and Upcoming Years</th></tr>
<tr><th>FY</th><th colspan="2">Target Summary</th></tr>
<tr><td>2021</td><td colspan="2" rowspan="2">NSF will obligate 100 percent of designated funding targets for all identified NSF-wide priority investments.</td></tr>
<tr><td>2020</td></tr>
<tr><th colspan="3">Reporting Year</th></tr>
<tr><th>FY</th><th>Target Summary</th><th>Result</th></tr>
<tr><td>2019</td><td>1. Monitor the progress of the following NSF-wide investments using a common set of milestones and indicators: Big Ideas.
2. Review the results with senior leaders quarterly in data-driven performance reviews.</td><td>Achieved</td></tr>
</table>

Strategic Alignment
- Strategic Goal 1: Expand knowledge in science, engineering, and learning (all Objectives)
- Strategic Goal 2: Advance the capability of the Nation to meet current and future challenges (all Objectives)

About This Goal
NSF instituted the Key Program Investments goal in FY 2014 to track the interim progress of major investments towards their long-term goals. Each year, NSF highlights a number of cross-agency investments in its Budget Request to Congress. Most are described in the NSF-Wide Investments chapter of the Budget Request. Although the overall impact of these investments might not be measurable for many years, tracking near-term indicators of progress can help the agency make formative changes or course corrections.

NSF selects a subset of these investments for closer quarterly tracking by agency leadership, based on internal assessments of the value that tracking is likely to add. For example, new programs, programs with recent changes, or high-profile programs may benefit from the attention of leadership, and programs that are stably operating or sunsetting have reduced need for monitoring.

Discussion of FY 2019 Results
NSF monitored ten Big Ideas investments under this goal in FY 2019. This was the first fiscal year when all Big Ideas issued solicitations. NSF monitored solicitation issuance dates, numbers of proposals received and awards made, and funding obligated. Reports were reviewed with senior leaders at three points (due to the lapse in funding in Q1 and Q2 at both NSF and OMB, Q1 and Q2 performance reporting requirements were considered together after the lapse ended).

FY 2020 and Planned FY 2021 Changes
The Big Ideas will remain the focus of this goal. The unit of measurement is being modified to simplify quarterly tracking and the determination of achievement.

Goal Change History
The intended purpose of tracking these key investments is to ensure that these projects meet internal milestones and issue funding adequate to achieve the desired advances in science and engineering. NSF's independent verification and validation team has pointed out weaknesses in the measurability, and therefore utility, of this goal. The measurement method was established in FY 2014 to accommodate programs with

different structures, which were not all tracked the same way within NSF's systems—a common issue at that time. Since the Big Ideas are defined and tracked similarly, NSF is changing from a qualitative approach (where the unit of analysis is a program) to a quantitative approach (unit of analysis is the percentage of funds obligated relative to a target). This change will make for a more quantifiable and meaningful goal.

Previous Years		
FY	**Target Summary**	**Result**
2018	1. Monitor the progress of the following NSF-wide investments using a common set of milestones and indicators: NSF INCLUDES, INFEWS, Risk and Resilience, and UtB. 2. Review the results with senior leaders quarterly in data-driven performance reviews.	Achieved
2017	1. Monitor the progress of the following NSF-wide investments using a common set of milestones and indicators: NSF INCLUDES, INFEWS, Risk and Resilience, and UtB. 2. Review the results with senior leaders quarterly in data-driven performance reviews.	Achieved
2016	Monitor the progress of the following NSF-wide investments using a common set of milestones and indicators: NSF INCLUDES, INFEWS, and UtB.	Achieved
2015	Monitor the progress of Cognitive Science and Neuroscience, CEMMSS, CIF21, SaTC, and SEES using a common set of milestones and indicators.	Achieved
2014	Monitor the progress of CEMMSS, CIF21, I-Corps™, INSPIRE, SaTC, and SEES using a common set of milestones and indicators.	Not achieved

By design, this goal's monitored programs change annually to match the funding priorities of the year. In addition to the annual change in the list of monitored programs, described in the narrative and the table below, the Goal Statements have changed slightly each year for this goal, as follows:

FY 2019: Ensure that key FY 2019 NSF-wide program investments are implemented and on track.
FY 2018: Ensure that key FY 2018 NSF-wide program investments are implemented and on track.
FY 2017: Ensure that key FY 2017 NSF-wide program investments are implemented and on track.
FY 2016: Ensure that key FY 2016 NSF-wide program investments are implemented and on track.
FY 2015: Meet critical targets for key program investments.
FY 2014: Meet critical targets for key FY 2014 program investments.

FY	CEMMS	SaTC	CIF21	SEES	UtB	INFEWS	NSF INCLUDES	Risk and Resilience
2014	✓	✓	✓	✓				
2015	✓	✓	✓	✓	✓			
2016					✓	✓	✓	
2017			sunset	sunset	✓	✓	✓	✓
2018	sunset				✓	✓	✓	✓

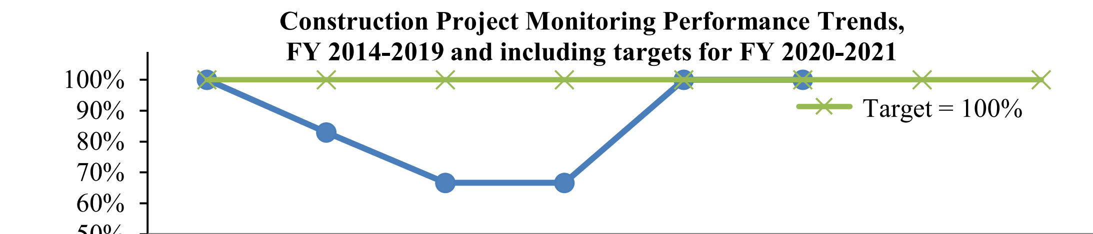
CEMMS: Cyber-enabled Materials, Manufacturing, and Smart Systems
SaTC: Secure and Trustworthy Cyberspace
CIF21: Cyberinfrastructure Framework for 21st Century Science and Engineering
SEES: Science, Engineering, and Education for Sustainability
UtB: Understanding the Brain
INFEWS: Innovations at the Nexus of Food, Energy and Water Systems
NSF INCLUDES: Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science

<u>Goal 3, Ensure that Infrastructure Investments are on Track</u>
Lead Organization: Large Facilities Office, Office of Budget, Finance, and Award Management.

Goal Statement
Ensure program integrity and responsible stewardship of major research facilities and infrastructure.

Measure, Milestone, or Deliverable

Current and Upcoming Years		
FY	**Target**	
2021 2020	Construction Project Monitoring (MREFC and R&RA): 1. Keep negative cost and schedule variance at or below 10 percent for 100 percent of Major Facilities in the Construction Stage that are over 10 percent complete. 2. Track cost and schedule performance for Mid-scale Research Infrastructure in the Construction Stage with a Total Project Cost (TPC) above $20.0 million that are over 10 percent complete and using Earned Value Management (EVM) principles.	
Reporting Year		
FY	**Target**	**Result**
2019	Construction Project Monitoring: For 100 percent of MREFC facilities under construction that are over 10 percent complete, keep negative cost and schedule variance at or below 10 percent.	Achieved.
Measure Information for All Years		



	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Result	100%	83%	67%	67%	100%	100%		
Target	100%	100%	100%	100%	100%	100%	100%	100%

Strategic Alignment
Strategic Goal 1: Expand knowledge in science, engineering, and learning. Objective 1.1, Knowledge: Advance knowledge through investments in ideas, people, and infrastructure.

About This Goal
The MREFC account supports the acquisition, construction, and commissioning of major research facilities and equipment that provide unique capabilities at the frontiers of science and engineering. Performance of construction projects funded by the MREFC account is monitored using the Earned Value Management System (EVMS). EVMS is an integrated management control system for assessing, understanding, and quantifying what a contractor or field activity is achieving with program dollars. Monitoring cost and schedule is a standard measure of performance for construction projects. Projects that are under 10 percent complete are not considered eligible for this goal because EVM data is less meaningful statistically in the very early stages of a project.

Discussion of FY 2019 Results
For more information about all projects currently funded from the MREFC account, see the Major Research

Equipment and Facilities Construction chapter of this Budget Request.

All of the projects that were over 10 percent complete by the end of FY 2019 were on track. At the end of FY 2019, the Daniel K. Inouye Solar Telescope was 94 percent complete, the Large Synoptic Survey Telescope was 75 percent complete, and the Regional Class Research Vessel project was 21 percent complete. Each project had cost and schedule variances well below the 10 percent thresholds. The National Ecological Observatory Network completed the construction phase in FY 2019.

FY 2020 and Planned FY 2021 Changes

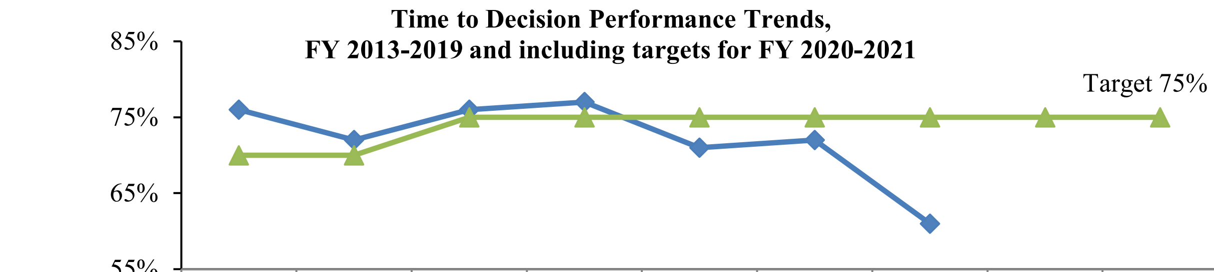
In FY 2020, the population of projects will expand. The Antarctic Infrastructure Modernization for Science project is likely to cross the 10 percent complete threshold during FY 2020. Additionally, projects funded by the NSF Mid-scale Research Infrastructure Big Idea (MSRI) will also be tracked by this goal. More specifically, those MSRI projects with a Total Project Cost above $20.0 million will be tracked using EVM principles.

<u>Goal 4, Make Timely Proposal Decisions</u>
Lead Organization: Office of Integrative Activities.

Goal Statement
Inform applicants whether their proposals have been declined or recommended for funding within 182 days, or six months, of deadline, target, or receipt date, whichever is later.

Measure, Milestone, or Deliverable

Current and Upcoming Years		
FY	**Target**	
2021	75 percent.	
2020		
Reporting Year		
FY	**Target**	**Result**
2019	75 percent.	Not Achieved.
Measure Information for All Years (see "Goal Change History" for details)		



	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Result	76%	72%	76%	77%	71%	72%	61%		
Target	70%	70%	75%	75%	75%	75%	75%	75%	75%

Strategic Alignment
Strategic Goal 3, Enhance NSF's performance of its mission. Objective 3.2, Processes and Operations: Continually improve agency operations.

About This Goal
Time to decision or "dwell time" is the amount of time that passes between receipt of a proposal and notification to the principal investigator (PI) about the funding decision. At the time of this goal's establishment in the early 2000s, one of the most significant issues raised in customer satisfaction surveys was the time it took NSF to process proposals, with only around 50 percent of proposals receiving responses within 6 months of submission or deadline. Too long a time period inhibits the progress of research as it delays the funding process, but too short a time period may inhibit review quality. The 75 percent target seeks to strike a balance between the need of the PI for timely action and the need of NSF for a credible and efficient merit review system. Since this goal was introduced, NSF's response times have improved, and over 70 percent of proposals have received responses in under 6 months for nearly two decades. More recent surveys have shown that this is now the second most common concern mentioned by PIs (see Goal 6, Improve Review Quality, for more recent survey results).

Discussion of FY 2019 Result
<u>Explanation of Unmet Goal</u>
NSF missed this goal in FY 2019 due to the 35-day lapse in funding during December 2018-January 2019. More specifically, this goal was missed due to key decisions that were made when prioritizing work upon

returning to normal operations. As in FY 2017, when NSF was relocating to its new headquarters in Alexandria, upon resumption of operations in Q2 FY 2019 NSF staff were directed to prioritize processing award decisions ahead of decline decisions. In FY 2017 this shift in work facilitated an early close-out, while in FY 2019 this shift made up for the lost weeks of award processing work in the middle of the fiscal year. This decision to prioritize awards is likely to affect the FY 2020 dwell time result, as NSF is now processing a backlog of likely declines.

FY 2020 and Planned FY 2021 Changes

NSF will continue its target of informing 75 percent of proposers of the decisions reached within 6 months of submission.

Goal Change History

In FY 2015, the target was raised from 70 to 75 percent to be more in line with the historical trend of achievement from 75 to 80 percent. The low dwell time result in FY 2014, 72 percent, was likely due to Foundation-wide delays in proposal processing after the lapse in funding authority in October 2013.

<u>Goal 5, Improve Review Quality</u>
Lead Organization: Office of Integrative Activities, Office of the Director.

Goal Statement
Improve the quality of written reviews of NSF proposals.

Measure, Milestone, or Deliverable

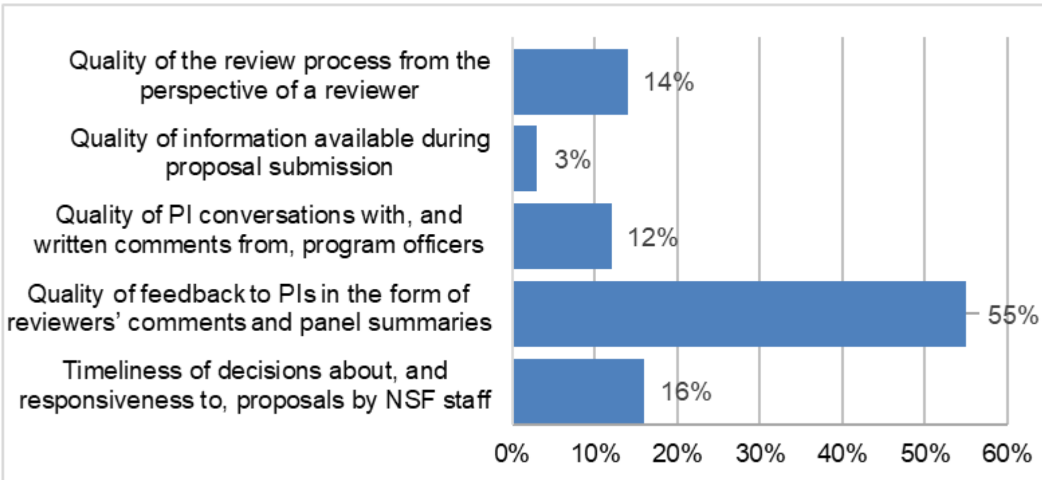
Current and Upcoming Years		
FY	**Target**	
2021	TBD mid-FY 2020	
2020	By September 30, 2020, 1. 140 NSF programs will have had reviewers view the presentation "Tips on how to write better reviews." 2. 10,000 reviewers of NSF proposals will have viewed "Tips on how to write better reviews" prior to preparing written reviews.	
Reporting Year		
FY	**Target**	**Result**
2019	By September 30, 2019, 1. 60 NSF programs will have had reviewers view the presentation "Tips on how to write better reviews." 2. 8,000 reviewers of NSF proposals will have viewed "Tips on how to write better reviews" prior to preparing written reviews. 3. Improve the perceptions reported by survey respondents in a repeat survey of proposers and reviewers. • Increase the percentage of PI survey respondents who agree that written reviews are thorough from a baseline of 55 percent (2015) to 57 percent in FY 2019. • Increase the percentage of PI survey respondents who agree that written reviews are technically sound from a baseline of 63 percent (2015) to 65 percent in FY 2019.	1. Achieved. 2. Achieved 3. Achieved
Previous Years		
2018	By September 30, 2018, 1. 50 NSF programs will have held orientation sessions that include "Tips on how to write better reviews." 2. 5000 reviewers of NSF proposals will have viewed "Tips on how to write better reviews" prior to preparing written reviews.	1. Achieved 2. Not achieved

Strategic Alignment
- Strategic Goal 1: Expand knowledge in science, engineering, and learning (all Objectives)
- Strategic Goal 3: Enhance NSF's performance of its mission. Objective 3.2, Processes and Operations: Continually improve agency operations.

About This Goal
This goal addresses and incorporates feedback NSF has received about its customer service. Committees of Visitors, program officers, and principal investigators (PIs) frequently note that the quality of individual written reviews is variable. In 2015, NSF conducted a survey of researchers who were submitting and/or reviewing proposals. Survey respondents identified the quality of reviews as the factor that would have the most significant effect on improving their proposals and fostering science (see chart below, n=22,174 respondents). A strategic review in the spring of 2015 recommended that NSF apply what was learned from the PI and reviewer survey to inform a new performance goal aimed at improving customer service. This goal was designed in response to that recommendation.

This goal measures the implementation of a pilot program, initiated in December 2016, to improve the quality of written reviews of NSF proposals. The pilot encourages NSF programs to use the video presentation "Tips on how to write better reviews" early in the review process to orient reviewers and provide information on how to write more effective reviews. The assumption is that orienting reviewers before the reviews are written (as opposed to at the beginning of a review panel, at which time the reviews have been drafted but not finalized) helps reviewers better understand and apply the review criteria. The intention is to make written reviews more useful to both PIs and NSF program staff.

Percentage of respondents identifying each item as the most significant improvement that could be made in the merit review process.[1]



Discussion of FY 2019 Results

Through September 30, 2019, reviewers across at least 296 programs viewed the orientation video, exceeding the target of 50 programs. 5,894 reviewers viewed the orientation video prior to preparing written reviews in FY 2019. Combined with the 3,022 reviewers viewing the video in FY 2018, this makes a total of 8,916 reviewers viewing the video, exceeding the target of 8,000 reviewers.

The survey mentioned in FY 2019's third target was delayed by the lapse in appropriations. Preliminary data was used to assess this result. These data showed that 11,999 out of 18,632 respondents (64.4 percent) agreed or strongly agreed that written responses were thorough, and 12,950 out of 18,537 respondents (67.9 percent) agreed that written reviews are technically sound. These both exceed the targets of, respectively, 57 and 65 percent.

FY 2020 and Planned FY 2021 Changes

Development of FY 2021 targets for this goal is dependent on the results of the 2019 survey, which will not be available until mid-2020. At a high level, the goal—to improve review quality—remains highly relevant to NSF. Without the survey data, though, it is not possible to assess whether the current activities are having the desired impacts, so NSF is not yet in a position to decide which specific steps to take towards that end. Therefore, targets will be developed in the second half of FY 2020 and published in the FY 2022 Plan/FY 2020 Report. The survey is biennial and will be fielded again in FY 2021.

[1] FY 2015 Merit Review Report, p.126. www.nsf.gov/nsb/publications/2016/nsb201641.pdf

<u>Goal 6, Foster a Culture of Inclusion</u>
Lead Organization: Office of Diversity and Inclusion (ODI), Office of the Director.

Goal Statement
Foster a culture of inclusion through change management efforts resulting in change leadership and accountability.

Measure, Milestone, or Deliverable

Current and Upcoming Years		
FY	**Target**	
2021	All NSF leaders will participate in culture change activities.	
2020	All NSF leaders will participate in culture change activities.	
Reporting Year		
FY	**Target**	**Result**
2019	In FY 2019, 100 percent of NSF leaders will participate in culture change activities.	Not Achieved

Strategic Alignment
Strategic Goal 3, Enhance NSF's performance of its mission. Objective 3.1, Human Capital: Attract, retain, and empower a talented and diverse workforce.

About This Goal
This goal incorporates principles from Renewing NSF, the agency operational reform plan initiated in FY 2017 in response to M-17-22, "Comprehensive Plan for Reforming the Federal Government."

Fostering inclusive work environments and realizing the full potential of the workforce's diversity requires agencies to employ effective management practices. NSF values diversity and inclusion: by engaging the talent of all our workforce, individuals are empowered to realize their full potential; by insuring that our workforce is diverse, our collective ability to deliver on our scientific mission is enhanced. NSF looks for ways to intensify and innovate diversity efforts through active leadership and including and engaging everyone in the workplace. This goal will encourage leaders to participate in engagement initiatives being used around the Foundation, including, but not limited to:

- New Inclusion Quotient (New IQ) workshops,
- Diversity and Inclusion Dialogues,
- Workforce Inclusiveness Assessment,
- Special Emphasis observances,
- Employee Resource Groups,
- Unconscious bias awareness training, and
- Inclusion learning activities for all employees.

Discussion of FY 2019 Results
For FY 2019, NSF expanded this goal's scope in two ways: to include all leaders, and to include participation in activities other than the New IQ that might contribute to culture change. Unrelated to this particular goal, NSF took steps in FY 2018 to help ensure that all NSF-funded research and learning environments are free from harassment by bolstering policies, guidelines, and communications so that organizations clearly understand expectations and individuals understand their rights. Internally, the agency has promoted an identical set of expectations for its staff and leaders. In relating anti-harassment efforts to the aims of this goal, NSF determined that leadership's participation in anti-harassment and anti-bullying training had the potential to contribute to culture change, since it could not only help them identify and stop harassment and bullying, but could actively promote an environment and a culture where all contributions are valued and everyone can reach their full potential.

Explanation of Unmet Goal

To keep in the spirit of expanding the goal's scope to the entire agency, NSF in FY 2019 defined "leaders" broadly, to mean all managers and executives. To simplify measurement in the first year of the expanded goal scope, NSF defined "participate in culture change activities" narrowly, as completion of a new anti-harassment and anti-bullying training module made available to all NSF staff. The training module was not available until the fourth quarter of FY 2019. Despite the late roll-out of the training, 55 percent of NSF staff completed both training modules in the last two months of FY 2019, including over half of managers and executives and over 80 percent of senior leaders. As of mid-January 2020, over 80 percent of NSF staff, including all senior leaders, have completed the training.

FY 2020 and Planned FY 2021 Changes

In FY 2020 emphasis on full completion of the anti-harassment and anti-bullying training by all staff will continue. The list of activities that will be considered to support culture change is anticipated to expand as more offerings are made available to NSF staff.

Goal Change History

While NSF has had a performance goal relating to diversity and inclusion since FY 2011, throughout the years, new directions have emerged under its umbrella. For five years, goals were largely focused on NSF's efforts to attain "Model EEO Agency"[2] status. Starting in FY 2016, this goal focused on inclusion, and New IQ workshops[3] were made available to NSF staff. The focus on leadership represents another new direction for this goal in FY 2019. For more information on previous formulations of this goal, refer to the FY 2015 Annual Performance Report in the FY 2017 NSF Budget Request (Model EEO Agency[2]) or the FY 2018/FY 2020 APPR in the FY 2020 NSF Budget Request (New IQ[3]).

Previous Years (see "Goal Change History" for details)		
FY	**Target Summary**	**Result**
2018	1. By September 30, 2018, ODI will conduct the new IQ process with four organizational units. 2. Improve the four NSF organizational units' New IQ Self-Survey Scores by five percent above established baseline.	1. Achieved. Four units. 2. Achieved. Increases averaged 10 percent.
2017	1. By September 30, 2017, ODI will conduct the new IQ process with three additional organizational units. 2. Improve the three NSF organizational units' New IQ Self-Survey Scores by seven percent above established baseline.	No targets achieved.
2016	1. By September 30, 2016, ODI will conduct the new IQ process with two NSF organizational units. 2. Improve the two NSF organizational units' New IQ Self-Survey Scores by five percent above established baseline.	No targets achieved
2015	Attain six of six essential elements of a model EEO agency, perform two compliance desk reviews under antidiscrimination laws.	Not Achieved (4/6 elements, 2 desk reviews)
2014	Attain six of six essential elements of a model EEO agency, perform two compliance desk reviews under antidiscrimination laws.	Not Achieved (5/6 elements, 0 desk reviews)
2013	Attain five of six essential elements of a model EEO agency.	Achieved
2012	Attain four of six essential elements of a model EEO agency.	Achieved
2011	Attain three elements of a model EEO agency.	Achieved

[2] nsf.gov/about/budget/fy2017/pdf/56_fy2017.pdf
[3] nsf.gov/about/budget/fy2020/pdf/67_fy2020.pdf

<u>Goal 7, Align Job Requirements with Competencies</u>
Lead Organization: Division of Human Resource Management, Office of Information and Resource Management

Goal Statement
Ensure that employee job requirements are aligned with competencies and skills needed for the future.

Measure, Milestone, or Deliverable

Current and Upcoming Years		
FY	**Target**	
2021	In FY 2021, the Division of Human Resource Management will review, modernize, or eliminate 10 percent of the existing position descriptions requiring review.	
2020	In FY 2020, the Division of Human Resource Management will review, modernize, or eliminate 10 percent of the existing position descriptions requiring review.	
Reporting Year		
FY	**Target Summary**	**Result**
2019	In FY 2019, the Division of Human Resource Management will review, modernize, or eliminate 10 percent of the existing position descriptions requiring review.	Achieved
Previous Year		
2018	This goal was initiated in FY 2019 to replace a retired goal entitled *"Use Evidence to Guide Management Decisions,"* in which agency leaders used data-driven reviews to inform decision making.	

Strategic Alignment
Strategic Goal 3, Enhance NSF's performance of its mission. Objective 3.1, Human Capital: Attract, retain, and empower a talented and diverse workforce.

About This Goal
This goal incorporates principles from Renewing NSF, the agency operational reform plan initiated in FY 2017 in response to M-17-22, "Comprehensive Plan for Reforming the Federal Government."

Technological improvements have automated many tasks once performed by NSF staff. Requirements for NSF's administrative staff have evolved from the more traditional competencies related to general clerical and office tasks such as categorizing, processing, and tracking paper forms to more advanced competencies related to the use of multiple automated data systems. Additionally, the increasing number of proposals NSF receives, processed by the relatively stable number of program officers, means greater support is needed in data processing, data mining, analytics, and use of automated processes. Further, NSF is promoting transdisciplinary and convergent research and will need to ensure its current and future workforce can adapt to this convergent approach. NSF will review and realign its workforce to ensure its greatest resource–NSF staff–are equipped with the knowledge, skills, and abilities for success now and in the future. Ultimately, this will result in increased alignment between NSF's organizational structure, its core mission, and strategic plan.

NSF will improve performance and increase accountability by systematically reviewing the NSF workforce from top to bottom. This review will allow NSF to revise position descriptions (PDs) that are outdated or do not reflect current and future work responsibilities. This PD modernization effort will enable NSF to identify the skills needed in today's work environment and will establish more relevant opportunities for training and developing NSF's existing workforce, while also enabling hiring managers to better target recruitment and outreach efforts to obtain the highest caliber of external candidates.

Discussion of FY 2019 Results

In FY 2019, NSF first identified a pool of 400 PDs that had the potential for being either updated or eliminated, based on vacancy rate or consolidation with other types of positions. NSF then performed a more detailed review of the PDs to determine their relevance to the current ways in which NSF performs its mission, and decided whether the PD was a candidate for updating or eliminating based on the current workforce management approaches of the relevant offices and directorates. After confirming with managers to verify the outdated nature of the PDs, NSF eliminated 40 PDs in FY 2019.

FY 2020 and Planned FY 2021 Changes

NSF anticipates continuing this goal's direction, reaching a cumulative 30 percent of existing PDs reviewed by the end of FY 2021.

Goal 8, Improve User Interactions with IT Systems

Lead Organization: Office of the Chief Information Officer and the Division of Information Systems, Office of Information and Resource Management

Goal Statement

Streamline and simplify user interactions with IT systems and functions that support the merit review process, reducing non-value-added steps and reducing the time spent managing the proposal and award lifecycle.

Measure, Milestone, or Deliverable

<table>
<tr><th colspan="3">Current and Upcoming Years</th></tr>
<tr><th>FY</th><th colspan="2">Target</th></tr>
<tr><td>2021</td><td colspan="2">By the end of FY 2021,
1. NSF IT systems will have been available 99.6 percent of the time, excluding 469 hours of planned downtime.
2. 90 percent of internal merit review functions will be accessible through a single portal.
3. 68 percent of external merit review functions will be accessible through a single portal.</td></tr>
<tr><td>2020</td><td colspan="2">By the end of FY 2020,
1. NSF IT systems will have been available 99.6 percent of the time, excluding 469 hours of planned downtime.
2. 86 percent of internal merit review functions will be accessible through a single portal.
3. 50 percent of external merit review functions will be accessible through a single portal.</td></tr>
<tr><th colspan="3">Reporting Year</th></tr>
<tr><th>FY</th><th>Target Summary</th><th>Result</th></tr>
<tr><td>2019</td><td>By the end of FY 2019,
1. NSF IT systems will have been available 99.5 percent of the time, excluding 469 hours of planned downtime.
2. 72 percent of internal merit review functions will be accessible through a single portal.
3. 32 percent of external merit review functions will be accessible through a single portal.</td><td>1. Achieved
2. Achieved
3. Achieved</td></tr>
<tr><th colspan="3">Previous Year</th></tr>
<tr><td>2018</td><td colspan="2">This goal was initiated in FY 2019 to replace a retired goal entitled “Use Evidence to Guide Management Decisions,” in which agency leaders used data-driven reviews to inform decision making.</td></tr>
</table>

Strategic Alignment

Strategic Goal 3, Enhance NSF’s performance of its mission. Objective 3.2, Processes and Operations: Continually improve agency operations.

About This Goal

This goal incorporates principles from Renewing NSF, the agency operational reform plan initiated in FY 2017 in response to M-17-22, “Comprehensive Plan for Reforming the Federal Government.”

As part of the Renewing NSF principle to make IT Work For All, NSF will focus on leveraging state-of-the-art IT solutions to develop flexible tools and improve upon current service offerings in order to streamline and simplify the interactions that staff and the research community have with NSF's IT systems. This will help ensure that their time is spent on activities where they can add the most value instead of administrative activities, thereby helping the agency more effectively carry out its mission. As part of this effort, NSF will offer single points of access to both internal and external users for the IT services that they need, ensure that IT services have close to 100 percent availability with downtime for critical maintenance and service releases carefully coordinated to minimize disruption. In addition, NSF will utilize new IT solutions for automating non-value-added steps for users, through services like robotic process automation.

Discussion of FY 2019 Results
Target 1 was exceeded in all four quarters. Target 2 was exceeded, with 79 percent of internal merit review functions were accessible through a single portal at the end of the FY. Target 3 was met, with 32 percent of external merit review functions accessible through a single portal at the end of the FY.

FY 2020 and Planned FY 2021 Changes
NSF is planning to change the second and third targets to monitor the modernization of proposal submission functions. The set of functions that would be monitored has not been finalized at the time of publication, so specific targets will be developed in the second half of FY 2020 and published in the FY 2022 Plan/FY 2020 Report.

FY 2019 MANAGEMENT CHALLENGE PROGRESS REPORT

Background

Under the Reports Consolidation Act of 2000, NSF's Inspector General is required to summarize what it considers to be the most significant management and performance challenges facing NSF in the coming year in a memo to the NSF Director. The management challenges are identified by NSF's Inspector General and announced at the beginning of each fiscal year. In response, the Director issues a memo to acknowledge receipt of the OIG Management Challenges and to provide a report on NSF's progress and achievements made over the prior year.

The OIG's challenges, NSF's response, and NSF's progress update towards addressing previously identified challenges are included in the annual Agency Financial Report (AFR) published in November on NSF's website.[1] This section provides NSF's progress report highlighting the significant actions taken in FY 2019 on the management challenges identified by NSF's Inspector General at the beginning of that fiscal year.

Enterprise Risk Management

Starting in FY 2018, NSF's Progress Report applied its Enterprise Risk Management framework to document its assessments of the inherent and residual risks for each of the OIG's Challenges, including actions to mitigate risks. NSF management's overview of the challenges presented represent NSF's view of the residual risk in light of the key actions NSF has already taken to address the OIG-identified challenge. Further, NSF management developed the anticipated milestones in consideration of NSF's strategic objectives, the risks inherent to NSF's work, and the key actions NSF has already taken to address those risks.

In response to NSF's incorporation of ERM principles in its FY 2018 report, the OIG updated its reporting format for FY 2019, and recognized NSF's progress by removing one Management Challenge cited for FY 2019, eliminating improper payments. In FY 2018, the OIG identified foreign talent plans as an emerging challenge area for FY 2019. OIG's inclusion of an emerging challenge in its FY 2019 Report enabled NSF to undertake responsive actions in FY 2019. The OIG made mitigating threats from foreign government talent recruitment programs a standalone challenge for FY 2020, and a progress report on this new challenge is included below.

FY 2019 Management Challenges

- Managing major multi-user research facilities
- Meeting Digital Accountability and Transparency Act of 2014 (DATA Act) reporting requirements
- Eliminating improper payments
- Managing the Intergovernmental Personnel Act (IPA) Program
- Managing the U.S. Antarctic Program
- Encouraging the ethical conduct of research

FY 2020 Management Challenges

- Managing major multi-user research facilities
- Meeting Digital Accountability and Transparency Act of 2014 (DATA Act) reporting requirements
- Managing the Intergovernmental Personnel Act (IPA) Program
- Managing the U.S. Antarctic Program
- Encouraging the ethical conduct of research
- Mitigating threats posed by foreign government talent recruitment programs

[1] www.nsf.gov/about/performance

Mitigating Threats Posed by Foreign Government Talent Recruitment Programs
NSF lead: Office Head, Office of International Science and Engineering

Summary of OIG Identified Challenge

a) Foreign government talent recruitment programs designed to benefit the foreign state by obtaining information and technology from abroad have the potential to exploit the openness of American universities and threaten the integrity of U.S. research initiatives. Talent recruitment programs target individuals with expertise in cutting-edge science, including NSF-funded researchers, merit review panelists, and career Federal employees or rotators who manage NSF's scientific programs.
b) Failure to disclose membership in such programs can have ramifications.
c) There is risk of fraud, waste, or abuse of NSF or other Government assets.

NSF Management's Overview of the Challenge and Action Plan to Address and Monitor the Challenge
NSF is committed to sustaining Americas' innovation leadership, economic strength, and national security, including the basic research ecosystem that underpins it. The values of openness, transparency, merit-based competition, and reciprocal collaboration are essential to the functioning of that basic research ecosystem. The maintenance of a vibrant and diverse research community – including both domestic and international talent – is also essential. However, our science and engineering enterprise is put at risk when some foreign governments endeavor to benefit from the global research ecosystem without upholding these values. Certain foreign-government-sponsored talent recruitment programs create new risks to the integrity of the ecosystem, including to NSF's mission and merit-review process. Faced with such a risk, NSF is responding.

The White House Office of Science and Technology Policy (OSTP) launched the Joint Committee on the Research Environment (JCORE) under the National Science and Technology Council on May 6, 2019, including a subcommittee on research security co-chaired by NSF. Under the leadership of OSTP, U.S. science funding agencies are committed to taking a risk-based approach to strike an appropriate balance between fostering the open and internationally collaborative environment that has contributed to the success of the U.S. research enterprise and mitigating emerging threats to the integrity of that enterprise. NSF also co-chairs a second JCORE subcommittee on coordinating administrative requirements for research across the science funding agencies, including those associated with research security. NSF is not the only agency or party involved in this important challenge, but we have a vital role to play. We work closely with other U.S. government science agencies to share policies and practices, and regularly engage with the academic research community to hear their concerns about this emerging challenge and clarify our positions, policies, and procedures.

NSF's Corrective Measures to Address the Challenge
Demonstrated Progress Through Agency Actions Taken in FY 2019

- Released a Dear Colleague Letter on Research Protection to the research community from Director Córdova.
- Co-chaired the White House's National Science and Technology Committee's JCORE subcommittee on research security; co-chaired the JCORE subcommittee on coordinating administrative requirements for research; engaged regularly with other U.S. agencies that fund basic research – including NIH, DOE, and USDA—and the State Department on science and security.
- Appointed top NSF leadership (i.e., the Head of the Office of International Science and Engineering) as the NSF lead on science and security; established a working group of Senior Executive Service-level leaders from relevant NSF Directorates and the Office of the Director; took a risk-based approach to protecting the basic research ecosystem.

- Increased capacity by hiring a new Program Manager who reports to the Head of the Office of International Science and Engineering with expertise in science and security as well as foreign talent programs.
- Issued a policy making it clear that NSF personnel and IPAs detailed to NSF cannot participate in foreign government talent recruitment programs; released a memo on research protection announcing the personnel policy to all NSF staff from Chief Operating Officer Crim.
- Issued a note to NSF staff reminding everyone that government ethics regulations require accurate and timely financial disclosure reports and that Federal ethics rules apply to both our career and rotator personnel.
- Analyzed the problem internally and with the assistance of external expertise; commissioned the independent scientific advisory group JASON to conduct a study on fundamental research and national security with the direction that it should include recommendations on ways for NSF and grantee institutions to achieve the best balance between scientific openness and security.
- Sought best practices through sessions with the National Science Board, the Advisory Committee on International Science and Engineering, and the Advisory Com mittee to the Directorate for Biological Sciences.
- Clarified requirements in the draft Proposal and Award Policies and Procedures Guide (PAPPG) regarding submission of information on:
  - Current and pending support
  - Professional appointments
  - Responsible and ethical conduct of research and the peer review process
- Communicated to the research community to increase awareness of the risks and compliance with the requirements; clarified PAPPG requirements and NSF's positions, policies, and procedures through presentations to multiple research community groups including the National Council of University Research Administrators, Council on Government Relations, Federal Demonstration Partnership, American Association of Universities, and National Academies of Science, Engineering and Medicine's Committee on Science, Engineering, Medicine, and Public Policy.
- Continue to communicate all of our actions and updates to our committees of jurisdiction in the House and Senate.

<u>NSF's Anticipated Action Plan Milestones</u>

- Continue coordinating with the U.S. interagency including through supporting and complementing OSTP's actions, co-chairing the JCORE subcommittee on research security, and advancing work along the subcommittee's four lines of effort:
  - Coordinating outreach and engagement with federal agencies, academic research institutions, companies, non-governmental organizations, researchers, and students.
  - Establishing and coordinating disclosure requirements for participating in the federally-funded research enterprise.
  - Developing best practices for academic research institutions, in collaboration with academia, professional societies, and other organizations.
  - Developing methods for identification, assessment, and management of risk in the research enterprise.
- Release the final 2020 PAPPG, including clarifications regarding disclosure requirements, along with publishing in the Federal Register responses to public comments on the draft PAPPG.
- Streamline the process for providing disclosures to NSF by implementing electronic formats for submission of biographical sketches and current and pending support information.
- Anticipate receipt of independent third-party report from JASON related to fundamental research and national security; convene Senior Executive Service-level leaders from relevant NSF Directorates to

evaluate the recommendations and, where appropriate, begin implementing; share the report publicly via the NSF website and encourage grantee institutions to consider its recommendations.

- Finalize a required training course for all NSF staff that defines the problem and why disclosure of all sources of support is vital to maintaining our robust research ecosystem and protecting taxpayer dollars.
- Continue and finalize actions taken in FY 2019.

Managing Major Multi-User Research Facilities
Co-Leads: Chief Financial Officer and Chief Officer for Research Facilities

Summary of OIG Identified Challenge
a) Manage inherent risk associated with previously highlighted concerns including unsupported proposal budgets, management fees and contingency funds, and the absence of certified earned value management systems.
b) Strengthen controls around subrecipients, subrecipient risk assessments and proper charging of construction and operations expenditures.
c) Manage the risk of cost or schedule increases for major facilities in construction.

NSF Management's Overview of the Challenge and Action Plan to Address and Monitor the Challenge
NSF understands the importance of its role in overseeing recipients' on-going management of major facility awards. The agency also recognizes the importance of assessing prospective recipients' capabilities for managing major facilities prior to award. Over the past several years, NSF has been in the process of strengthening its policies and procedures as illustrated below. This includes an annual Major Facilities Portfolio Risk Assessment to determine the necessary reviews and audits to be conducted by the Office of Budget, Finance and Award Management's (BFA) Large Facilities Office (LFO) and Cooperative Support Branch (CSB) within the Division of Acquisition and Cooperative Support (DACS). In close cooperation with NSF program offices, LFO and CSB conduct these reviews to safeguard NSF's significant, long-term investments in supporting the scientific endeavor. NSF leadership has shown its commitment to oversight in the past several years by strengthening the LFO and in establishing the Chief Officer for Research Facilities (CORF) position in the Office of the Director. The governance structure currently in place continues to help ensure consistent implementation of NSF's expanded controls for major facilities oversight.

NSF has recently undergone two Government Accountability Office (GAO) reviews related to its oversight of major facilities. The June 2018 report entitled *National Science Foundation: Revised Policies on Developing Costs and Schedules Could Improve Estimates for Large Facilities* (GAO-18-370) recommended that NSF should revise its policies for estimating and reviewing the costs and schedules of major facility projects to better incorporate the best practices in GAO's guides. The March 2019 report entitled *National Science Foundation: Cost and Schedule Performance of Large Facilities Construction Projects and Opportunities to Improve Project Management* (GAO-19-227) recommended that NSF conduct a workforce gap analysis for project management competencies, ensure recipients provide lessons learned and best practices to NSF, and establish criteria for recipient project management competencies to be incorporated into NSF's review process. NSF agreed with the GAO recommendations and has Corrective Action Plans (CAPs) in place as described below.

Based on NSF's risk-based evaluation of this Management Challenge, coupled with activities already completed and those planned for FY 2020, NSF has determined that the residual risk impact for cost overruns is "very low" and the likelihood is "low." NSF is confident that its current and planned policies and procedures related to major facility cost and schedule oversight adequately consider and balance risk, resources, benefit to the science community, and stewardship of federal funds.

NSF's Corrective Measures to Address the Challenge
Demonstrated Progress Through Agency Action Taken in Prior Fiscal Years
Strengthened controls over NSF's major facility portfolio in FY 2016 and FY 2017 based on the 2015 National Academy of Public Administration report recommendations and requirements in the American Innovation and Competitiveness Act of 2017 (AICA):
- Retaining a portion of the project budget contingency.

- Periodically conducting cost incurred audits.
- Completing reasonableness review of proposed costs in alignment with GAO good practices.
- Obtaining independent cost estimate reviews of the proposed construction and operations budgets in accordance with GAO good practices.
- Conducting earned value management system verification, validation and acceptance.
- Reviewing proposed fees for prohibited items and requiring Recipients to track fee expenditures.
- Developed the Major Facilities A-123 Oversight Process Narrative to summarize NSF's oversight processes.
- Revised the *Large Facilities Manual* (LFM) to incorporate new guidance for recipients related to cost estimating and analysis in accordance with GAO good practices.

FY 2018 Progress:

- Appointed CORF in the Office of the Director to address full life-cycle oversight, including strategic portfolio issues and promoting agency-wide acceptance of policies and procedures related to major facility oversight.
- Appointed an Accountable Directorate Representative (ADR) in each Directorate with major facilities and formed the Major Facilities Working Group (consisting of the ADRs) to review and socialize policies and procedures related to major facility oversight.
- Formed the Facilities Governance Board to approve major facility oversight policies and procedures at the agency level.
- Reinstituted the MREFC Panel as the Facilities Readiness Panel (FRP) to access only technical readiness for advancement through the Design Stage and into the Construction Stage.
- Revised the Integrated Project Team (IPT) Standard Operating Guidance (SOG) to include facilities in the Operations Stage.
- Developed the *Minimum Core Competency for Oversight of Major Facilities* SOG to codify the minimum competencies for the core IPT members.
- Conducted an independent third-party review of NSF's strengthened policies and procedures related to cost surveillance.
- Updated the *DACS/CSB Standardized Cost Analysis Guidance* SOG to include assessment of schedule due to the potential impact on costs.
- Revised and aligned BFA SOGs related to standardized cost analysis and pre-award budget reviews to specifically address AICA requirements and GAO good practices.

Demonstrated Progress through Agency Actions Taken in FY 2019

- Finalized *Selection of Independent Cost Estimate Review*s SOG already implemented in practice as part of the CAP for GAO-18-370.
- Revised the *Major Facilities Guide* (MFG), formerly the LFM, to incorporate GAO good practices on costs and to reserve a new section (4.3) on Schedule Development, Estimating, and Analysis as part of the CAP for GAO-18-370 and to include a requirement for Segregation of Funding Plans (section 3.4) and guidance on Final Construction Reviews (section 2.4.2).
- Received notification in September 2019 from GAO that the analysis by the GAO engineering sciences team found that NSF's practices in the new Major Facilities Guide and internal standard operating guidance fully meet GAO good practices.
- Drafted the *Major Facilities Oversight Reviews* SOG to more fully utilize external review panels in addressing elements of cost and schedule as part of the CAP for GAO-18-370.

- Received the independent third-party report related to cost surveillance; developed an implementation plan to address the findings and recommendations.
- Revised SOG 16-4 *DACS/CSB Standardized Cost Analysis Guidance* and SOG 17-3 *Guidance on Pre- and Post-Award Cost Monitoring Procedures for Large Facility Construction and Operations Awards Administered by CSB* to align with the AICA.

NSF's Anticipated Action Plan Milestones

- Initiate major facilities portfolio workforce gap analysis as part of Program Management Improvement Accountability Act (PMIAA) implementation and the CAP for GAO-19-227.
- Revise Major Facilities Cooperative Agreement Supplemental Terms and Conditions (and any major facility contract terms and conditions) to require recipients to participate in NSF's Knowledge Management Program as part of the CAP for GAO-19-227.
- Finalize the new *Major Facilities Oversight Reviews* SOG to more fully utilize external review panels in addressing elements of cost and schedule and to evaluate the competencies of Recipient Key Personnel (GAO-18-370 and GAO-19-227).
- Draft the new MFG Section 4.3, *Schedule Development, Estimating, and Analysis* and release for public comment.
- Draft new MFG Section on *Key Personnel* and release for public comment as part of CAP for GAO-19-227.

Meeting DATA Act Reporting Requirements
Lead: Chief Financial Officer and Office Head, OIRM

Summary of OIG Identified Challenge
NSF must report DATA Act information in accordance with government-wide financial data standards developed and issued by the Office of Management and Budget (OMB) and the U.S. Department of the Treasury.

NSF Management's Overview of the Challenge and Action Plan to Address and Monitor the Challenge
Each quarter, NSF successfully submits all DATA Act-required data to the U.S. Department of Treasury to be easily accessible to the public through USASpending.gov. In addition to these submissions, which began in April 2017, NSF is an integral part of the government-wide Chief Financial Officers Council (CFOC) and Council of Inspectors General on Integrity and Efficiency (CIGIE) communities that have worked collaboratively to ensure new OMB guidance and Treasury protocols appropriately align with audit community standards. Both councils are working to enhance not only the quality of government-wide spending data, but also the government's ability to assess that quality. As a result of this work, NSF implemented a data quality plan that is based on a government-wide model and conducted a risk assessment demonstrating that it has implemented internal controls to mitigate the risks associated with maintaining and publishing inaccurate spending data. NSF continues to deploy top leadership commitment to the management of its DATA Act program, including the agency CFO who serves as the Senior Accountable Official (SAO), the Deputy CFO, an executive-level Steering Committee, and several additional high-level executives and senior staffers.

In FY 2019, NSF continued to take actions in accordance with the recommendations from the NSF OIG's audit of NSF's FY 2017 second quarter spending data that were resolved and closed in FY 2018. These actions made progress to address the OIG finding that the data did not meet the then-current OMB quality requirements for accuracy, completeness and timeliness, noting that some of the errors were due to NSF reporting while others were caused by government-wide reporting issues. NSF conducted a root cause analysis of its challenges and noted that many of the OIG-identified errors were government-wide in nature and beyond NSF's control. NSF implemented a CAP after the FY 2017 audit, ultimately resolving all recommendations and the OIG has closed them all. Indeed, in the description of the FY 2019 DATA Act Management Challenge, the OIG noted that it is "encouraged by NSF's actions to improve its DATA Act reporting."

NSF has had a recognized history of outstanding government-wide DATA Act-related collaboration. In FY 2019, NSF intensified its leadership and engagement in this area not only to support government-wide DATA Act-related activities, but also to ensure that the developing standards in this area evolved to align with best practices and good governance for agencies like NSF. In FY 2019, NSF collaborated and led government-wide activities implementing now-current guidance, OMB M-18-16, updating Appendix A to OMB Circular No. A-123, Management of Reporting and Data Integrity Risk. This new guidance superseded prior DATA Act guidance and created a requirement for agencies to develop data quality plans that include management assurance of the quality of agency data.

NSF's progress on the DATA Act has been aided by the NSF Deputy CFO and other staff deeply engaging in supporting the activities relating to the Audit Collaboration Working Group of the CFOC and CIGIE. NSF was a major contributor in developing the Data Quality Plan Playbook, which serves as a reference guide for agencies designing their data quality plans. The CFOC also collaborated with GAO and CIGIE as they developed new audit guidelines and standards consistent with the new OMB guidance. In addition, the NSF Division Director for BFA's Division of Institution and Award Support and other NSF senior staff supported the government-wide financial assistance community's work to develop a framework for the required data quality plans, which NSF leveraged to prepare its own plan.

As part of its work to achieve reasonable assurance for internal controls over DATA Act reporting, NSF leveraged enterprise risk management to assess the risk of reporting inaccurate data to Treasury. Based on this evaluation and considering the causes analyzed and actions that NSF has taken to date, NSF believes that its risk of reporting inaccurate, incomplete, and untimely data has been mitigated.

<u>NSF's Corrective Measures to Address the Challenge</u>
Demonstrated Progress Through Agency Action Taken in Prior Fiscal Years
Developed and implemented CAP in response to the FY 2017 audit with the following actions:

- Examined processes identified as potential audit risks, identified ways to improve or strengthen the processes, and documented changes in NSF's standard operating procedures.
- Submitted corrections for data errors identified in the audit.
- Included comments with NSF's submissions to explain legitimate differences between File C (Award and Financial Detail) and Files D1/D2 (Financial Assistance and Procurement Award and Awardee Attributes).
- Reviewed submission process with the internal controls team and identified opportunities for improvement.
- Performed policy review of the application of "legitimate differences" guidance to warnings when linking Files C to D1/D2.
- Worked closely with the DATA Act Audit Collaboration Working Group of the CFOC and CIGIE to identify issues to improve DATA Act implementation and clarify government-wide guidance and audit standards.
- Worked with a subgroup of the Financial Assistance Committee for E-Government (FACE) in collaboration with a DATA Act Internal Control subgroup of the CFOC to provide a solid framework and data quality plan template that agencies can leverage and customize to develop their own data quality plans.
- Initiated implementation of OMB Circular A-123 Appendix A, requiring agencies to maintain a data quality plan that considers the incremental risks to data quality in federal spending data and any controls that would manage such risks. NSF's data quality plan will leverage the existing plans for the Financial (Files A-C) and Procurement (File D1) data as well incorporate the new data quality requirements for the Financial Assistance (File D2) data.
- Reviewed SharePoint processes to ensure all required BFA Division Director validations are complete, properly labelled, and available for SAO review.

Demonstrated Progress through Agency Actions Taken in FY 2019

- Devoted the staff resources to actively participate in the CFOC DATA Act Information Model Schema (DAIMS) workgroup on data quality improvements, which is a cross-agency group led by Treasury for introducing potential improvements to the DAIMS specifications for improving data quality on USASpending.gov. NSF worked to get the issue with zip codes resolved and incorporated into DAIMS v1.3 specifications.
- Continued ongoing work, through the NSF Deputy CFO and staff, with the joint working group of the CFOC and the CIGIE to provide input and recommendations around the next iteration of DATA Act policies, internal control, and audit guidance to OMB, Treasury, and CIGIE.
- Committed the NSF Deputy CFO to leading a subgroup on internal controls, serving as primary author of a government-wide DATA Act Playbook, and actively participating in developing best practices for financial assistance data quality.
- Instituted processes to monitor and independently validate the effectiveness and sustainability of its data quality measures. The NSF DATA Act Work Group (DAWG) worked with appropriate

stakeholders from the Internal Controls and Enterprise Risk Management groups in developing and executing a data quality plan that defines NSF's FY 2019 approach to achieve reasonable assurance for internal control over quarterly DATA Act reporting. The plan was prepared in accordance with OMB M-18-16, Appendix A to OMB Circular No. A-123.

- Conducted a risk assessment of the 57 essential reporting elements related to procurement, financial management and financial assistance data and submission processes and reviewed related system controls and Standard Operating Procedures (SOPs).
- Performed analysis of NSF's submission warnings to provide warning rationales, counts, and frequency of each identified warning during the execution phase of the data quality plan. This practice will continue with each quarterly submission and be reported in the annual assurance document.
- Updated documentation of DATA Act processes including, the DATA Act SOPs, Financial Assistance Broker Submission Standard Operating Guidance (FABS SOG), and NSF Acquisition Manual.
- Continued to monitor system processes to ensure data integrity and accuracy.
- Remained up-to-date with Treasury DAIMS specifications by making appropriate changes as well as introduced operational improvements to FABS file generation.
- Created a desk guide for the NSF Contracts Branch that includes step-by-step instructions intended to reduce recurring data errors.
- Added additional dry run and pre-validations between data submission quarters to increase accuracy.
- Incorporated lessons learned from feedback on data submissions to improve accuracy and efficiencies.

<u>NSF's Anticipated Action Plan Milestones</u>

- Implementing a SharePoint tool to assist in quarterly DATA Act submission process by tracking Division Director assurances and the SAO certification.
- Continuing to work closely with OMB, Treasury, and intra-governmental groups.
- Continuing to refine our validation and submission process.
- Continuing stewardship collaboration with NSF OIG and GAO to cooperate with and support their audit responsibilities and to resolve any recommendations through implementing a corrective action plan.

Eliminating Improper Payments
Lead: Chief Financial Officer

Summary of OIG Identified Challenge

a) There is a risk of fraud, waste, or abuse of NSF or other government assets. In addition, this challenge involves an operation that is related to key initiatives of the President.
b) NSF's risk assessment process needed significant improvements to ensure that the agency thoroughly assesses and documents its risk of improper payments, and
c) addresses the limitations in NSF's analysis of the OMB risk factors.

NSF Management's Overview of the Challenge and Action Plan to Address and Monitor the Challenge

NSF addressed the OIG's recommendations from the previous OIG reports. As a result, the OIG has determined that NSF was in compliance with the Improper Payment Elimination and Recovery Act (IPERA) risk for the years 2015 through 2018. This validates that NSF has taken the steps necessary to demonstrate compliance and effectiveness in the agency's implementation of IPERA. NSF has:

- Demonstrated strong commitment and top leadership support to incorporate risk management concepts into business processes and management functions.
- Participated in the government-wide working group for the cross-agency priority goal on Getting Payments Right.
- Ensured that NSF has the people and resources to effectively comply with IPERA by assigning a senior staff associate responsible for coordinating and integrating risk management and program integrity activities.
- Developed and completed a corrective action plan in July 2016 that addressed the root causes of the IPERA reporting issue, implemented solutions, and completed all OIG recommendations.
- Developed a corrective action plan following the FY 2018 IPERA Performance Audit.
- Established processes to monitor and validate the effectiveness and sustainability of the corrective measures.
- Incorporated corrective measures into policy and process documentation.

NSF's Corrective Measures to Address the Challenge

Demonstrated Progress Through Agency Action Taken in Prior Fiscal Years

- Developed and published a SOG for improper payments risk reviews incorporating the nine IPERA risk factors and additional considerations from the OIG review report.
- Completed improper payments risk reviews for FY 2016 and FY 2017. The risk reviews included input from subject matter experts for grants, contracts, charge cards, and payments to employees. Both reviews concluded that NSF did not have a significant risk of improper payments.
- OIG inspection of the FY 2016 and FY 2017 risk reviews found NSF in compliance with IPERA requirements.
- Collaborated with the OIG, BFA, and program offices on risk reduction activities including completion of an initial fraud risk assessment for grants under the Fraud Reduction and Data Analytics Act.
- Completed an improper payments risk assessment for FY 2018 that built on the improper payments risk reviews completed during FY 2016 and FY 2017.

Demonstrated Progress through Agency Actions Taken in FY 2019

- Conducted advanced and baseline grant monitoring activities including grant payment testing.
- Operated, evaluated, and reported on an effective internal controls program providing assurance that NSF controls over grants and grant payment processes are properly designed and operating effectively.

- Completed an IPERA risk review during FY 2019 as a continuation of NSF's three-year risk assessment cycle following standard operating guidance establishing a validated measure of performance in terms of monitoring improper payment risk. OIG found that NSF complied with IPERA reporting requirements based on review of NSF's Agency Financial Report and risk assessment. This is the fourth consecutive year NSF has been found compliant.
- Completed action items set forth in the CAP from the FY 2018 IPERA Performance Audit.

<u>NSF's Anticipated Action Plan Milestones</u>

- Continue advanced and baseline grant monitoring activities including grant payment testing.
- Continue internal controls program activities to provide assurance that NSF controls for its payment processes are operating effectively.
- Continue collaboration with the OIG on risk reduction activities.
- Continue to improve improper payments risk assessment and reporting compliance activities.

Managing the IPA Program
Co-Leads: Assistant Director, BIO and Office Head, OIRM

<u>Summary of OIG Identified Challenge</u>

a) Because individuals serve in a temporary capacity for up to 4 years, there is frequent turnover in staff at NSF, especially in senior leadership positions filled by IPAs.
b) IPAs can spend up to 50 days each year on Independent Research/Development (IR/D).
c) IPAs are not subject to Federal pay and benefits limits.

<u>NSF Management's Overview of the Challenge and Action Plan to Address and Monitor the Challenge</u>
NSF provides the opportunity for scientists, engineers, and educators to rotate into the Foundation as temporary Program Directors, advisors, and leaders. Rotators bring fresh perspectives from across the country and across all fields of science and engineering supported by the Foundation, helping influence new directions for research in science, engineering, and education, including emerging interdisciplinary areas. Many of these rotators remain involved in their professional research and development activities while working at NSF through participation in the IR/D program, which is managed by the NSF IR/D Council.

NSF takes a proactive approach in the management of the IPA Program to appropriately consider and mitigate inherent risks associated with its execution.

Demonstrated Top Leadership Commitment:
The IPA Steering Committee reports directly to NSF Director France A. Córdova and Chief Operating Officer (COO) F. Fleming Crim and has been in place since April 2016. The IPA Steering Committee is comprised of senior-level leadership across the agency, namely a Chair and Vice-Chair who are part of the agency's Senior Executive Service (SES), the Chairs of the NSF Executive Resources Board (ERB) and IR/D Council, Head of the Office of Diversity and Inclusion, and four at-large members, including two SES and two executive-level IPAs.

The IPA Steering Committee is charged with ensuring NSF is best utilizing the IPA hiring authority. It advises the Foundation's senior leadership on matters that directly concern policy on the use of the IPA Program, and on common approaches to budgeting and implementation of the program. It also regularly reports on its oversight and stewardship of the IPA Program, including costs associated with the program, to the Director and COO, to OMB, and to Congress, pursuant to the AICA.

Capacity:
The IPA Steering Committee is supported in the execution of its responsibilities by various NSF units with key expertise for risk management, reporting, and accountability, including BFA, the OIRM's Division of Human Resource Management, the Office of General Counsel (OGC), the Office of Legislative and Public Affairs, and the Office of Integrative Activities.

Demonstrated Progress:
NSF is constantly improving its management of the IPA Program and addressing the management challenges identified by the OIG as well as other agency-identified risks and challenges. In this way, NSF is ensuring the program fully supports the mission of the agency and the nation's interests. Indeed, NSF believes that the steps taken to date as described above have reduced the inherent risk substantially, such that the residual risk is acceptable to the agency.

<u>NSF's Corrective Measures to Address the Challenge</u>
Demonstrated Progress Through Agency Action Taken in Prior Fiscal Years

a) Because individuals serve in a temporary capacity for up to 4 years, there is frequent turnover in staff at NSF, especially in senior leadership positions filled by IPAs.
- Ensured there is a "bench" of staff ready for developmental detail assignments to vacant executive positions through the Federal Executive Institute (FEI), American University Executive Leadership Program, Harvard Business School Leadership Training, Individual Development Plans, and NSF Academy Leadership Development Program.
- Implemented the New Executive Transition Program (NeXT) in 2009 to onboard employees and IPAs transitioning into executive-level positions to help new executives reach full performance as quickly as possible by developing executive knowledge about NSF mission, culture, organization, people, and business processes.
- Instituted mandatory and optional training for Program Officers, including IPAs, on NSF's Merit Review process which teaches how research proposals are evaluated and how to execute the Program Officer role.
- Created a parallel performance management system in 2014 for IPAs to ensure clarity in setting expectations and providing feedback on performance.
- Established a knowledge transfer process in 2015 that exiting executives can use to transfer knowledge and information to incoming executives.
- Implemented a required three-day supervisory training and development course in 2015 called Federal Supervision at NSF designed to assist new federal supervisors (including IPAs) in understanding their roles and all the requirements pertaining to federal human capital management.
- Established a Steering Committee for Policy and Oversight of the IPA Program (IPA Steering Committee) in April 2016 to serve as the primary body for considering policy on NSF's use of IPAs, and to oversee common approaches to budgeting and implementation of the IPA program.
- Conducted analysis (January 2018) on IPA years of service and found that, on average, IPA executives serve 3.1 years at NSF and are 3 times more likely to stay for 3-4 years compared to staff-level IPAs. Non-executives serve, on average, 2.3 years at NSF. Per OPM, the average time a career SES spends in a position is 3.4 years and non-career SES is 1.7 years.[2]
- Engaged with the GAO on an inquiry into the turnover of IPAs.

b) IPAs can spend up to 50 days each year on Independent Research/Development (IR/D).
- Established the IR/D Council in October 2011 to develop and monitor internal controls related to the IR/D Program, including tracking the time spent on IR/D activities. Data from these internal controls are disseminated to NSF senior management quarterly for use in managing the IR/D Program within each organization.
- Developed an IR/D Guide in 2012 to clearly communicate NSF policies on the use of IR/D, including the possibility that participation in the IR/D Program could be curtailed if it compromised the completion of NSF duties.
- Designated IR/D experts in each Directorate/Office who receive annual training to ensure that NSF policies are implemented appropriately.
- Instituted a requirement that all IR/D plans provide an explanation of how the IR/D activities enhance the requestor's ability to perform NSF duties.
- Published a revised IR/D Guide in January 2017 that includes guidance limiting NSF payment of IPAs' IR/D travel to their home institutions to 12 trips per year. The guidance encourages IPAs to

[2] https://www.opm.gov/policy-data-oversight/senior-executive-service/facts-figures/#url=Demographics

combine other NSF official business and/or telework with these trips to more efficiently use of those travel dollars.
- Delivered a "Benefits of the NSF IR/D Program" report to the NSF Deputy Assistant Directors (DADs) in March 2018 highlighting the value of IR/D in recruitment, research currency, and ethics protection.
- Submitted the IR/D Annual Report to the DADs (November 2018), indicating that on average 75% of IPAs participated in IR/D, up from 72% in the prior year. On average, IPA IR/D plans requested 38 days of IR/D, yet only 19 days were used. As of October 2018, active IR/D plans for IPAs totaled $1.48M requested with an expected actual spend of approximately $750,000.

c) <u>IPAs are not subject to Federal pay and benefits limits.</u>
- NSF initiated a pilot requiring 10% cost sharing by IPAs' home institutions of their academic-year salaries and fringe benefits (per NSF Bulletin 16-11). This pilot applies to all new IPA agreements initiated in FY 2017 and beyond, including those for executive and program level staff. Additionally, NSF eliminated reimbursement for lost consulting.
- Received notice from the OIG in February 2017 closing the sole open audit recommendation related to IPA costs because of cost reduction efforts undertaken by NSF.
- Extended the cost-share pilot into FY 2018 to continue to evaluate the effectiveness of the 10% cost-share requirement. An evaluation of the effectiveness of the pilot launched in FY 2017 indicated a cost-share percentage increase from 7.2% in FY 2016 to 7.9% in FY 2017, which resulted in an average cost-share increase of almost $5,000 per IPA assignment.
- Engaged with the GAO on the salary reimbursements associated with IPAs. NSF does not set the salaries for rotators who are detailed to NSF using the IPA authority because their salaries are set by their home institutions.
- Submitted to Congress responses to the AICA (P.L. 114-329 Section 111 on Personnel Oversight regarding the Justifications for Rotator Pay Exceeding the SES Pay Max and Evaluation of the Cost-sharing Pilot (January 2018).

Demonstrated Progress through Agency Actions Taken in FY 2019

a) <u>Because individuals serve in a temporary capacity for up to 4 years, there is frequent turnover in staff at NSF, especially in senior leadership positions filled by IPAs</u>.
- Delivered the first IPA Program Annual Report to the Director of NSF. This report provides annual data and trend analyses on various aspects related to the use of IPAs at NSF for use by the Director and NSF senior managers in assessing and overseeing the program.
- Developed the CAP response to the GAO report, *A Workforce Strategy and Evaluation of Results Could Improve Use of Rotating Scientists, Engineers, and Educators* (GAO-18-533).

b) <u>IPAs can spend up to 50 days each year on Independent Research/Development (IR/D).</u>
- Monitored time spent on IR/D by both permanent and rotating staff, and provided quarterly data to NSF senior managers to ensure appropriate oversight of IR/D.
- Performed yearly data check to assure that no IPA IR/D participant travel was paid by NSF in excess of 12 trips per year.

c) <u>IPAs are not subject to Federal pay and benefits limits.</u>
- Extended the cost-share pilot into FY 2019 to continue to evaluate the effectiveness of the 10% cost-share requirement. A cost analysis of the IPA pilot launched for FY 2017 indicated a cost-share percentage increase from 7.2% in FY 2016 to 9.1% in FY 2018.

- Submitted to Congress annual responses to the AICA (P.L. 114-329 Section 111 on Personnel Oversight) on the Justifications for Rotator Pay Exceeding the SES Pay Max.

NSF's Anticipated Action Plan Milestones

a) Because individuals serve in a temporary capacity for up to 4 years, there is frequent turnover in staff at NSF, especially in senior leadership positions filled by IPAs.
   - Submit the IPA Program Annual Report covering the prior fiscal year to the Director of NSF.
   - Integrate activities associated with the CAP in response to GAO-18-533 into Renewing NSF goal 1 Adapting the Workforce to the Work.

b) IPAs can spend up to 50 days each year on Independent Research/Development (IR/D).
   - Provide quarterly data to NSF senior managers to ensure appropriate oversight of IR/D time and travel by both permanent and rotating staff.
   - Continue to perform yearly data check to assure that there are no IPA IR/D participants where NSF payment of travel to their home institutions exceeds 12 trips per year.

c) IPAs are not subject to Federal pay and benefits limits.
   - Submit to Congress annual responses to the AICA on the Justifications for Rotator Pay Exceeding the SES Pay Max.

Managing the U.S. Antarctic Program (USAP)
Co-Leads: Assistant Director, GEO, and Office Director, Polar Programs

Summary of OIG Identified Challenge

a) Fiscal oversight of the Antarctic Support Contractor (ASC) and its subcontractors.
b) Management of inventory.
c) Health and safety of research and contractors.
d) Modernization of facilities in the Antarctic Infrastructure Modernization for Science (AIMS) Project.

NSF Management's Overview of the Challenge and Action Plan to Address and Monitor the Challenge
NSF—through the Office of Polar Programs (OPP) in the Directorate for Geosciences (GEO)—funds and manages the U.S. Antarctic Program (USAP). The USAP supports United States' research and national policy goals in the Antarctic. The inherent risks associated with Antarctica's remote location, extreme environment, and the short period of time during which the continent is accessible has led to management challenges for NSF in the areas of: a) fiscal oversight of the ASC and its subcontractors; b) management of inventory; c) health and safety of researchers and contractors; and d) modernization of facilities in the AIMS project.

Through leadership commitments, dedication of staff and resources, corrective action planning, and monitoring implementation of plans, NSF has demonstrated significant progress in reducing the inherent risk to residual risk levels for USAP management that are well within acceptable ranges. The transition of the ASC responsibilities to Leidos has occurred without disruptions in operations or unwarranted increases in cost. Management controls and operating procedures are in place to monitor invoice processing, systems performance, indirect rates, and financial reporting for the USAP contractor. NSF performed root cause analyses of issues pertaining to the shipment and storage of property and inventory, and consequently developed and implemented process improvements. Routine NSF-led meetings are held with Leidos to emphasize prime contractor responsibilities to protect government property and inventory. All 2015 OIG misconduct-related action items, as expressed in the Audit of Health and Safety in the U.S. Antarctic Program, were closed by the OIG. NSF and USAP efforts continue to take positive steps to ensure USAP is well poised to address misconduct in the future through implementation of NSF processes for reporting and reviewing Code of Conduct violations. Additionally, NSF is closely monitoring Care Point's implementation of the selected pharmacy management software system. Planning and implementation of the modernization of McMurdo Station and other large facilities work in Antarctica are underway with cognizance by the National Science Board (NSB), OMB, and Congress. NSF successfully completed the AIMS Final Design Review (FDR) in Q1 of FY 2019, and the NSB authorized NSF to proceed with AIMS construction. NSF continues to engage the scientific community in efforts to minimize disruption that the AIMS construction process might have on Antarctic science. NSF developed a 5-year long-range capital plan to include lifecycle and real property investments for all Antarctic locations and is working to extend that plan to a 10-year horizon.

NSF's Corrective Measures to Address the Challenge
Demonstrated Progress Through Agency Action Taken in Prior Fiscal Years

a) Fiscal oversight of the Antarctic Support Contractor (ASC) and its subcontractors.
   - Held routine executive meetings with Lockheed Martin leadership to understand the strategic rationale for the transition to Leidos and the impact to the ASC.
   - Began implementing the novation agreement processed by the Defense Contract Management Agency (DCMA) as the cognizant Federal Agency, which concluded that restructuring was in the best interest of the government.

- Monitored Leidos' operations on legacy Lockheed Martin systems. The Accounting System, Estimating System, Material Management and Accounting System, Purchasing System, and Property System were approved by DCMA in a letter dated August 25, 2016.
- Monitored the transfer of business systems from Lockheed Martin to Leidos. Subsequently, the Leidos DCMA Divisional Administrative Contracting Officer reviewed and approved Leidos' business systems.

b) <u>Management of inventory.</u>

- Conducted two detailed root cause analyses in response to early FY 2017 failures, followed by process improvements. NSF directed the ASC to develop reports on the damaged science equipment and mishandled science samples explaining how and why the damage occurred, and implement corrective actions to avoid such damage in the future. NSF then approved the action plans and monitored contractor activity for effectiveness.
- Modified contract policy so that going forward senior ASC management will be directly involved in all high value-science sample shipments to ensure minimum risk. Final approval for shipment must come from the senior transportation manager.
- Ensured that appropriate mitigation for the risk of loss or damage was implemented by November 2016.
- Directed NSF's annual assessment of ASC performance, which will identify cargo failures and contractor responses. Emphasis will be placed on opportunity costs of mishandled science samples and replacement costs of damaged inventory. Penalties will be considered in the contractor award fee.
- Continued to monitor cargo shipments during the August 2017 - February 2018 cycle.
- Conducted weekly NSF-led meetings with the prime contractor focused on protecting government property.

c) <u>Health and safety of research and contractors.</u>

- <u>Code of Conduct</u>:
    - Developed a process for reporting and reviewing Code of Conduct violations, which states that each year the OPP will send a request to all USAP employing organizations and NSF's on-site representatives (for grantees) for a report of all significant instances of on-ice misconduct for the previous 12 months. **This audit action item (#1) regarding the USAP Code of Conduct was formally closed by the OIG on March 28, 2017.**
    - Continued to implement NSF process for reporting and reviewing Code of Conduct violations.
    - Updated Code of Conduct to clarify to the community the consequences (e.g., potential removal) of misconduct in Antarctica.
- <u>Law Enforcement:</u>
    - Oversaw NSF's law enforcement program's achievement of full compliance with all U.S. Marshals Service requirements for certification and training, and recommendations for law enforcement tools made by the Service.
    - Initiated planning for a future site visit to Antarctica, resources and schedules permitting. OPP had internal conversations with OGC and reached out to law enforcement organization contacts.
    - Reviewed the final report dated March 12, 2018, of a group of law enforcement officials who had conducted an on-site evaluation in February 2018. The Law Enforcement review and site visit assessed equipment and training for special deputies and reviewed other areas, such as legal jurisdiction, USAP law enforcement staffing, facilities, communications with the U.S.

Marshals Service, and detainment and transportation of suspects. The report contains recommendations and suggestions. **This audit action item (#3) regarding USAP Law Enforcement was formally closed by the OIG on June 12, 2018.**

- Breathalyzer Testing:
  - Procured breathalyzer units that do not require calibration. These units provide redundancy for the existing breathalyzer inventory. **This audit action sub-item (#4.2) regarding breathalyzer calibration was formally closed by the OIG on December 22, 2015.**
  - Continued to explore the advisability and feasibility of the OIG-recommended requirement for breathalyzer testing for all USAP participants.
  - Finalized a memo detailing the results of NSF exploration of the advisability and feasibility of implementing a requirement for breathalyzer testing for all USAP participants. NSF determined that since USAP supporting organizations have their own breathalyzer testing programs, the benefit of establishing and enforcing an NSF-managed breathalyzer program would not be worth the legal, contractual and financial obligations. NSF decided to accept the risk of not implementing its own breathalyzer program. **This audit action sub-item (#4.1) regarding the legality of requiring breathalyzer testing for all USAP participants was formally closed by the OIG on 02/05/2018.**

d) Modernization of facilities in the Antarctic Infrastructure Modernization for Science (AIMS) Project.

- Continued progress on the 2012 Blue Ribbon Panel (BRP) recommendations, including investment in life-cycle acquisitions and infrastructure upgrades.
- Addressed major infrastructure upgrades for McMurdo Station through the following design efforts:
  - Completed portions of designs for some of the AIMS project, including Core Facility and Utilities packages, and presented the designs to the MREFC Concept Design Review and Preliminary Design Review Panel.
  - Completed designs of the Vehicle Equipment/Operations Center using NSF Research and Related Activities funding.
  - Continued design on the Information Technology & Communications (IT&C) Primary Operations Center, Lodging Facility, and Palmer Pier Replacement projects.
  - Initiated construction of IT&C Primary Operations Center.
  - Completed presentation to the NSB, which resulted in the NSB's recommendation that the NSF Director or her designee include the AIMS project in a future budget request.
  - Completed ~ $2M in infrastructure investments in the Black Island Telecommunications Facility (BITF) to address BRP Recommendation 4.7-5, BITF risk management.
  - Issued a Sources Sought Notice on FBO.gov to apprise potential offerors on the AIMS project.
- Continued internal coordination with LFO to leverage institutional knowledge pertaining to previous large facilities work, including best practices and considerations outlined in NSF's Large Facilities Manual (NSF 17-066).
- Authorized additional design to advance the AIMS design beyond bridging documents (35%). Initiated and completed necessary initial solicitation efforts for individual AIMS components.
- Completed designs for and awarded IT&C Primary Addition for construction.
- Initiated acquisition of major components of the Ross Island Satellite communications Earth Station to address BITF deficiencies.
- Prepared for AIMS FDR, anticipated in Q1 of FY 2019.

- Continued to update the long-range capital plan to include lifecycle and real property investments for all Antarctic locations.

Demonstrated Progress through Agency Actions Taken in FY 2019

a) Fiscal oversight of the Antarctic Support Contractor (ASC) and its subcontractors.
- Continued to monitor invoices, annual program plans, business system reviews (accounting, estimating, purchasing systems), indirect rates, and financial reporting for the USAP contractor to ensure strong cost controls continue with the new entity.
- Completed incurred costs audit of Lockheed Martin; NSF is waiting for DCAA to execute the audit for Leidos.

b) Management of inventory.
- Directed NSF's annual assessment of ASC performance, which will identify cargo failures and contractor responses. Emphasis will be placed on opportunity costs of mishandled science samples and replacement costs of damaged inventory. Penalties will be considered in the contractor award fee.
- Continued to monitor cargo shipments during the August 2018 - February 2019 cycle.
- Conducted weekly NSF-led meetings with the prime contractor focused on protecting government property.
- OIG site visit to Antarctica was completed in November 2018 and a visit to Denver was completed in June 2019. The site visits included auditing of USAP property management processes.

c) Health and safety of research and contractors.
- Code of Conduct:
    - Continued to implement NSF process for reporting and reviewing Code of Conduct violations.
- Law Enforcement:
    - Completed law enforcement site visit to South Pole Station in FY19 Q2.
- Pharmacy Management:
    - Continued to monitor Care Point's implementation of a selected pharmacy management software system.

d) Modernization of facilities in the Antarctic Infrastructure Modernization for Science (AIMS) Project.
- Began construction of IT&C Primary Addition.
- Completed successful AIMS FDR in Q1 of FY 2019.
- Continued to engage the scientific community in efforts to minimize disruption that the AIMS planning and construction process might have on Antarctic science.
- Updated the long-range 5-year capital plan (FY20-24) to include lifecycle and real property investments for all Antarctic locations.
    - NSB authorized NSF to make contract modifications to begin AIMS construction.

NSF's Anticipated Action Plan Milestones

a) Fiscal oversight of the Antarctic Support Contractor (ASC) and its subcontractors.
- Continue to apply invoice processing in accordance with the current NSF Guidance and Instructions for Invoice Review and Processing SOP.
- Engage DCAA for a cost incurred audit of Leidos for the FY18 ASC contract.

b) Management of inventory.
- Monitor cargo during the upcoming shipment cycle (August 2019 - February 2020).
- Continue to conduct weekly NSF-led meetings with the prime contractor focused on protecting government property.

c) Health and safety of research and contractors.
- Code of Conduct:
  - Continue to implement the process for reporting and reviewing Code of Conduct violations.
  - Continue to update the Code of Conduct as circumstances warrant.
- Law Enforcement:
  - Perform law enforcement site visit at Palmer Station in FY20 Q1.
- Pharmacy Management:
  - Continue to monitor Care Point's implementation of the selected pharmacy management software system.

d) Modernization of facilities in the Antarctic Infrastructure Modernization for Science (AIMS) Project.
- Continue AIMS project management, to include areas of procurement, logistics, planning, and design.
- Extend the long-range Antarctic capital plan for lifecycle and real property investments to a 10-year horizon (FY21-30).

Encouraging the Ethical Conduct of Research
Lead: Chief Operating Officer

Summary of OIG Identified Challenge

a) Respond to broader definition of the Responsible Conduct of Research (RCR) which includes protecting the integrity of data; complying with relevant requirements; communicating openly with researchers, institutions, and funding agencies; mentoring; ensuring responsible authorship; managing conflicts of interests; and establishing research environments free of harassment.
b) Respond to encouragement to provide substantive guidance to the research community on mentoring and RCR training to accomplish the goals of the America COMPETES Act.
c) Foster the implementation of effective RCR training—including its content and how it is delivered—for all researchers, especially new members of the research community.

NSF Management's Overview of the Challenge and Action Plan to Address and Monitor the Challenge

The Responsible and Ethical Conduct of Research (RECR) is critical for excellence, as well as public trust, in science and engineering. NSF expressly defines this issue to be inclusive of both the responsible conduct and ethical conduct of research, recognizing a broad conceptualization of this topic. NSF does not tolerate research misconduct (RM) in proposing or performing research funded by NSF, in reviewing research proposals submitted to NSF, or in reporting research results funded by NSF. Allegations of RM are taken seriously and are investigated by NSF's OIG. The OIG refers completed investigations of RM to NSF for action. Upon determination of RM, NSF takes appropriate action against individuals or organizations.

Beyond NSF's RM role, NSF works to foster and maintain ethical research environments in which RECR is not only taught but practiced. RECR includes rigor and integrity, honest and objective peer review, protection of proprietary information and intellectual property, and treating students and colleagues with fairness and respect.

NSF leadership commits to RECR through increased programmatic investments, specifically the repositioned cross-directorate grants program, Ethical and Responsible Research, previously titled Cultivating Cultures for Ethical STEM; dedicated professional staff and senior executives in the Office of the Director and in the Research Directorates focused on ethics, research integrity, accountability, and research protection; and the oversight and stewardship of the revitalized Online Ethics Center at the National Academy of Engineering.

NSF's Corrective Measures to Address the Challenge

Demonstrated Progress Through Agency Action Taken in Prior Fiscal Years

- Issued Important Notice No. 140, Training in Responsible Conduct of Research – A Reminder of the NSF Requirement, from the NSF Director on August 17, 2017.
- Published revisions to Proposal and Award Policies and Procedures Guide (PAPPG) to point to promising practices in RECR training, including the encouragement of faculty training.
- Conducted outreach to principal investigator and awardee community on promising practices in RECR training, including involvement of STEM faculty in teaching and mentoring.
- Revised the Cultivating Cultures for Ethical STEM (CCE-STEM) Program Solicitation to incorporate research on promising practices in RECR training.
- Renewed and refreshed the mission of the Online Ethics Center to develop communities of promising practices in RECR education.
- Published and communicated widely NSF's new harassment policy.

Demonstrated Progress through Agency Actions Taken in FY 2019

a) Respond to broader definition of the Responsible Conduct of Research (RCR) which includes protecting the integrity of data; complying with relevant requirements; communicating openly with researchers, institutions, and funding agencies; mentoring; ensuring responsible authorship; managing conflicts of interests; and establishing research environments free of harassment.
   - Provided a comprehensive definition of RECR in the draft 2020 PAPPG: "The responsible and ethical conduct of research involves not only a responsibility to generate and disseminate knowledge with rigor and integrity, but also a responsibility to (a) conduct peer review with the highest ethical standards, (b) diligently protect proprietary information and intellectual property from inappropriate disclosure, and (c) treat students and colleagues fairly and with respect."
   - Implemented NSF's harassment policy.
   - Issued in draft 2020 PAPPG clarification of requirements for disclosure of institutional/professional appointments to achieve full transparency.
   - Provided intramural and extramural guidance, resources, and consultation for the inclusion of ethics considerations in citizen science, collaborative/team science, and international science by NSF program officers overseeing the Ethics and Responsible Research Program.
   - Issued Dear Colleague Letter encouraging researchers in computer and information science and engineering to include fairness, ethics, accountability, and transparency in their proposals.
   - Provided Program Officer training on NSF harassment policy.

b) Respond to encouragement to provide substantive guidance to the research community on mentoring and RCR training to accomplish the goals of the America COMPETES Act.
   - Provided guidance in the draft 2020 PAPPG on reference material to use in designing RECR training (NASEM Reports: Fostering Integrity in Research; Sexual Harassment of Women: Climate, Culture, and Consequences in Academic Sciences, Engineering, and Medicine; and Reproducibility and Replicability in Science).
   - Provided guidance and encouragement in draft 2020 PAPPG on training faculty in RECR.
   - Presented guidance and NSF perspectives to university research integrity officers and other research administrators at a workshop on RECR tools and methods for university leaders.
   - Funded Online Ethics Center workshop on training STEM faculty new to teaching ethics using a "train the trainer" approach for capacity building across diverse STEM communities.
   - Revised the solicitation for the Ethical and Responsible Research Program to also address topics such as the ethics of behavior at scientific field stations and the ethics of scientific reproducibility, as well as to enhance visibility across STEM fields funded by NSF.

c) Foster the implementation of effective RCR training – including its content and how it is delivered – for all researchers, especially new members of the research community.
   - Continued to encourage the training of faculty in RECR.
   - Continued to encourage STEM faculty to incorporate RECR into their mentoring, teaching, and curriculum development.
   - Funded the Online Ethics Center to hold a workshop on identifying promising practices and innovative programs in RECR education and practice.
   - Issued Dear Colleague Letter welcoming proposals in Education and Human Resources (EHR) on equity, inclusion, and ethics in STEM.

NSF’s Anticipated Action Plan Milestones

a) Respond to broader definition of the Responsible Conduct of Research (RCR) which includes protecting the integrity of data; complying with relevant requirements; communicating openly with researchers, institutions, and funding agencies; mentoring; ensuring responsible authorship; managing conflicts of interests; and establishing research environments free of harassment.
   - Publish the final 2020 PAPPG.
   - Develop further improvements for the 2021 PAPPG based on community feedback.
   - Highlight changes to RECR provisions on 2020 PAPPG web page.
   - Create RECR landing page that leads directly to NSF’s encompassing RECR definition, policies, and programs.
   - Increase the incorporation of ethics considerations into NSF research opportunities.

b) Respond to encouragement to provide substantive guidance to the research community on mentoring and RCR training to accomplish the goals of the America COMPETES Act.
   - Continue to fund the Online Ethics Center and research on best practices.
   - Hold promising practices workshops (including the Online Ethics Center workshop funded in FY 2019) and incorporate findings into guidance and outreach.
   - Publish final 2020 PAPPG.
   - Continue outreach on 2020 PAPPG.

c) Foster the implementation of effective RCR training – including its content and how it is delivered – for all researchers, especially new members of the research community.
   - Continue to encourage and provide guidance for faculty to engage in RECR teaching and mentoring.
   - Continue to work with academic institutions on promising practices for educating researchers at all levels.
   - Fund projects in equity, inclusion, and ethics in STEM as a result of EHR Dear Colleague Letter.

GAO-IG ACT EXHIBITS

Pursuant to P.L. 115-331, the Good Accounting in Government Act, the following three tables report on outstanding NSF OIG and GAO recommendations and their associated status as of December 31, 2019.

Open OIG Recommendations – Internal Audits

Open OIG Recommendations - Internal Audits

OIG Number	Title (Final Audit Report Date)	OIG Recommendation	Status of Recommendation[1]	Timeline for Final Implementation
17-2-009	Audit of Preservation of Electronic Records and Cooperation with Congressional Requests (7/6/17)	2. Develop policies, procedures, and controls to capture and retain work-related text messages, social media posts, and electronic records created on government and non-government accounts to meet NARA requirements.	Resolved	Implementation date to be determined, at this time. Implementation of the Smarsh tool, which NSF identified as a system to automate capture and retention of work-related text messages, has been delayed because Smarsh's FedRAMP certification has been delayed. FedRAMP certification was originally projected to be complete June 30, 2019, later extended to September 30, 2019, and then further extended, with no projected date at this time. As such, NSF is looking to consider other options to meet this requirement.
18-2-005	Audit of NSF's Oversight of Grantees' Subrecipient Monitoring	Continue efforts to update NSF's policies and procedures to ensure they align with the Uniform Guidance, including: a. FL-99 Pre-Award Review b. BFA Business Systems Review Guide c. SOG 2016-4, BFA's DACS Cooperative Support Branch Standardized Cost Analysis Guidance d. Large Facilities Manual	Resolved	Partial implementation of recommendation as of 12/31/2019. Projected implementation date for all corrective actions is June 30, 2020.
18-2-005	Audit of NSF's Oversight of Grantees' Subrecipient Monitoring	Ensure NSF's guidance includes a specific mechanism to verify that PTEs of large and complex awards completed subrecipient risk assessments.	Resolved	Projected implementation date is June 30, 2020.
19-2-003	NSF Could Improve its Controls to Prevent Inappropriate Use of Electronic Devices	Ensure that all existing NSF-owned mobile devices (iPhones and iPads) are enrolled in AirWatch.	Resolved	Projected implementation date is February 15, 2020.
19-2-003	NSF Could Improve its Controls to Prevent Inappropriate Use of Electronic Devices	Develop an enforcement mechanism for offices and directorates to complete the annual recertification process for mobile devices and have all users sign the certificate of awareness.	Unresolved	NSF is evaluating the potential to combine the annual recertification process for mobile devices with the annual IT security awareness training. Projected resolution and implementation date is February 15, 2020.
19-2-003	NSF Could Improve its Controls to Prevent Inappropriate Use of Electronic Devices	Annually educate users on acceptable mobile device use and the consequence of personal and inappropriate use.	Resolved	Projected implementation date is April 1, 2020.

[1] "Resolved" status indicates where NSF and OIG have agreed upon the appropriate corrective action to address the recommendation but where implementation is ongoing or closing of the recommendation is pending OIG review to confirm responsiveness. "Unresolved" status indicates where NSF and the OIG have not yet agreed upon the appropriate corrective action to address the recommendation.

Open OIG Recommendations – External Audits

Open OIG Recommendations - External Audits

OIG Number	Title (Final Audit Report Date)	OIG Recommendation	Status of Recommendation[1]	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implementation
16-1-004	University of Washington (2/11/2016)	1.1) Repay $1,824,117 of questioned senior salaries.	Resolved	12/11/2019	$1,824,117	$ -	$1,824,117	1/31/2020
16-1-004	University of Washington (2/11/2016)	1.2) Strengthen controls over senior salaries.	Resolved	12/11/2019	$ -	$ -	$ -	1/31/2020
16-1-004	University of Washington (2/11/2016)	2.1) Resolve $122,893 questioned equipment, materials, and supplies costs.	Resolved	12/11/2019	$ 122,893	$ 44,143	$ 78,750	1/31/2020
16-1-004	University of Washington (2/11/2016)	2.2) Strengthen controls over equipment, materials, and supplies.	Resolved	12/11/2019	$ -	$ -	$ -	1/31/2020
16-1-004	University of Washington (2/11/2016)	3.1) Resolve $36,240 of questioned purchase card transaction costs.	Resolved	12/11/2019	$ 36,240	$ 12,868	$ 23,372	1/31/2020
16-1-004	University of Washington (2/11/2016)	3.2) Strengthen controls over purchase card transactions charging costs to awards.	Resolved	12/11/2019	$ -	$ -	$ -	1/31/2020
16-1-004	University of Washington (2/11/2016)	4.1) Resolve $8,821 of questioned promotional and interest costs.	Resolved	12/11/2019	$ 8,821	$ 8,821	$ -	1/31/2020
16-1-004	University of Washington (2/11/2016)	4.2) Strengthen controls over unallowable costs such as promotional items.	Resolved	12/11/2019	$ -	$ -	$ -	1/31/2020
16-1-004	University of Washington (2/11/2016)	5.1) Resolve $6,648 of preaward costs questioned.	Resolved	12/11/2019	$ 6,648	$ 6,648	$ -	1/31/2020
16-1-004	University of Washington (2/11/2016)	5.2) Strengthen controls over preaward purchases.	Resolved	12/11/2019	$ -	$ -	$ -	1/31/2020
16-1-004	University of Washington (2/11/2016)	6.1) Resolve $2,650 of questioned meal expenditures.	Resolved	12/11/2019	$ 2,650	$ 2,650	$ -	1/31/2020
16-1-004	University of Washington (2/11/2016)	6.2) Strengthen controls over approving meal expenditures.	Resolved	12/11/2019	$ -	$ -	$ -	1/31/2020
16-1-004	University of Washington (2/11/2016)	7.1) Resolve $1,740 of questioned travel costs occurring after award expiration.	Resolved	12/11/2019	$ 1,740	$ 1,740	$ -	1/31/2020
16-1-004	University of Washington (2/11/2016)	7.2) Strengthen controls over travel near or after award expiration.	Resolved	12/11/2019	$ -	$ -	$ -	1/31/2020
18-1-007	University of Montana (9/27/2018)	1.1) Repay $342,020 in unallowable research base salaries.	Resolved	8/29/2019	$ 342,020	$ 342,020	$ -	1/31/2020
18-1-007	University of Montana (9/27/2018)	1.2) Update salary policies to use employees' IBS rates when allocating salary expenses to awards.	Resolved	8/29/2019	$ -	$ -	$ -	1/31/2020
18-1-007	University of Montana (9/27/2018)	2.1) Repay $18,932 in inappropriately allocated expenses.	Resolved	8/29/2019	$ 18,932	$ 18,932	$ -	1/31/2020
18-1-007	University of Montana (9/27/2018)	2.2) Strengthen controls over allocating expenses incurred within the final 90 days of an award.	Resolved	8/29/2019	$ -	$ -	$ -	1/31/2020
18-1-007	University of Montana (9/27/2018)	2.3) Strengthen controls over allocating tuition expenses to sponsored projects.	Resolved	8/29/2019	$ -	$ -	$ -	1/31/2020
18-1-007	University of Montana (9/27/2018)	3.1) Repay $6,827 in unallowable expenses.	Resolved	8/29/2019	$ 6,827	$ 6,827	$ -	1/31/2020
18-1-007	University of Montana (9/27/2018)	3.2) Strengthen controls over allocating travel expenses to sponsored projects.	Resolved	8/29/2019	$ -	$ -	$ -	1/31/2020
18-1-007	University of Montana (9/27/2018)	3.3) Strengthen controls over direct charging non-standard expenses to sponsored projects.	Resolved	8/29/2019	$ -	$ -	$ -	1/31/2020

Open OIG Recommendations - External Audits

OIG Number	Title (Final Audit Report Date)	OIG Recommendation	Status of Recommendation[1]	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implementation
18-1-007	University of Montana (9/27/2018)	3.4) Develop a written policy for mailroom expense distribution based on actual costs incurred.	Resolved	8/29/2019	$ -	$ -	$ -	1/31/2020
19-1-002	University of Wyoming (12/21/2018)	1.1) Unallowable costs incurred due to lack of supporting documentation.	Resolved	9/30/2019	$ 44,330	$ 44,330	$ -	1/31/2020
19-1-002	University of Wyoming (12/21/2018)	1.2) Strengthen controls over documentation requirements.	Resolved	9/30/2019	$ -	$ -	$ -	1/31/2020
19-1-002	University of Wyoming (12/21/2018)	2.1) Unallowable relocation costs.	Resolved	9/30/2019	$ 15,581	$ 15,581	$ -	1/31/2020
19-1-002	University of Wyoming (12/21/2018)	2.2) Strengthen controls over prior approvals for relocation costs.	Resolved	9/30/2019	$ -	$ -	$ -	1/31/2020
19-1-002	University of Wyoming (12/21/2018)	2.3)Strengthen controls over proposing relocation costs.	Resolved	9/30/2019	$ -	$ -	$ -	1/31/2020
19-1-002	University of Wyoming (12/21/2018)	3.1) Inadequate support for cost transfers.	Resolved	9/30/2019	$ 381,772	$ 147,365	$ 234,407	1/31/2020
19-1-002	University of Wyoming (12/21/2018)	3.2) Strengthen controls over cost transfers.	Resolved	9/30/2019	$ -	$ -	$ -	1/31/2020
19-1-002	University of Wyoming (12/21/2018)	4.1) Strengthen controls over approvals of personnel activity reports.	Resolved	9/30/2019	$ -	$ -	$ -	1/31/2020
19-1-002	University of Wyoming (12/21/2018)	5.1) Strengthen controls over timely submission of personnel activity reports.	Resolved	9/30/2019	$ -	$ -	$ -	1/31/2020
19-1-002	University of Wyoming (12/21/2018)	6.1) Strengthen controls over purchase card limits.	Resolved	9/30/2019	$ -	$ -	$ -	1/31/2020

[1] "Resolved" status indicates management decisions have been agreed upon by the awardee, NSF Management, and NSF OIG.

GAO Open Recommendation Over One Year as of February 2020

GAO Open Recommendations over 1 Year as of February 2020

GAO Number	Title (Final Audit Report Date)	GAO Recommendation	Status of Recommendation	Timeline for Final Implementation
GAO-18-656	Science and Technology: Considerations for Maintaining U.S. Competitiveness in Quantum Computing, Synthetic Biology, and Other Potentially Transformational Research Areas	Recommendation 4: As the QIS Subcommittee moves forward, the National Science Foundation co-chair, in coordination with other co-chairs and participating agency officials, should take steps to fully implement leading practices that enhance and sustain collaboration.	Open	The QIS subcommittee is preparing a Strategic Plan that will set forth recommendations for moving the US QIS effort forward, including agency collaborations. The plan will be released following approval by the NQI-authorized Advisory Committee. The tentative date for release is spring 2020. Implementation of recommendations should begin in FY 2021.
GAO-18-656	Science and Technology: Considerations for Maintaining U.S. Competitiveness in Quantum Computing, Synthetic Biology, and Other Potentially Transformational Research Areas	Recommendation 5: As the Interagency Working Group on Synthetic Biology moves forward, the Director of the National Science Foundation, in coordination with participating agency officials, should take steps to fully implement leading practices that enhance and sustain collaboration.	Open	NSF implemented the recommendation by the formation of the Interagency Synthetic Biology Working Group (SBWG), charged in Q4 FY 2018 under the Biological Sciences Subcommittee of the Committee on Science at NSTC. The SBWG is comprised of 16 agencies across USG and meets regularly to facilitate communication, coordination and collaboration across agencies with an interest in synthetic biology. A key SBWG activity Q4 FY 2019 was the convening of a workshop that included representatives across USG, academia, and industry to examine and refine a roadmap for basic research, technology, infrastructure, and workforce needs for synthetic biology. Workshop results will inform priorities for SBWG collaboration in FY 2020 and beyond.
GAO-18-533	National Science Foundation: A Workforce Strategy and Evaluation of Results Could Improve Use of Rotating Scientists, Engineers, and Educators	Recommendation 1: The NSF Director of Human Resource Management should complete the development of an agency-wide workforce strategy for balancing the agency's use of IPA and VSEE rotators with permanent staff as part of NSF's current agency reform planning efforts or updates to its human capital operating plan.	Open	Accomplishments: -Q4 FY 2019: New permanent HRM Division Director and Deputy Assistant Director of the Directorate of Social, Behavioral, and Economic Research assigned co-ownership of Renewing NSF Goal 1: Adapting the Workforce to the Work. Planned Activities: - Plan implementaiton of activities to advance Renewing NSF Goal 1. - HRM and Budget Divisions conduct a "roadshow" to all NSF components to discuss resource management including how FTE and IPA resources are used.

GAO Open Recommendations over 1 Year as of February 2020

GAO Number	Title (Final Audit Report Date)	GAO Recommendation	Status of Recommendation	Timeline for Final Implementation
GAO-18-533	National Science Foundation: A Workforce Strategy and Evaluation of Results Could Improve Use of Rotating Scientists, Engineers, and Educators	Recommendation 2: The NSF Director of Human Resource Management should evaluate the contributions of the IPA and VSEE rotator programs toward NSF's human capital goals and the contributions the programs have made toward achieving programmatic results.	Open	NSF is working on an evaluation and anticipates providing a status report on March 31, 2020.
GAO-18-93	Federal Chief Officers: Critical Actions Needed to Address Shortcomings and Challenges in Implementing Responsibilities	Recommendation 22: The Director of the National Science Foundation should ensure that the agency's IT management policies address the role of the CIO for key responsibilities in the five areas we identified.	Open	NSF has implemented this recommendation by establishing new agency IT management policies and updating existing policies to more specifically address the role of the CIO in the five areas identified by GAO. NSF plans to provide updated documentation to GAO in Q2 FY 2020.
GAO-18-370	National Science Foundation: Revised Policies on Developing Costs and Schedules Could Improve Estimates for Large Facilities	Recommendation 1: The Director of NSF should revise the agency's policies for estimating the costs of large facilities projects, and for reviewing those costs, to better incorporate the best practices in GAO's cost guide.	Open	The Major Facilities Guide (NSF 19-68; September 2019) has been revised to incorporate GAO's "purpose" of the cost estimate, methods for sensitivity analysis, minimum requirements for a 3-tier Work Breakdown Structure, and application of GAO's 12-steps of a high-quality cost estimate. Internal Standard Operating Guidance on selection of independent cost estimate reviews in support of NSF's cost analysis has been finalized. New internal Standard Operating Guidance related to more effectively utilizing external review panels to address elements of cost has been drafted and is planned for implementation in Q3 FY 2020.
GAO-18-370	National Science Foundation: Revised Policies on Developing Costs and Schedules Could Improve Estimates for Large Facilities	Recommendation 2: The Director of NSF should revise the agency's policies for developing schedules for large facilities projects, and for reviewing those schedules, to better incorporate the best practices in GAO's schedule guide.	Open	Section 4.3 of the Major Facilities Guide (MFG) has been reserved, an outline developed, and content is being created to describe NSF's expectations in relation to the GAO Schedule Guide. A targeted interim update to the MFG is (which will include Section 4.3) is planned for Q3 FY2020. Internal Standard Operating Guidance related to the NSF cost analysis has been updated to incorporate an assessment of schedule. New internal Standard Operating Guidance related to more effectively utilizing external review panels to address elements of schedule has been drafted and is planned for implementation in Q3 FY 2020.

GAO Open Recommendations over 1 Year as of February 2020

GAO Number	Title (Final Audit Report Date)	GAO Recommendation	Status of Recommendation	Timeline for Final Implementation
GAO-16-511	Information Technology Agencies Need to Improve Their Application Inventories to Achieve Additional Savings (09/29/2016)	Recommendation 17: To improve federal agencies' efforts to rationalize their portfolio of applications, the Secretaries of Defense, Homeland Security, the Interior, and Labor; and the Director of the National Science Foundation should direct the CIOs and other responsible officials to modify existing investment management processes to address applications more completely. Specifically, the Director of the National Science Foundation should direct the CIO to consistently document evaluations for all applications and report cost information for them in the roadmap or other documentation.	Open	The NSF has implemented this recommendation. In March 2019, the Foundation provided examples of how applications are documented and reported on in the rationalization process. Closure of the recommendation is pending GAO review.
GAO-16-573	Federal Research Grants: Opportunities Remain for Agencies to Streamline Administrative Requirements (06/22/2016)	Recommendation 9: To further standardize administrative research requirements, the Secretary of Energy, the NASA Administrator, the Secretary of Health and Human Services, and the Director of NSF should coordinate through Office of Science and Technology Policy's (OSTP) Research Business Models working group to identify additional areas where they can standardize requirements and report on these efforts.	Open	NSF is an active member of the former OSTP Research Business Models working group, now the Coordinating Administrative Research Requirements subcommittee of the NSTC Joint Committee on the Reserach Environment. In serving as both a member and co-chair of the group, NSF continues to provide strategic leadership to identify additional areas where standarization or reduction of requirements may help reduce administrative burden.

GAO Open Recommendations over 1 Year as of February 2020

GAO Number	Title (Final Audit Report Date)	GAO Recommendation	Status of Recommendation	Timeline for Final Implementation
GAO-12-791	Organizational Transformation: Enterprise Architecture Value Needs to Be Measured and Reported (09/26/2012)	Recommendation 21: To enhance federal agencies' ability to realize enterprise architecture benefits, the Secretaries of the Departments of Agriculture, the Air Force, the Army, Commerce, Defense, Education, Energy, Homeland Security, the Interior, Labor, the Navy, State, Transportation, the Treasury, and Veterans Affairs; the Attorney General; the Administrators of the Environmental Protection Agency, General Services Administration, National Aeronautics and Space Administration, and Small Business Administration; the Commissioners of the Nuclear Regulatory Commission and Social Security Administration; and the Directors of the National Science Foundation and the Office of Personnel Management should fully establish an approach for measuring enterprise architecture outcomes, including a documented method (i.e., steps to be followed) and metrics that are measurable, meaningful, repeatable, consistent, actionable, and aligned with the agency's enterprise architecture's strategic goals and intended purpose.	Open	The NSF implemented GAO's recommendation by establishing an approach for measuring enterprise architecture outcomes. In November 2019, NSF provided GAO with supporting documentation. Closure of the recommendation is pending GAO review.
GAO-12-791	Organizational Transformation: Enterprise Architecture Value Needs to Be Measured and Reported (09/26/2012)	Recommendation 45: To enhance federal agencies' ability to realize enterprise architecture benefits, the Secretaries of the Departments of Agriculture, the Air Force, the Army, Commerce, Defense, Education, Energy, Homeland Security, the Interior, Labor, the Navy, State, Transportation, the Treasury, and Veterans Affairs; the Attorney General; the Administrators of the Environmental Protection Agency, General Services Administration, National Aeronautics and Space Administration, and Small Business Administration; the Commissioners of the Nuclear Regulatory Commission and Social Security Administration; and the Directors of the National Science Foundation and the Office of Personnel Management should periodically measure and report enterprise architecture outcomes and benefits to top agency officials (i.e., executives with authority to commit resources or make changes to the program) and to OMB.	Open	The NSF has implemented this recommendation. In November 2019, the Foundation provided evidence to GAO that it periodically measures and reports Enterprise Architecture outcomes to top agency officials. Closure of the recommendation is pending GAO review.

OTHER INFORMATION

Management Reviews

Each quarter, NSF senior leadership reviews progress towards all performance goals of the agency in a data-driven review meeting led by the Chief Operating Officer and Performance Improvement Officer. The quarterly progress of the Agency Priority Goals (APGs) and performance goals are reviewed.

Alignment of Human Capital Efforts with Organizational Performance

In order to drive individual and organizational performance, NSF requires that the performance plans of all employees, executives, and the general workforce contain individual goals aligned with the agency's mission and strategic goals. NSF provides training and makes tools and templates available for all supervisors and employees on linking performance plans to agency mission, as well as providing assistance and training on the policies, processes, requirements, and timeframes for the development of performance plans and appraisals.

NSF also directly aligns its strategic human capital and accountability efforts to the agency goals identified in the NSF Strategic Plan. Agency performance goals currently outline specific human capital goals, and NSF uses HRStat as the agency reporting mechanism to articulate the nexus between NSF's strategic goals/objectives, including agency performance goals, and human capital initiatives at the agency. Senior leaders are briefed quarterly regarding the status of agency performance goals and the human capital initiatives aligned to those goals.

Strategies and Collaborations

No one standard strategy is used across NSF for achievement of goals. Goal leaders at NSF choose strategies tailored to their stakeholders' needs and their institutional capabilities. NSF goals often involve testing the impacts of new activities or new approaches to existing activities, so feedback mechanisms are built in. Use of analysis, evidence, and evaluation findings is also at the discretion of each individual goal leader, as is the decision to collaborate with other agencies or external entities or to invest in contract support for their activities. Performance at NSF is reviewed quarterly by NSF's Performance Improvement Officer, who reports on goal progress to NSF senior management.

Advisory Committees and Committees of Visitors

Each directorate and office has an external advisory committee that typically meets twice a year to review and provide advice on program management, discuss current issues, and review and provide advice on the impact of policies, programs, and activities in the disciplines and fields encompassed by the directorate or office. In addition to directorate and office advisory committees, NSF is also advised by external committees on specific topics. Recent examples include: astronomy and astrophysics; environmental research and education; equal opportunities in science and engineering; direction, development, and enhancements of innovations; polar programs; advanced cyberinfrastructure; international and integrative activities; the agency's merit review processes; and business and operations.

Committees of Visitors (COVs) are subcommittees of NSF directorate advisory committees. COV reviews provide NSF with external expert judgments in two areas: (1) assessments of the quality and integrity of program operations and program-level technical and managerial matters pertaining to proposal decisions; and (2) comments on how the outputs and outcomes generated by awardees have contributed to the attainment of NSF's mission and strategic outcome goals. COV reviews are conducted at regular intervals of approximately four years for programs and offices that recommend or award grants, cooperative agreements, and/or contracts and whose main focus is the conduct or support of NSF research and education in science and engineering. Approximately one-fourth of NSF's divisions are assessed each year.

A COV typically consists of up to 20 external experts, selected to ensure independence, programmatic coverage, and geographic balance. COV members come from academia, industry, government, and the public sector. They meet for two or three days to review and assess program priorities, program management, and award accomplishments or outcomes. Each COV prepares a report and the division or program that is being reviewed must prepare a response to the COV recommendations. These reports and responses are submitted to the parent advisory committee and to the Director of NSF. All reports and responses are public and posted on NSF's website.[1]

In FY 2019, six directorates convened ten COVs, covering all or part of ten divisions. A table of the COVs performed in recent years and planned through FY 2021 is provided on the next page. The chapters of the directorates also contain information on these COVs, as well as information on *ad hoc* reports.

Evaluations and Research

Evaluations at NSF are currently performed at the discretion of the individual directorate, office, or program being evaluated. A list of major external evaluations completed in FY 2019 follows. For more details about how the results of these specific evaluations are being used to shape agency decisions, see the chapter of the sponsoring directorate. Directorate chapters also contain a list of selected high-impact events (workshops, symposia, or other meetings resulting in publications) that inform their decision-making. For more information about program evaluation and collection and management of NSF programmatic data, see the Office of Integrative Activities chapter's section on NSF's Evaluation and Assessment Capability.

Major External Evaluations Completed in FY 2019

DIR	Name of Evaluation	Evaluator	Link to report
BIO	Science Breakthroughs to Advance Food and Agricultural Research by 2030	National Academies	www.nap.edu/catalog/25059
CISE	Quantum Computing: Progress and Prospects	National Academies	www.nap.edu/catalog/25196
CISE	A 20-Year Community Roadmap for Artificial Intelligence Research in the US	Computing Community Consortium	cra.org/ccc/wp-content/uploads/sites/2/2019/08/Community-Roadmap-for-AI-Research.pdf
ENG	Environmental Engineering for the 21st Century: Addressing Grand Challenges	National Academies	www.nap.edu/catalog/25121
MPS	Frontiers of Materials Research: A Decadal Survey	National Academies	www.nap.edu/catalog/25244
MPS	Manipulating Quantum Systems: An Assessment of Atomic, Molecular, and Optical Physics in the United States	National Academies	www.nap.edu/catalog/25613

[1] www.nsf.gov/od/oia/activities/cov/covs.jsp

List of Committees of Visitors Meetings, FY 2016-FY 2021

DIR	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020 (planned)	FY 2021 (projected)
BIO	Biological Infrastructure (DBI)	-	Molecular and Cellular Biosciences (MCB) Integrative Organismal Systems (IOS)	Environmental Biology (DEB)	DBI	-
CISE	-	-	Advanced Cyberinfrastructure	-	Computing and Communication Foundations Computer and Network Systems Information and Intelligent Systems	-
EHR	-	EHR Core Research Undergraduate Education (DUE): TUES, STEP, WIDER, IUSE: EHR	-	Graduate Education (DGE) DUE	Research on Learning in Formal and Informal Settings	Human Resource Development
ENG	Engineering, Education and Centers (EEC) Industrial Innovation and Partnerships (IIP)	-	Electrical, Communications and Cyber Systems Emerging Frontiers and Multidisciplinary Activities	Chemical, Bioengineering, Environmental and Transport Systems Civil, Mechanical and Manufacturing Innovations	EEC IIP	-

DIR	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020 (planned)	FY 2021 (projected)
GEO	Atmospheric and Geospace Sciences (AGS): Atmosphere Section	Education and Diversity Programs Earth Sciences (EAR)	AGS: Geospace OCE: Integrative Programs	Ocean Sciences: Research Programs	AGS	Education and Diversity Programs EAR
MPS	Chemistry (CHE) Mathematical Sciences (DMS)	-	-	Astronomy Materials Research Physics	CHE DMS	-
SBE	Social and Economic Sciences (SES)	-	-	Behavioral and Cognitive Sciences	Office of Multidisciplinary Activities SES	-
OPP, OIA, and OISE	Major Research Infrastructure (MRI) Office of Polar Programs (OPP): Antarctic Sciences OPP: Arctic Sciences	-	International Science and Engineering National Academies: Board on International Science Organizations	-	Established Program to Stimulate Competitive Research (EPSCoR) OPP: Antarctic Sciences OPP: Arctic Sciences	MRI

Data Verification and Validation

It is NSF's practice to follow Government Accountability Office (GAO) guidance and engage external contractors to conduct an independent validation and verification (V&V) review of its annual performance information, data, and processes. The guidance from GAO indicates that agencies should "…describe the means the agency will use to verify its performance data…" and "…provide confidence that [their] performance information will be credible."[2]

In FY 2019, NSF contracted with Nexight Group to perform the independent verification and validation. Nexight assessed the validity of NSF data and verified the reliability of the methods used to collect, process, maintain, and report that data. Nexight's FY 2019 report concluded:

> The Nexight Team was able to verify the reliability of the processes used to generate the performance measure results for eight performance goals. Although some of the measures have issues that should be addressed in future years, the data collection processes for all measures adhere to the five V&V criteria—Complete, Consistent, Accurate, Timely, and Valid—and are sufficient to ensure that the results are usable. The Nexight Team was also able to confirm the results reported for twelve of the fourteen performance measures. Due to lack of access to primary data, the Nexight Team was only able to partially confirm the results for the remaining two measures.
>
> Overall, the Nexight Team verifies that NSF relies on sound data collection practices, internal controls, and manual checks of system queries to ensure accurate performance reporting. Based on the V&V assessment, the Nexight Team has confidence in the systems, policies, and procedures used by NSF to calculate results for its performance measures. NSF continues to take concerted steps to improve the quality of its systems and data. The Nexight Team confirms NSF's commitment to ensuring the accuracy of its reported Government Performance and Results Act (GPRA) results, and the reliability of its processes for collecting, processing, maintaining, and reporting data for its performance goals. [3]

The data and information required to measure progress towards NSF's performance goals fall into three broad categories.

1. <u>NSF automated administrative systems</u>. Performance monitoring can be a valuable secondary function of such systems. Reporting can include data from systems that:
   - Store and approve publications such as solicitations announcements, and Dear Colleague Letters;
   - Collect transactional data about proposal and award management;
   - Perform financial transactions;
   - Store human resources data; or
   - Permit keyword search of abstract or full texts of proposals and awards.

   The data were used either directly or for achieving milestones that involve the writing of a report. While not all goals require a high level of accuracy, data from these systems are highly reliable.
2. <u>Data requests of external parties</u>. Qualitative or quantitative information is solicited directly from awardees.

[2] GAO, The Results Act: An Evaluator's Guide to Assessing Agency Annual Performance Plans, GAO/GGD-10.1.20 (Washington, D.C.: April 1998), pp. 40-41.
[3] Nexight Group with Energetics Incorporated, *National Science Foundation Performance Measurement Verification and Validation Report, Fiscal Year 2019*. December 2019.

3. Reports on internal activities. Milestone achievement is often determined from review of records of certain activities and events. Records of this sort tend to be compiled from review of the evidence provided by goal leaders.

Lower-Priority Program Activities

The President's Budget identifies the lower-priority program activities, where applicable, as required under the GPRA Modernization Act (31 U.S.C. 1115(b)(10)). The public can access the volume at www.whitehouse.gov/omb/budget.

Use of Non-Federal Parties

No non-federal parties were involved in preparation of this Annual Performance Report.

Classified Appendices Not Available to the Public

None.

TECHNICAL INFORMATION

FY 2021 APPROPRIATIONS LANGUAGE

National Science Foundation

RESEARCH AND RELATED ACTIVITIES

For necessary expenses in carrying out the National Science Foundation Act of 1950 (42 U.S.C. 1861 et seq.), and Public Law 86–209 (42 U.S.C. 1880 et seq.); services as authorized by section 3109 of title 5, United States Code; maintenance and operation of aircraft and purchase of flight services for research support; acquisition of aircraft; and authorized travel; $6,213,020,000, to remain available until September 30, 2022, of which not to exceed $544,000,000 shall remain available until expended for polar research and operations support, and for reimbursement to other Federal agencies for operational and science support and logistical and other related activities for the United States Antarctic program: *Provided*, That receipts for scientific support services and materials furnished by the National Research Centers and other National Science Foundation supported research facilities may be credited to this appropriation.

EDUCATION AND HUMAN RESOURCES

For necessary expenses in carrying out science, mathematics and engineering education and human resources programs and activities pursuant to the National Science Foundation Act of 1950 (42 U.S.C. 1861 et seq.), including services as authorized by section 3109 of title 5, United States Code, authorized travel, and rental of conference rooms in the District of Columbia, $930,930,000, to remain available until September 30, 2022.

MAJOR RESEARCH EQUIPMENT AND FACILITIES CONSTRUCTION

For necessary expenses for the acquisition, construction, commissioning, and upgrading of major research equipment, facilities, and other such capital assets pursuant to the National Science Foundation Act of 1950 (42 U.S.C. 1861 et seq.), including authorized travel, $229,750,000, to remain available until expended.

AGENCY OPERATIONS AND AWARD MANAGEMENT

For agency operations and award management necessary in carrying out the National Science Foundation Act of 1950 (42 U.S.C. 1861 et seq.); services authorized by section 3109 of title 5, United States Code; hire of passenger motor vehicles; uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; rental of conference rooms in the District of Columbia; and reimbursement of the Department of Homeland Security for security guard services; $345,640,000: *Provided*, That not to exceed $8,280 is for official reception and representation expenses: *Provided further*, That contracts may be entered into under this heading in fiscal year 2021 for maintenance and operation of facilities and for other services to be provided during the next fiscal year.

OFFICE OF INSPECTOR GENERAL

For necessary expenses of the Office of Inspector General as authorized by the Inspector General Act of 1978, $17,850,000, of which $400,000 shall remain available until September 30, 2022.

OFFICE OF THE NATIONAL SCIENCE BOARD

For necessary expenses (including payment of salaries, authorized travel, hire of passenger motor vehicles, the rental of conference rooms in the District of Columbia, and the employment of experts and consultants under section 3109 of title 5, United States Code) involved in carrying out section 4 of the National Science Foundation Act of 1950 (42 U.S.C. 1863) and Public Law 86–209 (42 U.S.C. 1880 et seq.), $4,210,000: *Provided*, That not to exceed $2,500 shall be available for official reception and representation expenses.

ADMINISTRATIVE PROVISION
(INCLUDING TRANSFER OF FUNDS)

Not to exceed 5 percent of any appropriation made available for the current fiscal year for the National Science Foundation in this Act may be transferred between such appropriations, but no such appropriation shall be increased by more than 10 percent by any such transfers. Any transfer pursuant to this paragraph shall be treated as a reprogramming of funds under section 505 of this Act and shall not be available for obligation except in compliance with the procedures set forth in that section.

The Director of the National Science Foundation (NSF) shall notify the Committees on Appropriations of the House of Representatives and the Senate at least 30 days in advance of any planned divestment through transfer, decommissioning, termination, or deconstruction of any NSF-owned facilities or any NSF capital assets (including land, structures, and equipment) valued greater than $2,500,000.

SUMMARY OF FY 2021 NSF BUDGETARY RESOURCES BY ACCOUNT

(Dollars in Millions)

Discretionary Accounts	FY 2019 Actual	FY 2020 Enacted	FY 2021 Request	Change Over FY 2020 Enacted Amount	Change Over FY 2020 Enacted Percent
RESEARCH AND RELATED ACTIVITIES					
Appropriation	$6,520.00	$6,737.20	$6,213.02	-$524.18	-7.8%
Unobligated Balance Available Start of Year	28.87	16.21		-16.21	
Unobligated Balance Available End of Year	-16.21				
Adjustments to Prior Year Accounts[1]	60.97				
Subtotal, R&RA	**6,593.63**	**6,753.41**	**6,213.02**		
Transfer to/from other funds	-15.49				
Total Budgetary Resources	**$6,578.14**	**$6,753.41**	**$6,213.02**	**-$540.39**	**-8.0%**
EDUCATION AND HUMAN RESOURCES					
Appropriation	$910.00	$940.00	$930.93	-$9.07	-1.0%
Unobligated Balance Available Start of Year	14.27	5.66		-5.66	
Unobligated Balance Available End of Year	-5.66				
Adjustments to Prior Year Accounts[1]	3.92				
Subtotal, EHR	**922.53**	**945.66**	**930.93**		
Transfer to/from other funds	12.00				
Total Budgetary Resources	**$934.53**	**$945.66**	**$930.93**	**-$14.73**	**-1.6%**
MAJOR RESEARCH EQUIPMENT & FACILITIES CONSTRUCTION					
Appropriation	$295.74	$243.23	$229.75	-$13.48	-5.5%
Unobligated Balance Available Start of Year	28.43	38.95		-38.95	
Unobligated Balance Available End of Year	-38.95				
Adjustments to Prior Year Accounts[1]	0.05				
Subtotal, MREFC	**285.27**	**282.18**	**229.75**		
Transfer to/from other funds	-				
Total Budgetary Resources	**$285.27**	**$282.18**	**$229.75**	**-$52.43**	**-18.6%**

SUMMARY OF FY 2021 NSF BUDGETARY RESOURCES BY ACCOUNT
(Dollars in Millions)

Discretionary Accounts	FY 2019 Actual	FY 2020 Enacted	FY 2021 Request	Change Over FY 2020 Enacted Amount	Change Over FY 2020 Enacted Percent
AGENCY OPERATIONS AND AWARD MANAGEMENT					
Appropriation	$329.54	$336.90	$345.64	$8.74	2.6%
Unobligated Balance Available Start of Year	0.19	0.15		-0.15	
Unobligated Balance Available End of Year	-0.15				
Adjustments to Prior Year Accounts[1]	-0.38				
Subtotal, AOAM	**329.20**	**337.05**	**345.64**		
Transfer to/from other funds	3.49				
Total Budgetary Resources	**$332.69**	**$337.05**	**$345.64**	**$8.59**	**2.5%**
OFFICE OF INSPECTOR GENERAL					
Appropriation	$15.35	$16.50	$17.85	$1.35	8.2%
Unobligated Balance Available Start of Year	0.40	0.40		-0.40	
Unobligated Balance Available End of Year	-0.40				
Adjustments to Prior Year Accounts[1]	-0.07				
Total Budgetary Resources	**$15.28**	**$16.90**	**$17.85**	**$0.95**	**5.6%**
OFFICE OF THE NATIONAL SCIENCE BOARD					
Appropriation	$4.37	$4.50	$4.21	-$0.29	-6.4%
Unobligated Balance - Expired	-0.05				
Total Budgetary Resources	**$4.32**	**$4.50**	**$4.21**	**-$0.29**	**-6.4%**
TOTAL DISCRETIONARY, NATIONAL SCIENCE FOUNDATION	**$8,150.23**	**$8,339.70**	**$7,741.40**	**-$598.30**	**-7.2%**

Totals exclude reimbursable amounts.

[1] Adjustments include upward and downward adjustments to prior year obligations in unexpired accounts.

SUMMARY OF FY 2021 NSF BUDGETARY RESOURCES BY ACCOUNT

(Dollars in Millions)

Mandatory Accounts	FY 2019 Actual	FY 2020 Enacted	FY 2021 Request	Change Over FY 2020 Enacted Amount	Change Over FY 2020 Enacted Percent
EDUCATION AND HUMAN RESOURCES, H-1B					
Appropriation, Mandatory (H1-B Non-Immigrant Petitioner Fees)	$156.72	$157.00	$157.00	-	-
Unobligated Balance Available Start of Year	64.68	77.47		-77.47	
Sequestration Previously Unavailable	10.30	9.72	9.26	-0.45	
Sequestration Pursuant OMB M-13-06	-9.72	-9.26	-		
Unobligated Balance Available End of Year	-77.47				
Adjustments to Prior Year Accounts[1]	4.49				
Total Budgetary Resources	**$149.00**	**$234.92**	**$166.26**	**-$68.66**	**-29.2%**
DONATIONS					
Mandatory Programs (Special or Trust Fund)	$32.36	$40.00	$40.00	-	-
Unobligated Balance Available Start of Year	31.76	25.12		-25.12	
Sequestration Previously Unavailable	-	-	-	-	
Sequestration Pursuant OMB M-13-06	-	-			
Unobligated Balance Available End of Year	-25.12				
Adjustments to Prior Year Accounts[1]	0.04				
Total Budgetary Resources	**$39.04**	**$65.12**	**$40.00**	**-$25.12**	**-38.6%**
TOTAL MANDATORY, NATIONAL SCIENCE FOUNDATION	**$188.04**	**$300.03**	**$206.26**	**-$93.77**	**-31.3%**
TOTAL, NATIONAL SCIENCE FOUNDATION	**$8,338.27**	**$8,639.73**	**$7,947.66**	**-$692.07**	**-8.0%**

Totals exclude reimbursable amounts.

[1] Adjustments include upward and downward adjustments to prior year obligations in unexpired accounts.

NSF FY 2021 REQUEST FUNDING BY PROGRAM
(Dollars in Millions)

	FY 2019 Actual	FY 2020 Enacted[1]	FY 2021 Request	FY 2021 Request change over FY 2019 Actual Amount	FY 2021 Request change over FY 2019 Actual Percent
BIOLOGICAL SCIENCES (BIO)					
BIOLOGICAL INFRASTRUCTURE	$180.79	-	$158.07	-$22.72	-12.6%
EMERGING FRONTIERS	110.27	-	89.89	-20.38	-18.5%
ENVIRONMENTAL BIOLOGY	153.60	-	150.26	-3.34	-2.2%
INTEGRATIVE ORGANISMAL SYSTEMS	194.38	-	175.84	-18.54	-9.5%
MOLECULAR & CELLULAR BIOSCIENCES	144.70	-	130.89	-13.81	-9.5%
TOTAL, BIO	**$783.75**	**-**	**$704.95**	**-$78.80**	**-10.1%**
COMPUTER & INFORMATION SCIENCE & ENGINEERING (CISE)					
ADVANCED CYBERINFRASTRUCTURE	$221.84	-	$232.72	$10.88	4.9%
COMPUTING & COMMUNICATION FOUNDATIONS	193.55	-	202.96	9.41	4.9%
COMPUTER & NETWORK SYSTEMS	229.42	-	240.42	11.00	4.8%
INFORMATION & INTELLIGENT SYSTEMS	208.37	-	240.05	31.68	15.2%
INFORMATION TECHNOLOGY RESEARCH	131.93	-	146.25	14.32	10.9%
TOTAL, CISE	**$985.12**	**-**	**$1,062.40**	**$77.28**	**7.8%**
ENGINEERING (ENG)					
CHEMICAL, BIOENGINEERING, ENVIRONMENTAL, & TRANSPORT SYSTEMS	$190.47	-	$160.29	-$30.18	-15.8%
CIVIL, MECHANICAL, & MANUFACTURING INNOVATION	237.91	-	200.54	-37.37	-15.7%
ELECTRICAL, COMMUNICATIONS, & CYBER SYSTEMS	118.03	-	103.74	-14.29	-12.1%
INDUSTRIAL INNOVATION & PARTNERSHIPS	268.67	-	257.90	-10.77	-4.0%
[SBIR/STTR][2]	*[211.65]*		*[209.25]*	*[-2.40]*	*[-1.1%]*
ENGINEERING EDUCATION & CENTERS	102.76	-	89.49	-13.27	-12.9%
EMERGING FRONTIERS AND MULTIDISCIPLINARY ACTIVITIES	73.30	-	97.82	24.52	33.4%
TOTAL, ENG	**$991.15**	**-**	**$909.78**	**-$81.37**	**-8.2%**

NSF FY 2021 REQUEST FUNDING BY PROGRAM

(Dollars in Millions)

	FY 2019 Actual	FY 2020 Enacted[1]	FY 2021 Request	FY 2021 Request change over FY 2019 Actual: Amount	FY 2021 Request change over FY 2019 Actual: Percent
GEOSCIENCES (GEO)					
ATMOSPHERIC & GEOSPACE SCIENCES	$303.41	-	$234.45	-$68.96	-22.7%
EARTH SCIENCES	181.96	-	168.24	-13.72	-7.5%
INTEGRATIVE & COLLABORATIVE EDUCATION AND RESEARCH	113.79	-	94.71	-19.08	-16.8%
OCEAN SCIENCES	370.73	-	339.21	-31.52	-8.5%
TOTAL, GEO	**$969.88**	**-**	**$836.61**	**-$133.27**	**-13.7%**
MATHEMATICAL & PHYSICAL SCIENCES (MPS)					
ASTRONOMICAL SCIENCES	$287.01	-	$242.10	-$44.91	-15.6%
CHEMISTRY	247.27	-	218.71	-28.56	-11.6%
MATERIALS RESEARCH	302.99	-	280.22	-22.77	-7.5%
MATHEMATICAL SCIENCES	237.03	-	214.79	-22.24	-9.4%
PHYSICS	285.23	-	257.83	-27.40	-9.6%
MULTIDISCIPLINARY ACTIVITIES	131.08	-	234.67	103.59	79.0%
TOTAL, MPS	**$1,490.61**	**-**	**$1,448.32**	**-$42.29**	**-2.8%**
SOCIAL, BEHAVIORAL & ECONOMIC SCIENCES (SBE)					
BEHAVIORAL AND COGNITIVE SCIENCES	$94.35	-	$85.14	-$9.21	-9.8%
SOCIAL AND ECONOMIC SCIENCES	96.43	-	86.66	-9.77	-10.1%
MULTIDISCIPLINARY ACTIVITIES	26.16	-	22.93	-3.23	-12.4%
NATIONAL CENTER FOR SCIENCE & ENGINEERING STATISTICS	54.23	-	52.11	-2.12	-3.9%
TOTAL, SBE	**$271.17**	**-**	**$246.84**	**-$24.33**	**-9.0%**

NSF FY 2021 REQUEST FUNDING BY PROGRAM

(Dollars in Millions)

	FY 2019 Actual	FY 2020 Enacted[1]	FY 2021 Request	FY 2021 Request change over FY 2019 Actual Amount	FY 2021 Request change over FY 2019 Actual Percent
OFFICE OF INTERNATIONAL SCIENCE AND ENGINEERING (OISE)	**$49.00**	**-**	**$44.01**	**-$4.99**	**-10.2%**
OFFICE OF POLAR PROGRAMS (OPP)					
OFFICE OF POLAR PROGRAMS	$488.68	-	$419.78	-$68.90	-14.1%
[US Antarctic Logistical Support Activities]	*[81.30]*		*[71.00]*	*[-10.30]*	*[-12.7%]*
Total, OPP	**$488.68**	**-**	**$419.78**	**-$68.90**	**-14.1%**
INTEGRATIVE ACTIVITIES (IA)					
CONVERGENCE ACCELERATOR	$41.39	-	$70.00	$28.61	69.1%
ESTABLISHED PROGRAM TO STIMULATE COMPETITIVE RESEARCH (EPSCoR)	175.67	-	163.67	-12.00	-6.8%
INTEGRATIVE ACTIVITIES	330.26	-	305.06	-25.20	-7.6%
TOTAL, IA	**$547.31**	**-**	**$538.73**	**-$8.58**	**-1.6%**
UNITED STATES ARCTIC RESEARCH COMMISSION	**$1.48**	**-**	**$1.60**	**$0.13**	**8.5%**
TOTAL, RESEARCH AND RELATED ACTIVITIES	**$6,578.14**	**$6,737.20**	**$6,213.02**	**-$365.12**	**-5.6%**
EDUCATION & HUMAN RESOURCES (EHR)					
GRADUATE EDUCATION	$253.33	-	$282.03	$28.70	11.3%
HUMAN RESOURCE DEVELOPMENT	188.11	-	188.78	0.67	0.4%
RESEARCH ON LEARNING IN FORMAL AND INFORMAL SETTINGS	228.27	-	223.53	-4.74	-2.1%
UNDERGRADUATE EDUCATION	264.82	-	236.59	-28.23	-10.7%
TOTAL, EDUCATION & HUMAN RESOURCES	**$934.53**	**$940.00**	**$930.93**	**-$3.60**	**-0.4%**

NSF FY 2021 REQUEST FUNDING BY PROGRAM
(Dollars in Millions)

	FY 2019 Actual	FY 2020 Enacted[1]	FY 2021 Request	FY 2021 Request change over FY 2019 Actual	
				Amount	Percent
MAJOR RESEARCH EQUIPMENT & FACILITIES CONSTRUCTION	**$285.27**	**$243.23**	**$229.75**	**-$55.52**	**-19.5%**
AGENCY OPERATIONS AND AWARD MANAGEMENT	**$332.69**	**$336.90**	**$345.64**	**$12.95**	**3.9%**
OFFICE OF INSPECTOR GENERAL	**$15.28**	**$16.50**	**$17.85**	**$2.57**	**16.8%**
OFFICE OF THE NATIONAL SCIENCE BOARD	**$4.32**	**$4.50**	**$4.21**	**-$0.11**	**-2.6%**
TOTAL, NATIONAL SCIENCE FOUNDATION	**$8,150.23**	**$8,278.33**	**$7,741.40**	**-$408.83**	**-5.0%**

[1] Funding amounts below the account level for the FY 2020 Enacted were not available at the time of printing.

[2] Funding for SBIR/STTR includes $5.0 million for SBIR/STTR Operations.

OBJECT CLASSIFICATION
NSF Consolidated Obligations
(Dollars in Millions)

Object Class Code	Standard Title	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
11.1	Full-time permanent	$174	-	$186
11.3	Other than full-time permanent	13	-	15
11.5	Other personnel compensation	3	-	3
11.8	Special personal service payment	43	-	44
	Total personnel compensation	233	-	248
12.1	Civilian personnel benefits	58	-	65
21.0	Travel and transportation of persons	20	-	19
23.1	Rental payments	23	-	26
23.2	Rental payments to others	1	-	-
23.3	Communications, utilities, and miscellaneous charges	2	-	2
25.1	Advisory and assistance services	198	-	196
25.2	Other services	22	-	24
25.3	Purchases of goods and services from Government accounts	213	-	207
25.4	Operation and maintenance of facilities	172	-	172
25.5	Research and development contracts	7	-	6
26.0	Supplies and materials	1	-	1
31.0	Equipment	6	-	2
32.0	Land and Structures	103	-	90
41.0	Grants, subsidies, and contributions	7,092	-	6,684
	Total, Direct obligations [1]	**$8,151**	**-**	**$7,742**

[1] Excludes obligations for mandatory and reimbursable accounts.

REIMBURSABLE ACTIVITY

Reimbursements for the Research and Related Activities Appropriation and the Education and Human Resources Appropriation are realized from other federal agencies that have entered into interagency agreements with the Foundation. NSF enters into agreements (including Memoranda of Understanding) with other U.S. government agencies, as authorized by the NSF Act, 42 U.S.C. 1870 (c), and the Economy Act, 31 U.S.C. 1535, under which NSF assumes some responsibility for activities supported by these agencies. These activities can include jointly funded projects and programs, support of research operations and logistics, and access to NSF supported research facilities.

Reimbursements by Agency

(Dollars in Millions)

DEPARTMENT/AGENCY	FY 2019 Actual
DEFENSE	
Air Force	$8.71
Navy	5.10
Army	5.39
Other DoD (DARPA, NSA & Intelligence)	21.74
Subtotal, DoD	$40.95
Commerce (Including Census, NOAA, & NIST)	8.12
Energy	11.03
Health & Human Services	28.20
Homeland Security	4.12
NASA	8.97
Transportation	3.95
OTHER (less than $500,000)	2.47
TOTAL REIMBURSEMENTS	**$107.81**

Totals may not add due to rounding

Consistent with applicable legislation and GAO decisions, agreements include reimbursement for costs that are incurred in the management and administration of these awards.

EXPLANATION OF FY 2019 CARRYOVER INTO FY 2020 BY ACCOUNT

The National Science Foundation's total unobligated balance of $166.35 million ($63.76 million from Discretionary accounts, including $2.39 million for Incoming Interagency Reimbursable Agreements, and $102.59 million from Mandatory accounts) is described below.

Distribution of FY 2019 Carryover into FY 2020
Discretionary and Mandatory Accounts
(Dollars in Millions)

Discretionary Accounts	Amount
Research and Related Activities	$18.60
Education and Human Resources	5.66
Major Research Equipment and Facilities Construction	38.95
Agency Operations and Award Management	0.15
Office of Inspector General	0.40
Total, Discretionary	**$63.76**

Mandatory Accounts	
H-1B Non-Immigrant Petitioner	77.47
Donations	25.12
Total, Mandatory	**$102.59**

DISCRETIONARY

Within the Research and Related Activities (R&RA) account, $18.60 million (including $2.39 million in reimbursable funds) was carried over into FY 2020.

Directorate for Engineering STTR Phase I and II
- Amount: $4.04 million
- Purpose: Funds will be used on STTR Phase I or Phase II awards.
- Obligation: Anticipated FY 2020 Quarter 2

Directorate for Engineering SBIR Phase I and II
- Amount: $3.77 million
- Purpose: Funds will be used on SBIR Phase I or Phase II awards.
- Obligation: Anticipated FY 2020 Quarter 2

Integrative Activities for STC Program
- Amount: $95,895
- Purpose: These carryover funds will be used for an STC professional development workshop for students involved in the STCs.
- Obligation: Anticipated FY 2020 Quarter 2

Integrative Activities for Convergence Accelerator
- Amount: $2.65 million
- Purpose: These funds will be used to fund initial Convergence Accelerator Phase 2 awards. The Convergence Accelerator teams are working on the technical tracks—AI & Future Jobs

and National Talent Ecosystem—which are based on the Future of Work at the Human-Technology Frontier (FW-HTF) Big Idea. The Phase 2 awards will be determined based on a proposal submission and a Pitch Competition in March 2020. This plan meets the current organizational goals to fund use-inspired convergence research with multi-disciplinary and multi-institutional teams, including industry and other participants.

- Obligation: Anticipated FY 2020 Quarter 3

Integrative Activities for Program Planning and Policy Development

- Amount: $2.65 million
- Purpose: These funds will be used for contracts in Quarters 1-3 of FY 2020: to implement the Committee of Visitors dashboard, automate the productions of the Merit Review Digest, develop the web infrastructure for the online Merit Review Summary, and to analyze administrative data on NSF's merit review process.
- Obligation: Anticipated FY 2020 Quarter 3

Office of Polar Programs

- Amount: $1.90 million
- Purpose: Unobligated balance carried forward for future projects.
- Obligation: Funds were obligated during FY 2020 Quarter 1

National Coordination Office for Networking and Information Technology Research and Development

- Amount: $202,499
- Purpose: Operational funds are needed to continue government procurements and operations (credit card purchases, government travel, mailroom operations, etc.).
- Obligation: Anticipated FY 2020 Quarter 2

National Nanotechnology Coordination Office

- Amount: $33,366
- Purpose: Funding for the National Nanotechnology Coordination Office (NNCO) for the required Quadrennial Review of the National Nanotechnology Initiative, rent for NNCO's new location, and other NNCO operational expenses.
- Obligation: Anticipated FY 2020 Quarter 2

The remaining R&RA carryover of $870,000 consists of funds from throughout the Foundation for projects that were not funded in FY 2019.

Within the <u>Education and Human Resources (EHR)</u> account, $5.66 million was carried over into FY 2020.

Excellence Awards in Science and Engineering

- Amount: $2.32 million
- Purpose: These funds will be used to recognize recipients of the Presidential Awards for Excellence in Mathematics and Science Teaching and recipients of the Presidential Awards for Excellence in Science, Mathematics and Engineering Mentoring.
- Obligation: Funds were obligated during FY 2020 Quarter 1

Robert Noyce Teacher Scholarship Program

- Amount: $3.34 million
- Purpose: Recovered no-year funds will be applied to Noyce future commitments.
- Obligation: Anticipated FY 2020 Quarter 2

Within the Major Research Equipment and Facilities Construction (MREFC) account, $38.95 million was carried over into FY 2020.

Regional Class Research Vessels
- Amount: $35.97 million
- Purpose: Budget contingency funding not obligated in FY 2019.
- Obligation: Anticipated FY 2020 Quarter 3

Vera C. Rubin Observatory
- Amount: $82,943
- Purpose: Budget contingency funding not obligated in FY 2019.
- Obligation: Anticipated FY 2020 Quarter 3

National Ecological Observatory Network
- Amount: $1.35 million
- Purpose: NSF-held management reserve funding not obligated in FY 2019.
- Obligation: Anticipated FY 2020 Quarter 3

Dedicated Construction Oversight
- Amount: $64,155
- Purpose: Budget contingency funding not obligated in FY 2019.
- Obligation: Anticipated FY 2020 Quarter 4

The remaining MREFC carryover of $1.48 million resulted from downward adjustments recovered at the close of FY 2019.

Within the Agency Operations and Award Management (AOAM) account, $146,243 in recovered no-year funds was carried over into FY 2020.

NSF Headquarters Relocation
- Amount: $146,243
- Purpose: Budget contingency funding not obligated in FY 2019.
- Obligation: Anticipated FY 2020 Quarter 4

Within the Office of Inspector General (OIG) two-year account, $400,000 was carried over into FY 2020.

Office of the Inspector General
- Amount: $400,000
- Purpose: Funds are expected to be used to procure financial and forensic audit services. The selection of awards and institutions to be audited will require careful preparation and is subject to changing circumstances and new information that may require additional time to process.
- Obligation: Anticipated FY 2020 Quarter 4

MANDATORY

Within the H-1B account, $77.47 million was carried over into FY 2020.

Innovation Technology Experiences for Students
- Amount: $32.19 million

- Purpose: Since NSF receives the largest payments of H-1B visa fees in August and September, there was insufficient time to obligate the receipts on awards before the end of the fiscal year.
- Obligation: Anticipated FY 2020 Quarter 2

Scholarships in Science, Technology, Engineering, and Mathematics
- Amount: $45.28 million
- Purpose: Since NSF receives the largest payments of H-1B visa fees in August and September, there was insufficient time to obligate the receipts on awards before the end of the fiscal year.
- Obligation: Anticipated FY 2020 Quarter 2

Within the Donations account, $25.12 million was carried over into FY 2020. Donations are received from foreign governments, organizations, and individuals to fund various cooperative efforts in science, research, and education.

EXPLANATION OF VARIANCE OF FY 2019 ACTUALS AND FY 2019 ENACTED

Explanation of Variance of FY 2019 Actuals and FY 2019 Enacted

(Dollars in Millions)

	FY 2019 Enacted Level	FY 2019 Actuals	FY 2019 Actuals change over FY 2019 Enacted: Amount	FY 2019 Actuals change over FY 2019 Enacted: Percent	Explanation of Variance: FY 2019 Actuals vs. FY 2019 Enacted: Appropriation Transfer (Net)	Obligations From Prior Year Appropriations	Recoveries and Other Adjustments	Unobligated Funds Carried Over to FY 2020
Research and Related Activities	$6,520.00	$6,578.14	$58.14	0.9%	-$15.49	$56.14	$33.70	-$16.21
Education and Human Resources	910.00	934.53	24.53	2.7%	12.00	14.85	3.34	-5.66
Major Research Equipment and Facilities Construction	295.74	285.27	-10.47	-3.5%	-	-	28.49	-38.95
Award Management and Agency Operations	329.54	332.69	3.15	1.0%	3.49	0.05	-0.24	-0.15
Office of Inspector General	15.35	15.27	-0.08	-0.5%	-	0.39	-0.07	-0.40
Office of the National Science Board	4.37	4.32	-0.05	-1.1%	-	-	-0.05	-
Total, National Science Foundation	**$8,075.00**	**$8,150.23**	**$75.23**	**0.9%**	**-**	**$71.44**	**$65.16**	**-$61.37**

Totals exclude reimbursable obligations

In the FY 2021 NSF Budget Request, the amounts shown in the column labeled FY 2019 Actuals represent the actual obligations that occurred in FY 2019. These amounts include the obligation of prior year appropriations and other adjustments, and are therefore different from the FY 2019 Enacted Level. The sources of the variation are:

- Transfer of funds across appropriation accounts.
- Obligations (of carryover) from prior year appropriations.
- Recoveries and other adjustments.
- Unobligated funds carried over to the next year.

Most activities in the R&RA and EHR accounts have two-year funding, so the carry over and the recoveries are associated with the FY 2018 appropriation. Funding for Polar Programs, Robert Noyce Teacher Scholarship Program, and Major Research Equipment and Facilities Construction activities have no-year funding, so additional obligations in FY 2019 could also be associated with earlier years.

QUANTITATIVE DATA TABLE

NATIONAL SCIENCE FOUNDATION
Research and Development Special Analysis
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
Investment Activities			
Conduct of Research and Development			
Basic Research	$5,212.09	-	$5,017.70
Applied Research	784.05	-	786.66
Subtotal, Conduct of R&D	5,996.14	-	5,804.36
Physical Assets			
Research and Development Facilities	298.93	-	242.47
Research and Development Major Equipment	353.21	-	280.05
Subtotal, R&D Facilities & Major Equipment	652.14	-	522.52
Total, Research and Development	6,648.28	-	6,326.88
Conduct of Education and Training	731.85	-	680.13
Non-Investment Activities	770.10	-	734.39
TOTAL	$8,150.23	$8,278.33	$7,741.40

QUANTITATIVE DATA TABLE

RESEARCH AND RELATED ACTIVITIES
Research and Development Special Analysis
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
Investment Activities			
Conduct of Research and Development			
Basic Research	$5,051.14	-	$4,850.70
Applied Research	478.31	-	468.83
Subtotal, Conduct of R&D	5,529.45	-	5,319.53
Physical Assets			
Research and Development Facilities	13.66	-	12.72
Research and Development Major Equipment	352.99	-	280.05
Subtotal, R&D Facilities & Major Equipment	366.65	-	292.77
Total, Research and Development	5,896.10	-	5,612.30
Conduct of Education and Training	305.22	-	264.03
Non-Investment Activities	376.82	-	336.69
TOTAL	$6,578.14	$6,737.20	$6,213.02

QUANTITATIVE DATA TABLE

EDUCATION AND HUMAN RESOURCES
Research and Development Special Analysis
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
Investment Activities			
Conduct of Research and Development			
Basic Research	$160.95	-	$167.00
Applied Research	305.73	-	317.83
Subtotal, Conduct of R&D	466.68	-	484.83
Physical Assets			
Research and Development Facilities	-	-	-
Research and Development Major Equipment	0.22	-	-
Subtotal, R&D Facilities & Major Equipment	0.22	-	-
Total, Research and Development	466.90	-	484.83
Conduct of Education and Training	426.63	-	416.10
Non-Investment Activities	41.00	-	30.00
TOTAL	$934.53	$940.00	$930.93

QUANTITATIVE DATA TABLE

MAJOR RESEARCH EQUIPMENT AND FACILITIES CONSTRUCTION
Research and Development Special Analysis
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
Investment Activities			
Conduct of Research and Development			
Basic Research	-	-	-
Applied Research	-	-	-
Subtotal, Conduct of R&D	-	-	-
Physical Assets			
Research and Development Facilities	$285.27	-	$229.75
Research and Development Major Equipment	-	-	-
Subtotal, R&D Facilities & Major Equipment	285.27	-	229.75
Total, Research and Development	285.27	-	229.75
Conduct of Education and Training	-	-	-
Non-Investment Activities	-	-	-
TOTAL	$285.27	$243.23	$229.75

QUANTITATIVE DATA TABLE

AGENCY OPERATIONS AND AWARD MANAGEMENT
Research and Development Special Analysis
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
Investment Activities			
Conduct of Research and Development			
Basic Research	-	-	-
Applied Research	-	-	-
Subtotal, Conduct of R&D	-	-	-
Physical Assets			
Research and Development Facilities	-	-	-
Research and Development Major Equipment	-	-	-
Subtotal, R&D Facilities & Major Equipment	-	-	-
Total, Research and Development	-	-	-
Conduct of Education and Training	-	-	-
Non-Investment Activities	$332.69	-	$345.64
TOTAL	$332.69	$336.90	$345.64

QUANTITATIVE DATA TABLE

OFFICE OF INSPECTOR GENERAL
Research and Development Special Analysis
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
Investment Activities			
Conduct of Research and Development			
Basic Research	-	-	-
Applied Research	-	-	-
Subtotal, Conduct of R&D	-	-	-
Physical Assets			
Research and Development Facilities	-	-	-
Research and Development Major Equipment	-	-	-
Subtotal, R&D Facilities & Major Equipment	-	-	-
Total, Research and Development	-	-	-
Conduct of Education and Training	-	-	-
Non-Investment Activities	$15.28	-	$17.85
TOTAL	$15.28	$16.50	$17.85

QUANTITATIVE DATA TABLE

NATIONAL SCIENCE BOARD
Research and Development Special Analysis
(Dollars in Millions)

	FY 2019 Actual	FY 2020 (TBD)	FY 2021 Request
Investment Activities			
Conduct of Research and Development			
Basic Research	-	-	-
Applied Research	-	-	-
Subtotal, Conduct of R&D	-	-	-
Physical Assets			
Research and Development Facilities	-	-	-
Research and Development Major Equipment	-	-	-
Subtotal, R&D Facilities & Major Equipment	-	-	-
Total, Research and Development	-	-	-
Conduct of Education and Training	-	-	-
Non-Investment Activities	$4.32	-	$4.21
TOTAL	$4.32	$4.50	$4.21