NATIONAL SCIENCE FOUNDATION

FY 2023 Budget Request to Congress

March 28, 2022

NOTES

Table and Figure Notes

Numbers in the tables and figures may not sum to totals due to rounding.

Common Acronyms Used in NSF's Budget Submission

Appropriation Accounts
- AOAM - Agency Operations and Award Management
- EDU - STEM Education (formerly 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
- EDU - Directorate for STEM Education (formerly EHR - Dir. for Education and Human Resources)
- GEO - Directorate for Geosciences
- MPS - Directorate for Mathematical and Physical Sciences
- SBE - Directorate for Social, Behavioral, and Economic Sciences
- TIP - Directorate for Technology, Innovation, and Partnerships
- 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]

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

NSF Big Ideas

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
- URoL - Understanding the Rules of Life: Predicting Phenotype
- WoU - Windows on the Universe: The Era of Multi-messenger Astrophysics

Notes

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

Other Frequently Used Acronyms

- STEM - science, technology, engineering, and mathematics
- R&D - research and development
- O&M - operations and maintenance
- AI - artificial intelligence
- MSI – minority-serving institutions

NSF FY 2023 BUDGET REQUEST TO CONGRESS
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NSF FY 2023 Budget Request to Congress

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…"***

The National Science Foundation's FY 2023 Budget Request of $10.492 billion supports research across all fields of science, technology, engineering, and mathematics, and all levels of science, technology, engineering, and mathematics (STEM) education. NSF investments support the economic and national security interests of the Nation and development of a science and engineering workforce that draws on the talents of all Americans.

Over the past seven decades, NSF has funded research and researchers, innovations and innovators, and infrastructure that have garnered incredible benefits to the nation. The Internet, Google, Qualcomm, 3D printing, the economic theory underpinning spectrum auctioning and kidney exchanges, and even the polymerase chain reaction (PCR) testing technique that has been critical in the fight against COVID-19 have been supported by NSF investments. Many of the technologies and industries that are the focus of national conversations around competitiveness today, including artificial intelligence, quantum information science, advanced manufacturing, advanced wireless, and biotechnology, to name a few, are rooted in sustained NSF support for research at the frontiers of science and engineering.

As NSF looks to the future, the agency intends to strengthen at speed and scale its capacity to continue to produce breakthroughs, to innovate, to identify new industries, to accelerate the translation of research results to practice, and to cultivate the diverse workforce needed to power our country forward. NSF has the know-how and energy to help create a brighter future for our Nation. The NSF Director's vision expressed in **three pillars** that point to opportunities that we must seize:

1. **Strengthening Established NSF**
   For more than 70 years, NSF has been making investments that expand the frontiers of knowledge and technology. This will continue to be our central focus: to accelerate discovery and enhance state of the art research capabilities

2. **Bringing the "Missing Millions" into the STEM Workforce**
   The National Science Board (NSB) in its *Vision 2030*[1] report states, "Faster progress in increasing diversity is needed to reduce a significant talent gap" and they name that talent gap the "Missing Millions." NSB estimates that, for the S&E workforce to be representative of the U.S. population in FY 2030, the number of women in STEM must nearly double from the number in the 2020 U.S. S&E workforce, the number of Black or African Americans must more than double, and the number of Hispanic or Latinos must triple. These estimates are based on projections from the U.S. Census and Bureau of Labor Statistics, together with data from the National Center for Science

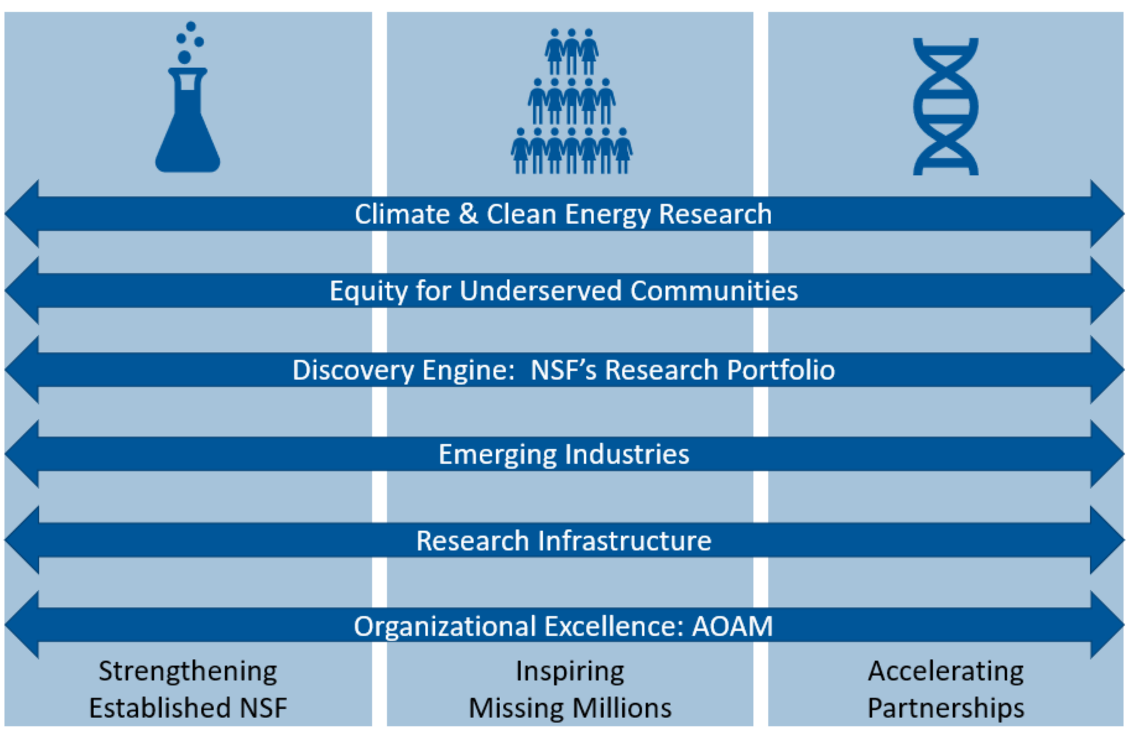
[1] www.nsf.gov/nsb/publications/2020/nsb202015.pdf

and Engineering Statistics (NCSES).

There is tremendous untapped STEM potential throughout the Nation. Every demographic and socioeconomic group in every geographic region of the country has talented people who can participate in STEM and contribute to the innovation enterprise. We plan to scale up existing pathways into STEM fields and create new tracks. NSF's commitment to finding talent provides opportunities that lead to a well-paid workforce and a vibrant U.S. economy.

3. **Accelerating Partnerships**
   Global competition for leadership and talent in science, engineering and technology is at an all-time high, inspiring and motivating us to accelerate our progress to be in the vanguard of discovery and innovation. For the U.S. to remain a global leader, we must continue to invest in breakthrough technologies and innovation, fostering partnerships, and nurturing talent, thereby encouraging the innovation that has been the source of our leadership over the past seven decades. To this end, NSF will accelerate its practices of not only pursuing direct partnerships with other agencies, private industry, philanthropy, and like-minded countries, but also fostering environments where partnerships thrive, thereby leveraging resources and delivering results.

These three pillars cross six themes in NSF's FY 2023 Budget Request — **Climate and Clean Energy Research, Equity for Underserved Communities, Discovery Engine, Emerging Industries, Research Infrastructure, and Organizational Excellence/Agency Operations and Award Management** — and align with the Administration's priorities of responding to the pandemic, tackling climate change, spurring economic recovery, innovating for equity, and ensuring national security & economic resilience. The themes, expanded upon below, appear repeatedly in the broad portfolio of fundamental research that is the heart of NSF's mission. They animate new efforts and connect existing efforts throughout the research portfolio. Most importantly, they point to opportunities NSF must seize.



STRATEGIC THEMES FOR FY 2023

NSF's six themes support the Administration's priorities and give shape to the organizing principles for the Fiscal Year 2023 discretionary budget request. These themes are:

Climate & Clean Energy

Accelerating climate research, understanding impacts of climate change, and developing solutions requires bold thinking, convergent approaches, and an overarching commitment to environmental equity, justice, and education. Action must be taken with urgency to advance knowledge, empower communities, and generate innovative technological solutions. Through FY 2023 investments, NSF will support a focus on taking aggressive action to tackle climate change and meet the urgent demands of the climate crisis while addressing the threat that the climate crisis poses to our economy. Of the total invested, focal areas include:

- **Clean Energy Technology (CET)** ($500.0 million) and NSF's clean-energy investments in high-risk, high-reward ideas from researchers across the science and engineering spectrum create broad new understanding and innovations that may increase energy efficiency, enhance sustainability, mitigate climate change, or lead to other societal benefits. NSF's investments in integrated clean energy research and education span longstanding programs as well as focused new solicitations and will continue to advance the fundamental science and engineering underlying clean energy technologies and infrastructure to continue to decrease energy prices and build our domestic supply chain. NSF also will support multidisciplinary research in areas such as affordable green housing and sustainable systems for clean water, clean transit, and other infrastructure.

- **U.S. Global Change Research Program (USGCRP)** ($913.40 million) continues to support research that contributes to the USGCRP goals 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 2023, NSF will continue to engage with other USGCRP agencies on priorities from intra-seasonal to centennial predictability, predictions, and projections; water cycle research; impacts of climate change on the nation's critical ecosystems, including coastal, freshwater, agricultural and forests systems; 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 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.

In FY 2023, NSF will enhance its investment in **greenhouse gas (GHG) research**, where NSF-funded projects will examine GHG flux measurements, study the coupled climate and dynamics of short-lived local pollutants and long-lived GHGs, and build understanding of methane production. NSF will also develop the **National Discovery Cloud (NDC) for Climate**, a new resource that will federate advanced compute, data, software and networking resources, democratizing access to a cyberinfrastructure ecosystem that is increasingly necessary to further climate-related S&E.

Equity for Underserved Communities

NSF is strongly committed to the development of a future-focused science and engineering workforce that draws on the talents of all Americans, wherever they are found. Increasing equity in underserved communities must cover a wide set of stakeholders, from individuals traditionally identified as underrepresented or underserved, to institutions of higher education that serve groups underrepresented in STEM, to those communities, lands and jurisdictions across the country that currently lack resources and opportunities for robust education, workforce development, and regional innovation.

In FY 2023, NSF intends to build on existing programs and develop new ones to strengthen and scale equity investments. For individuals, NSF will focus on groups that are underserved and underrepresented in STEM, but especially those who are extremely underrepresented in STEM (those with low presence and/or low visibility in NSF programs) as well as the relevant intersections or configurations of gender, race, ethnicity, and geographical location that comprise identity. For institutions, NSF will be more intentional in how we engage Minority Serving Institutions (MSIs) in our programs, starting with those classified as MSIs, but also focusing on the importance of MSI-bridge programs (funding open to all institutions that encourage participation by MSIs). For jurisdictions, NSF will expand support for individuals and institutions in EPSCoR jurisdictions to ensure geographic diversity.

NSF's commitment to finding talent provides opportunities that build strong STEM pathways that lead to a well-paid workforce and support the U.S. economy. To that end, the following programs are increased in the FY 2023 Budget Request to Congress.

- **Growing Research Access for Nationally Transformative Equity and Diversity (GRANTED)** ($50.0 million) is a new initiative that will improve the Nation's research support and service capacity at emerging and underserved research institutions. GRANTED will use a variety of mechanisms and programs to further NSF's reach in advancing the geography of innovation and engaging the Missing Millions. GRANTED activities will support the enhancement of research administration and post-award management as well as the implementation of effective practices for competitive proposal development, through mechanisms such as research-coordination networks (RCNs) and institutional partnership grants, ideas labs, and research enterprise hubs in different geographic regions. GRANTED funding in FY 2023 will focus on support for minority-serving institutions and aim to mitigate the barriers to competitiveness at underserved institutions within the Nation's research enterprise as NSF contributes to the Administration's priority on equity.

- **Alliances for Graduate Education and the Professoriate (AGEP)** ($14.0 million) program aims to increase the number of African American, Hispanic American, Native American Indian, Alaska Native, Native Hawaiian and Native Pacific Islander (or AGEP population) faculty in STEM at all types of institutions of higher education. The program funds projects that increase the understanding of institutional policies and practices to help doctoral candidates, postdoctoral scholars, and faculty improve their academic pathways to tenure and promotion in the STEM professoriate.

- **Centers of Research Excellence in Science and Technology (CREST)** ($41.0 million) enhance the research capabilities of minority-serving institutions (MSI) through the establishment of centers that effectively integrate education and research. CREST promotes the development of new knowledge, enhancements of the research productivity of individual faculty, and an expanded presence of students historically underrepresented in STEM disciplines.

- The **Hispanic-Serving Institutions Program (HSI)** ($60.50 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.

- **Historically Black Colleges and Universities Excellence in Research (HBCU-EiR)** ($37.93 million) program supports projects that enable STEM and STEM education faculty to further develop research capacity at HBCUs and to conduct research.

- **Historically Black Colleges and Universities Undergraduate Program (HBCU-UP)** ($48.50 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 success of HBCU undergraduates so that they may pursue STEM graduate programs and/or careers.

- The **Louis Stokes Alliances for Minority Participation (LSAMP)** ($70.50 million) is an alliance-based program that works to increase the number of STEM baccalaureate and graduate degrees awarded to populations historically underrepresented in STEM disciplines.

- **NSF INCLUDES** ($50.50 million) is a comprehensive national initiative to enhance U.S. leadership in STEM discoveries and innovations focused on NSF's commitment to diversity, inclusion, and broadening participation in these fields. The vision of NSF INCLUDES is to catalyze the STEM enterprise to work collaboratively for inclusive change, resulting in a STEM workforce that reflects the population of the Nation.

- The **Tribal Colleges and Universities Program (TCUP)** ($23.0 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.

- **Established Program to Stimulate Competitive Research (EPSCoR)** ($247.25 million) 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 and geographic diversity.

<u>Discovery Engine</u>

NSF funds groundbreaking research on vital problems and challenges. These efforts build and strengthen the scientific and societal bedrock upon which the Nation's future success and prosperity depend—both now and for decades to come.

NSF's support for innovative research helps to improve quality of life, enhance national security, and fuel American leadership in a wide range of technological and industrial sectors. NSF starts and fuels dynamic collaborations and supports innovation in all areas of STEM education. NSF creates opportunity and broadens participation in America's science and engineering enterprise. Because NSF does all this and more simultaneously, it can integrate these approaches in its research portfolio to maximize benefits for our Nation where and when it is most needed.

For example, in FY 2023 NSF proposes to launch Global Centers to create an international center-level activity to address grand societal challenges. The program will seek partners from multiple sectors in the U.S. and abroad to leverage financial contributions and capabilities. The proposed activity will bring together interdisciplinary and international research teams to support use-inspired research. In FY 2023, the Global Centers activity is expected to facilitate the education and development of a globally engaged workforce to support the climate and clean energy disciplines.

NSF's research portfolio, through which both research and education opportunities are funded, is the endeavor for which the agency is best known. This research portfolio refers broadly to foundational research whose topics and goals are identified and driven by research communities and individual investigators who directly advance the frontiers of science. Resulting disciplinary or interdisciplinary proposals are submitted to a rigorous peer-review process through which NSF identifies and supports groundbreaking research concepts that are then implemented by tens of thousands of students and researchers in over 2,000 research institutions.

This budget strengthens established NSF programs. In FY 2023, NSF expects to

- Evaluate almost 50,000 proposals through the competitive merit review process and make approximately 13,500 **new competitive awards**, of which 11,500 are expected to be new research grants.

- Expand support for **fellowship programs.** Some of this increase will support activities dedicated to promoting equity in underserved communities. Touching all NSF directorates, this funding will invest in programs across the agency, such as Research and Monitoring for Postbaccalaureates in Biological Sciences (RaMP), Entrepreneurial Fellows, Atmospheric and Geospace Sciences Postdoctoral Research Fellowships (AGS-PRF), and MPS-ASCEND External Mentoring. In addition to the Discovery Engine theme, this funding includes, but is not limited to, support for the goals described in the Equity theme above.

- Fund 2,750 new **Graduate Research Fellowship Program** (GRFP) fellows and increase the GRFP stipend by $3,000 to $37,000 per year.

Emerging Industries for U.S. Competitiveness

As the U.S. faces intensifying global competition for science and technology leadership, NSF is ready to strengthen and scale investments in breakthrough technologies, innovation, and translation. A foundation of NSF's investment in Emerging Industries is also a focus on nurturing diverse talent. Building on NSF's deep relationships with over 2,000 of America's leading research institutions, we plan to harness the innovative spirit that exists in all corners of our country, which offers the potential for sustained leadership, and we must prepare a broader spectrum of students to be able to pursue the jobs of the future.

The President's Fiscal Year 2023 discretionary request advances the frontiers of research into the future by focusing on the translation of research to the marketplace and making targeted investments in new industries.

- **The Directorate for Technology, Innovation, and Partnerships (TIP)** ($879.87 million), in close collaboration with all of NSF's directorates and offices, advances emerging technologies to address societal and economic challenges and opportunities; accelerates the translation of research results from the lab to market and society; and cultivates new education pathways leading to a diverse and skilled future technical workforce comprising researchers, practitioners, technicians, and entrepreneurs. Building on NSF's longstanding leadership in science and engineering research and education, TIP serves as a crosscutting platform that leverages, energizes, and rapidly advances use-inspired research and innovation. Further, TIP opens new possibilities for research and education by catalyzing strategic partnerships that link academia; industry, including startups and small businesses; federal, state, local, and tribal governments; nonprofits and philanthropic organizations; civil society; and communities of practice to cultivate 21st-century innovation ecosystems that give rise to future jobs and enhance the Nation's long-term competitiveness.

- **Advanced Manufacturing** ($421.51 million). Manufacturing is essential to almost every sector of the U.S. economy, spurring it forward 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 advances in manufacturing materials, technologies, and systems through fundamental, multidisciplinary research that transforms manufacturing capabilities, methods, and practices. In FY 2023, NSF will continue investments in 1) future manufacturing that does not exist or is not possible today, or exists but is not yet viable for mass production; 2) workforce development through such programs as Advanced Technological Education, Faculty Early Career Development Program (CAREER), Engineering Research Initiation, Grant Opportunities for Academic Liaison with Industry, Sites and Supplements for both Research Experiences for Undergraduates and Research Experiences for Teachers programs, as well as in manufacturing engineering education in research projects; and 3) translation to practice that speeds the translation of fundamental discoveries into products and processes through its Engineering Research Centers, Industry-University Cooperative Research Centers, as well as the NSF Lab-to-Market Platform and other activities in TIP.

- **Advanced Wireless** ($168.56 million) networks and systems provide the backbone that connects users, devices, applications, and services that will continue to enrich America's economy. NSF has a proven track record of investing in fundamental research on wireless technologies. For example, today's fifth-generation ("5G") wireless networks and systems have been enabled by ground-breaking NSF-funded research on millimeter-wave capabilities, advanced antenna systems, and other novel algorithms and protocols dating back to 2004. NSF partners with other federal agencies and industry on such research. Looking forward to FY 2023 and beyond, NSF-supported research will innovate in areas critical to future generations of wireless networks and systems, such as new wireless devices, circuits, protocols, and systems; security and resilience; mobile edge computing; distributed machine learning, and inferences across mobile devices; and fine-grained and real-time dynamic spectrum allocation and sharing. This research will offer new insights capable of making wireless communication faster, smarter, more affordable, and more robust and secure—with profound implications for science and society.

- **Artificial Intelligence** ($734.41 million) is advancing rapidly and holds the potential to vastly transform our lives. NSF-funded research is now laying the seeds for advances in AI that will transform essentially every area of human endeavor, including science, education, energy, manufacturing, and agriculture. NSF's ability to bring together numerous fields of scientific inquiry uniquely positions the agency to lead the Nation in expanding the frontiers of AI. Additionally, 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. In FY 2023, NSF's AI investments include continued support for the National AI Research Institutes program to create national hubs for universities, federal and local agencies, industry, and nonprofit to advance AI research and workforce development. NSF's AI investments also support foundational research through directorate-level programs, and education and workforce development through efforts such as the CyberCorps®: Scholarship for Service (SFS), Computer Science for All, Innovative Technology Experiences for Students and Teachers programs, and the Data Science Corps programs.

- **Biotechnology** ($392.26 million) comprises the data, tools, research infrastructure, workforce capacity, and innovation that enable the discovery, use, and alteration of living organisms, their constituent components, and their biologically related processes. NSF has long supported the breadth of fundamental research that catalyzes the development of biotechnology. In FY 2023, NSF investments will include continued support for discovery of fundamental biological principles and the development of biotechnologies and other tools that permit measurement and use-inspired manipulation and design of living systems and their components; investments in bioinformatics, computational biology and artificial intelligence to support biotechnology; sustained support for synthetic and engineering biology to accelerate the design-build-test-learn cycle and leverage bio-inspired design to develop bio-machines, bio-based robots, and biomanufacturing technologies to address many of today's challenges; and investment in the biotech workforce through such programs as the Advanced Technological Education program at two-year institutions, sites and supplements for Research Experiences for Undergraduates and Research Experiences for Teachers, and the NSF Research Traineeship Program that prepares graduate students to conduct research in convergent areas and acquire skills that allow them to succeed in diverse employment settings.

- **Microelectronics and Semiconductors** ($145.69 million) are omnipresent in today's world, in transportation, communications, healthcare, manufacturing, and information technology. Yet, U.S.-led innovations in this area have slowed in recent decades, and the Nation is now facing historically unprecedented global competition. The overarching objective of NSF's investment in microelectronics and semiconductors is to develop new paradigms in semiconductor capabilities. Ongoing activities and new, complementary opportunities will leverage and create advances in materials, devices, circuits, architectures, and related software and applications. In FY 2023, NSF will invest in foundational research, both individual investigator projects and multidisciplinary teams; in use-inspired research to investigate new methods for device integration; in partnerships and infrastructure such as NSF Quantum Foundries; and in workforce development through programs such as CAREER, Research Experiences for Teachers, Non-Academic Research Internships for Graduate Students and NSF Innovation Corps (I-Corps™).

- **Quantum Information Science (QIS)** ($261.0 million) research 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 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 three 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 National Quantum Initiative (NQI) and address the Administration's focus on helping build new industries. In FY 2023, NSF will invest in foundational quantum science advances, helping mature a relatively new field; in quantum computing, supporting investigators as they explore alternate quantum computing architectures; in cross-disciplinary teams of engineers, mathematicians, and physical scientists to explore emerging quantum network systems; in quantum sensing and metrology; and, through the Convergence Accelerator, in future applications that promote the rapid translation of basic quantum knowledge into the private sector.

Research Infrastructure

Research infrastructure (RI), from the scale of individual laboratories all the way up to major multi-user research facilities, is at the heart of the scientific endeavor. Definitions of RI have evolved significantly over the years as remote access and cyberinfrastructure have increasingly become critical parts of almost every tool in use by the research community. These attributes have become even more essential during the COVID-19 pandemic and are essential components of efforts to expand access to traditionally underserved groups and communities. Likewise, NSF investments in science and engineering have transformed discovery and innovation, giving rise to new and different forms of RI.

The Nation's science and engineering activities rely on instrumentation that is geographically and technically accessible, cost effective, and managed well. To meet the infrastructure needs of the entire community, NSF is dedicated to supporting activities that ensure that instrumentation and infrastructure can be designed, developed, acquired, or constructed across the Nation, through programs with focused oversight and investments. Moreover, a sizeable portion of NSF's resources is invested in the ongoing operations and maintenance (O&M) activities necessary to keep research infrastructure at the cutting edge, and available and accessible to those who use it to advance the boundaries of science.

The FY 2023 facilities O&M request continues to reflect a balance among multiple priorities. NSF divisions carefully allocate resources between research grants and O&M costs for research infrastructure. In addition to regular O&M needs to keep a facility functional, support for upgrades, significant periodic maintenance, and infrastructure renewal must also be addressed within Facilities O&M, which accounts for 10 percent of NSF's total request in FY 2023. NSF continues to explore ways to invest in research infrastructure, at all scales, to keep pace with changing technologies, increased demand by users, and expanding research opportunities.

The **Major Research Instrumentation (MRI)** program is responsible for catalyzing new knowledge and discoveries by helping STEM professionals acquire or develop the enabling instrumentation needed at their institutions. MRI grants support instrumentation in all NSF-supported research disciplines. MRI makes awards of up to $4.0 million, for projects with total costs (including matching funding) as high as $6.0 million.

The American Innovation and Competitiveness Act (AICA) enacted in 2017, 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 **Major Research Equipment and Facilities Construction (MREFC)** threshold. NSF responded by introducing the **Mid-scale Research Infrastructure (Mid-scale RI)** program as one of NSF's Big Ideas. This dedicated funding line implements a high-priority, agency-wide mechanism that includes upgrades to major facilities as well as stand-alone projects.

The goals of the Mid-Scale RI program are to:

- Provide access to cutting-edge mid-scale research infrastructure, including instrumentation.
- Enable agile development and implementation of frontier scientific and engineering research infrastructure with a high potential to significantly advance the Nation's research capabilities.
- Train early-career scientists and engineers in the development and use of advanced research infrastructure.

In FY 2023, NSF will invest a total of $126.25 million in Mid-scale RI, split between two tracks, Mid-scale RI-1 ($50.0 million), funded through the Research & Related Activities account, and Mid-scale RI-2 ($76.25 million), funded through the MREFC account. Both use a biennial funding opportunity; the second solicitations for Mid-scale RI-1 (NSF-21-5055) and Mid-scale RI-2 (NSF-21-5376) were issued in FY 2021. Subject to availability of funding in FY 2023, Mid-scale RI-1 will support projects from the FY 2022 competition.

In FY 2021, NSF divested its four LC-130H aircraft used in South Pole support to the U.S. Air Force to improve the efficiency of their operational support. The first science support season under this new arrangement was successfully completed in February 2022. The aircraft will continue to be operated by the New York Air National Guard under the existing Memorandum of Agreement with the Department of Defense without any loss of continuity.

NSF Responsiveness to COVID-19 Impacts on Operating Facilities

Many operating facilities continued to experience impacts from COVID-19 in FY 2022, primarily the loss of science caused by having to suspend or reduce operations due to the pandemic; this loss of science does not generally result in NSF costs beyond the appropriated dollars except in a few cases. Additional NSF costs are being incurred by several major multi-user facilities due to quarantine, testing and COVID-19-mitigation protocols, and by Antarctic Facility Operations because of the extensive quarantine and transportation procedures required to assure that COVID-19 is not carried to the U.S. Antarctic facilities.

Major Research Equipment and Facilities Construction

Construction projects that require an investment of more than $100 million are supported in NSF's MREFC account. The FY 2023 Budget Request includes funding for four construction projects—the Antarctic Infrastructure Recapitalization program (formerly Antarctic Infrastructure Modernization for Science or AIMS), the two detector upgrades to operate at the High Luminosity-Large Hadron Collider

Upgrade (HL-LHC), the Vera C. Rubin Observatory, and the Regional Class Research Vessels (RCRV)—as well as Mid-scale RI-2, covering projects in the $20 million to $100 million range.

MREFC Account Funding, by Project

(Dollars in Millions)

	FY 2021 Actual	FY 2021 ARP Actual	FY 2022[1] Request	FY 2023 Request
Antarctic Infrastructure Recapitalization	$3.86	-	$90.00	$60.00
DKIST	9.38	8.95	-	-
HL-LHC Upgrade	28.74	-	36.00	33.00
Mid-scale Research Infrastructure	74.04	-	76.25	76.25
RCRV[2]	10.98	-	5.00	1.98
Vera C. Rubin Observatory	34.09	-	40.75	15.00
Dedicated Construction Oversight	0.17	-	1.00	1.00
Total	**$161.27**	**$8.95**	**$249.00**	**$187.23**

[1] A total of $260.21 million was carried forward from FY 2021 into FY 2022: $73.68 million for Mid-scale RI including $6.45 million in ARP funding, $115.84 million for AIMS, $14.05 million in ARP funding for RCRV, $46.74 million for the Rubin Observatory including $30.0 million in ARP funding, $553,350 in ARP funding for DKIST, $4.26 million for LHC, and $830,000 for Dedicated Construction Oversight.

[2] FY 2022 Request excludes $25.0 million in one-time funding for necessary expenses related to RCRV construction impacted by Hurricane Ida as provided in P.L. 117-43, the "Extending Government Funding and Delivering Emergency Assistance Act."

The COVID-19 pandemic constitutes an unforeseen event that was not within the control of the recipients managing the ongoing major facility construction projects. NSF has policies for responding to these unforeseen events that were established in advance of the COVID-19 pandemic, which subsequently have been further refined to support the current situation. As appropriate, re-baselining of several projects has taken place in FY 2021 and FY 2022, as the cost and schedule impacts of COVID-19 become better known for FY 2023 and beyond.

NSF manages all U.S. Antarctic activities as a single, integrated program, making Antarctic research possible for scientists supported by NSF and other U.S. agencies. Impacts of the COVID-19 pandemic on U.S. Antarctic Program (USAP) operations required construction activities at McMurdo Station to be suspended and caused a significant delay to overall AIMS completion. In the meantime, other investments in facilities and infrastructure on the continent have emerged as priorities that cannot be deferred until after completion of AIMS. As a result, the **Antarctic Infrastructure Recapitalization** (AIR) program was conceived as a portfolio of investments in infrastructure across the USAP stations that will subsume AIMS. On-ice AIMS construction will continue in FY 2023 with a focus on meeting near-term needs, and unfunded parts of AIMS will be considered for incorporation into the longer-term AIR program. Some FY 2023 funding ($60.0 million) will be used to fund adjusted AIMS scope, if necessary, and the remainder to transition to a broader recapitalization of NSF's Antarctic infrastructure.

The Large Hadron Collider is the world's largest and highest energy particle accelerator. Located near Geneva, Switzerland and operated by the European Organization for Nuclear Research (CERN), 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.

In FY 2023, funding for **HL-LHC Upgrade** ($33.0 million) will support year three of the five-year project that began in FY 2020, prior to the onset of the COVID-19 pandemic. This investment will upgrade components 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. Pandemic impacts are likely to result in future, and not yet quantified, changes to upgrade plans.

The **Regional Class Research Vessels** ($1.98 million) are designed to meet the needs of researchers for work in coastal zones in support of biological, chemical, physical, and geological oceanography. The vessels will be capable of precise station-keeping for water column and sediment sampling, as well as supporting the use of remotely operated and autonomous vehicles. They will also enable virtual participation of shore-based scientists using telepresence/data presence technology, greatly expanding the potential user base. RCRV is the NSF-supported contribution to right-sizing and modernization of the U.S. Academic Research Fleet. The first of three vessels under construction is planned for delivery in 2023, with subsequent vessels being delivered six and twelve months thereafter. The project timeline has been lengthened by the impacts of the COVID-19 pandemic and damage caused by Hurricane Ida.

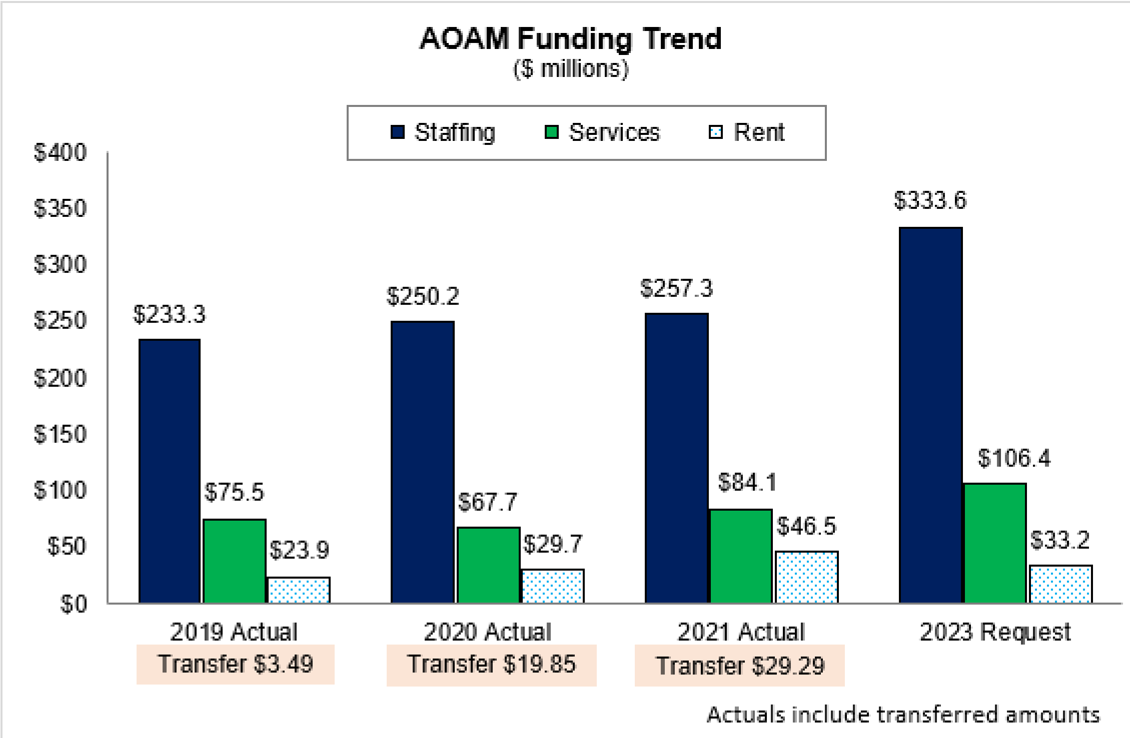
Vera C. Rubin Observatory ($15.0 million) will be an 8-meter-class wide-field optical telescope capable of carrying out surveys of the entire southern sky. It will collect nearly 40 terabytes of multi-color imaging data every night to produce the deepest, widest-field sky image ever. It will also issue alerts for moving and transient objects within 60 seconds of their discovery. FY 2023 will be the tenth year of funding, with project completion expected in FY 2024. Approximately two years of delay has accrued as the result of the COVID-19 pandemic.

<u>Organizational Excellence - Agency Operations and Award Management (AOAM)</u>

The $9.80 billion in research funding that NSF will support in FY 2023 is managed by the staff at NSF who enable research and steward the taxpayer investment. Investments in the Agency Operations and Award Management (AOAM) account provide the fundamental framework through which the Foundation's science and engineering research and education programs are administered. AOAM is the avenue by which NSF directly supports and responds to the Administration's management and performance priorities, including a growing research science and security framework vital to the well-being of the NSF-funded scientific enterprise. AOAM funds the essential services NSF needs to operate, and investments in the AOAM account continue to be an NSF priority.

In FY 2023, NSF requests a total of $473.20 million for AOAM, an increase of $88.68 million or 23 percent above FY 2021 Actuals for the AOAM account. Even with this large increase, NSF continues to operate as a lean agency with AOAM costs representing under 5 percent of NSF's total FY 2023 budget.

In the AOAM account, over three-quarters of the total AOAM funding covers NSF personnel and NSF's headquarters location in Alexandria, VA with the remaining quarter going to mission support services. Over the last several fiscal year budget requests, NSF reduced or held flat mission support services costs to accommodate the year-over-year increases in the fixed costs for staffing and rent while minimizing growth to the AOAM account in the Request. NSF then exercised its transfer authority to restore funding for those reduced activities.



The large increase in AOAM costs in FY 2023 is a course correction aimed at requesting the amount NSF estimates it needs and decreasing the reliance on the transfer authority to cover the full cost of doing business. The requested level also will enable NSF to continue standing up the new Directorate for Technology, Innovation and Partnerships, and to grow agency administration and operations, including additional staffing needs, to effectively and efficiently meet the needs of a $10.49 billion federal research agency. Further, NSF anticipates continuing to move toward a hybrid in-person/remote work environment and requests resources for the additional information technology and training for staff and supervisors necessary to achieve this approach. In addition, NSF requests increases to provide for strategic human capital management and changes at the NSF headquarters building to respond to COVID-19 impacts and the new hybrid work posture, continuing work to establish the effort for Science and Security, a return to a normal travel posture, and NSF-wide implementation of the Program Management Improvement Accountability Act (PMIAA) and other 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), and Foundations for Evidence-Based Policymaking Act of 2018 (Evidence Act).

RESEARCH SECURITY STRATEGY AND POLICY UPDATE

NSF is expanding capabilities and competencies to protect the U.S. science and engineering enterprise through its Research Security Strategy and Policy activity. In January 2022, the National Science and Technology Council issued implementation guidance for National Security Presidential Memorandum 33 (NSPM-33) on National Security Strategy for United States Government-Supported Research and Development. NSF's overall activities respond to the JASON report, "Fundamental Research Security," which was commissioned by NSF and published in December 2019, as well as subsequent legislation passed by Congress. NSF participation in discussions with the U.S. research community and with international colleagues, and development of common frameworks for understanding research security is a major component of the NSF Research Security activity that is expected to continue to grow in FY 2023. NSF is commissioning a JASON study in FY 2022 to provide guidance on the establishment of a Research on Research Security funding program that is expected to begin in FY 2023. Specific activities for FY 2023 include the following:

- NSF is working together with other federal research agencies to establish uniform mechanisms for research investigators to provide agencies with consistent information on their appointments, activities, and sources of financial support; many of these mechanisms will be made available to the community during FY 2023.

- NSF will establish a Research on Research Security funding program in FY 2023 using guidance from a JASON study that will occur in FY 2022. NSF is seeking U.S. federal agency and non-profit organization partners to collaborate on this program. Primary goals of the program will include assessment of the characteristics that distinguish research security from research integrity, improving the quantitative understanding of the scale and scope of research security risks, developing methodologies to assess the potential impact of research security threats, and assessing the additional research security risks in an innovation system that includes more use-inspired research rather than staying well within the bounds of fundamental research.

- NSF has established new analytic capabilities to proactively identify conflicts of commitment, vulnerabilities of pre-publication research, and risks to the merit review system, and has published a System of Records Notice that will enable NSF to begin utilizing those capabilities in FY 2022 and FY 2023.

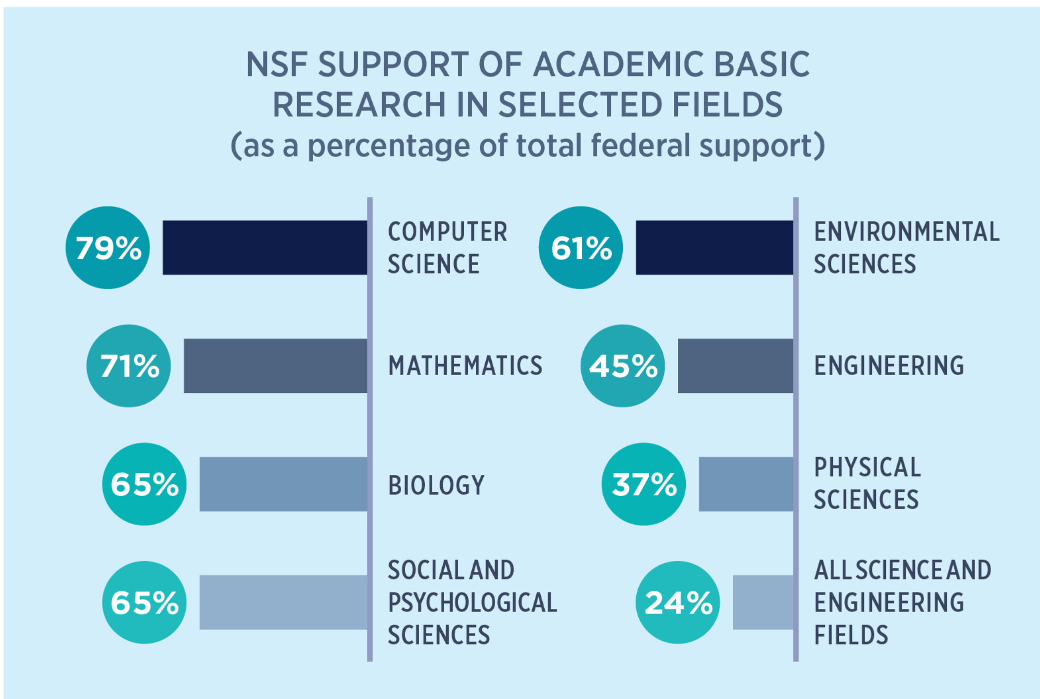
- To ensure clear understanding of research security issues, NSF disclosure requirements, and the tenets of beneficial international collaboration, NSF has developed training resources for staff that will continue to be refined in FY 2023.

- Through a partnership with the federal government interagency community, NSF is issuing a solicitation to develop training resources for the research community, which will be funded in late FY 2022 or early FY 2023.

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 annual budget represents approximately 24 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. In most major fields of science, NSF support of basic research at U.S. institutions is over 50 percent.



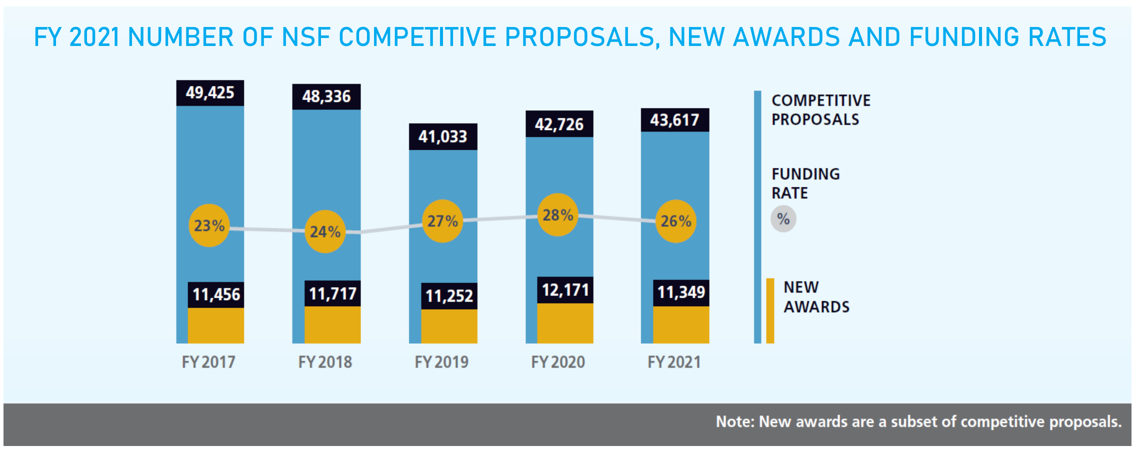
Note: Biology includes Biological Sciences and Environmental Biology. Biology and Psychological Sciences exclude National Institutes of Health.
Source: NSF/National Center for Science and Engineering Statistics, Survey of Federal Funds for Research & Development, FY 2019.

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.

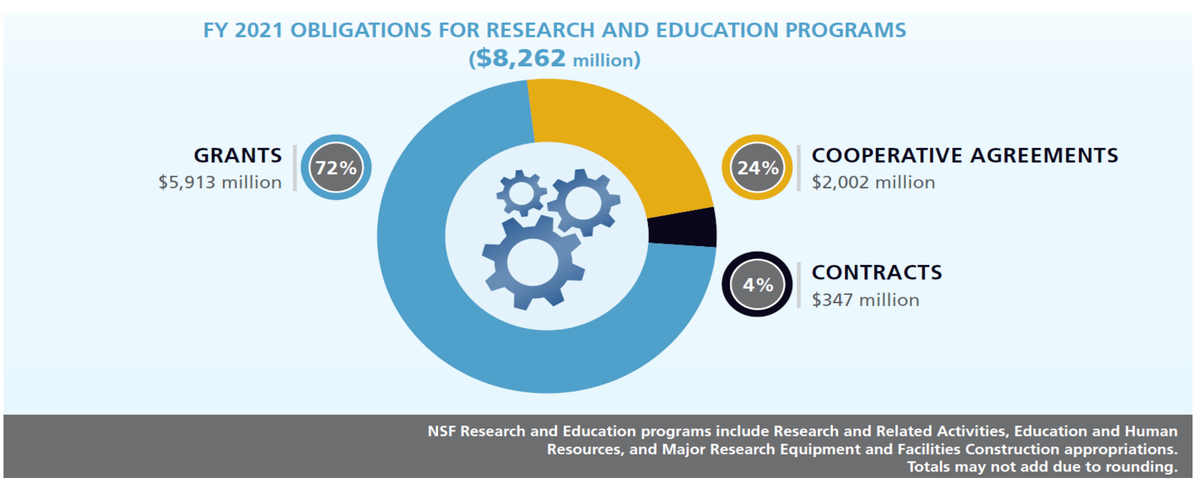
NSF BY THE NUMBERS

In FY 2023, NSF expects to evaluate almost 50,000 proposals through a competitive merit review process and approximately 13,500 new competitive awards, 11,500 of which are expected to be new research grants and the remainder contracts and cooperative agreements

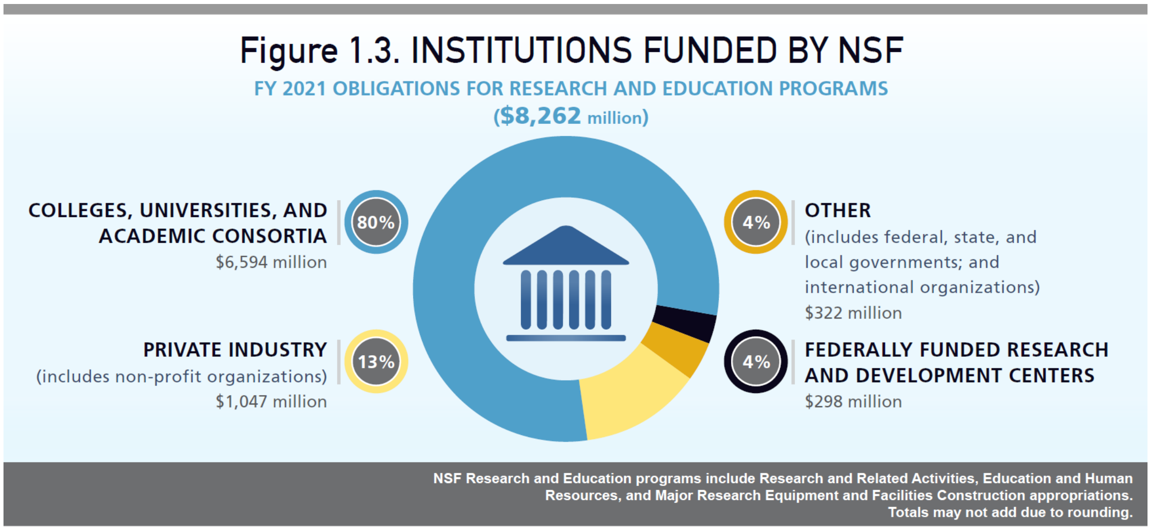
NSF continuously monitors key portfolio, proposal workload, and financial measures to understand short- and long-term trends and to help inform management decisions. The chart below presents a high-level, agency-wide estimate of funding rates, or proposal "success," as a comparison of the number of competitive proposals, new awards, and funding rate between FY 2017 and FY 2021. Estimates for FY 2023 can be found the Summary Tables chapter of this document.



The following two charts show the distribution of NSF's obligations by funding mechanism and institution type. While the data is based on FY 2021, the relative shares in FY 2023 are expected to be similar. As shown below, 96 percent of NSF's FY 2021 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 required primarily for NSF or other government use.



Most NSF awards are to academic institutions. In FY 2021, 80 percent of support for research and education programs ($6,594.0 million) was awarded to 822 different colleges, universities, and academic consortia. Private industry, including small businesses and non-profit organizations, accounted for 13 percent ($1,047.0 million), and support to Federally Funded Research and Development Centers accounted for 4 percent, or $298.0 million. Other recipients (federal, state, and local governments; and international organizations) received 4 percent ($322.0 million) of support for research and education programs.

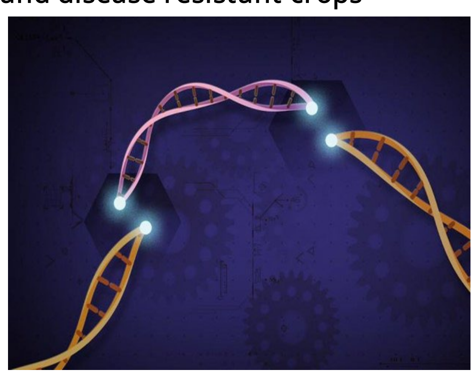


HIGHLIGHTS

For over 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.

New CRISPR technologies enable development of climate and disease resistant crops

Over the past decade, huge leaps forward have been made in CRISPR—the gene editing technology that won the 2020 Nobel Prize in Chemistry. One of the most anticipated applications of CRISPR is the ability to strengthen the food supply by designing crops that are more robust, higher yield, and resistant to pests and climate change. NSF-funded researchers at the University of Maryland have made the next big step toward this goal. They've developed new techniques that not only expand the range of what CRISPR can do in plant genomes, but also allow these tools to operate on multiple parts of the genome simultaneously. By making it possible to imbue crops with multiple beneficial attributes at once, researchers are bringing us closer to a more resilient and sustainable food supply.



Scientists are expanding genome editing and engineering in plants to improve the efficiency of food production. *Credit: National Institutes of Health.*

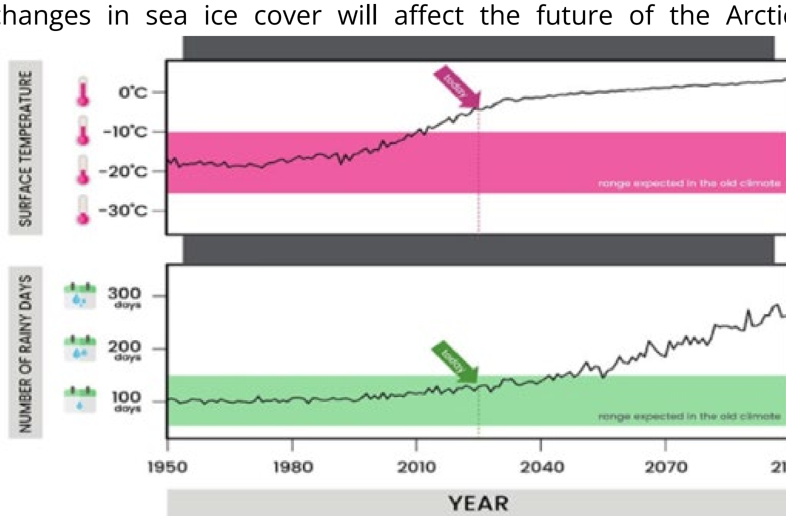
CyberCorps Scholarship for Service: Secure Embedded Systems

From large scale and high-profile ransomware attacks to more pervasive vulnerabilities in consumer technology and online systems, the need to strengthen the nation's cybersecurity workforce only continues to grow. To help accomplish that, Morgan State University (MSU), a Historically Black College and University (HBCU) in Baltimore, Maryland, has launched the Secured Embedded Systems Scholarship Program (SES2). Supported by funding through NSF's CyberCorps® Scholarship for Service and the American Rescue Plan, this is an initiative to recruit, mentor, and financially support cybersecurity students at every level of higher education. The program focuses on connected embedded systems—products that have network technology built in, such as baby monitors, smart cars, and even critical infrastructure like power grids. By focusing on this specific area, and by supporting participants ranging from pre- freshmen through doctorate students, MSU is building the next generation of cybersecurity professionals.

In the SES2 program, MSU students follow an innovative curriculum in secure embedded systems, experience challenging research opportunities, and receive peer and professional mentoring. *Credit: MSU.*

Fast-warming Arctic transitioning to new climate state

The Arctic is experiencing climate change at a rapid and dramatic pace, leading to significant uncertainty about what regional weather patterns will look like in the future. With NSF funding, researchers from the National Center for Atmospheric Research—the Nation's premier research center for meteorology, climate science, and atmospheric research, headquartered in Boulder, CO—are working to understand how changes in sea ice cover will affect the future of the Arctic environment. Sea ice plays a critical role in climate and meteorology by reflecting heat and light, but when light-colored Arctic ice melts, it is replaced by darker ocean water, which absorbs more heat and accelerates the changes taking place. By improving our ability to measure sea ice, researchers are enabling better climate models that will help us navigate the enormous changes in the Arctic and better understand what they mean for the global climate.



The Arctic is transitioning to a new climate state because of rapid warming. *Credit: Simmi Sinha/UCAR.*

Room-Temperature Superconductor

Researchers at the University of Rochester have set a new record in the quest to achieve superconductivity at room temperature. Superconducting materials have special properties—including zero electrical resistance—that could revolutionize technology at every level, from microscopic sensors to high-efficiency batteries to medical imaging and mag-lev trains. But until now, superconductivity has only been achieved at extremely low temperatures that are difficult and expensive to accomplish. Supported by NSF, the researchers squeezed a mixture of hydrogen, sulfur, and carbon to intense pressures to produce a tiny dot of superconducting material at 58 degrees Fahrenheit—the kind of temperatures seen in Rochester, NY in October and much easier to achieve than usual superconducting temperatures of hundreds of degrees below zero.

The goal of new research is to develop room temperature superconducting materials. Currently, extreme cold is required to achieve superconductivity, as demonstrated in this photo in which a magnet floats over a superconductor cooled in liquid nitrogen. *Credit: University of Rochester / Adam Fenster.*

Wireless research for universal and affordable rural broadband

Iowa State University researchers installed hardware to drive innovation in rural broadband connectivity. *Credit: Iowa State University/ Christopher Gannon.*

Iowa State University and the areas surrounding Ames, Iowa are the latest testbed for largescale wireless technology research that is extending the reach of broadband and other communications platforms. Known as the Wireless Living Lab for Smart and Connected Rural Communities, it is an $8 million public-private partnership funded by NSF, the U.S. Department of Agriculture, and an industry consortium that is exploring how cutting-edge communications technology can be deployed to enable highspeed, universal, and affordable rural broadband connectivity. With a special emphasis on agricultural applications in crop and livestock farms, the wireless research platform will be an extensive collaboration between researchers, students, communities, industry partners, and state and local governments, working together to connect the unconnected.

Sitting Bull College's Native American Prairie Ecosystems Research Center (PERC)

NSF's Tribal Colleges and Universities Program (TCUP) is a critical STEM pathway for broadening participation, strengthening science and engineering capabilities, and increasing STEM opportunities in tribal communities. At Sitting Bull College (SBC) in Fort Yates, North Dakota, PERC is leveraging diverse research expertise and local indigenous ecological knowledge to study challenges in prairie ecosystems and help design new solutions and approaches in soil science, water quality, wildlife and plant ecology, microbiology, molecular ecology, and engineering. SBC and PERC are leading the way in North Dakota as the primary center for tribal knowledge about the Great Plains region. PERC leverages the resources and faculty of SBC and local reservation communities to solve issues that arise in the community using practices that align with cultural traditions and have a direct impact on tribal communities in the Great Plains.

Sitting Bull College Fort Yates, North Dakota, US. *Credit: U.S Department of Interior.*

Eco-friendlier plastic

Plastic waste is a huge problem. Besides being made from petroleum, a non-renewable resource, most plastic products take a long time to break down, lingering for decades or even centuries in landfills and polluting water systems. Researchers at the FAMU-FSU College of Engineering—a joint engineering program between Florida A&M University and Florida State University—have made important progress on how industry could produce more sustainable plastics from renewable biomass. The researchers' breakthrough is in understanding how sustainable polymers behave when heated and cooled to their final shape. The team found that the polymers derived from biomass have properties very different from similar materials—rapid cooling and slow cooling each produce a different type of material, but mid-range cooling processes prevent the polymer from solidifying at all. Understanding the properties of these sustainable polymers could be a step toward revolutionizing how plastics are produced.


Principal Investigator Dr. Alamo with drawings of new polymer research that may revolutionize how plastics are processed. *Credit: FAMU-FSU.*

Synthetic biology startup helps fight COVID

NSF investments sometimes pay off in more ways than one. Take Ginkgo Bioworks as an example. It's a synthetic biology company whose founders received early funding from NSF as Graduate Research Fellows in the early 2000s and then in 2009 through the Small Business Innovation Research (SBIR) program based on research conducted at an NSF Engineering Research Center. Today, Ginkgo Bioworks operates a cell programming platform intended to make biology "easier to engineer" and is valued at billions of dollars—hardly a small business anymore. But when the COVID-19 outbreak began in March of 2020, they knew that beating the pandemic would require scaling up efforts throughout the biotech community. They committed $25.0 million of their resources for use by companies and laboratories developing diagnostic tools, drugs, vaccines, and therapeutics—at no cost to the users. They also stepped up to help coordinate matching resources to researchers, including private funding and R&D information. Ginkgo Bioworks shows how NSF investments keep paying off and can deliver returns to society when we need them most.

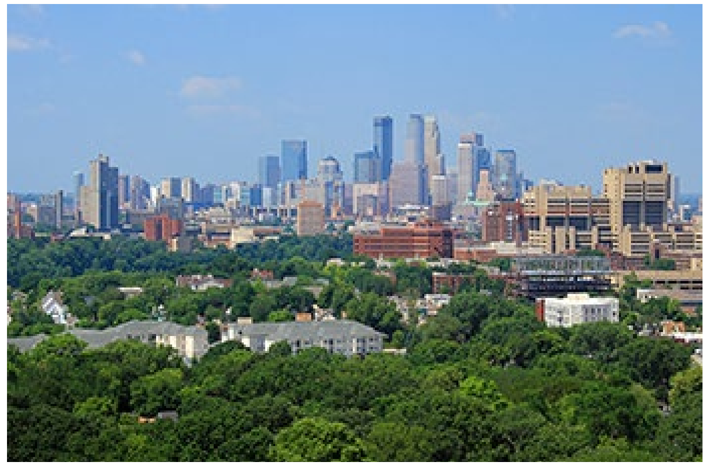
Image of a laboratory that designs and builds custom microbes and was supported through an SBIR grant. *Credit: Gingko Bioworks.*

Societal Experts Action Network helps community leaders save lives

How can state and local leaders and decision-makers draw on the vast research in social and behavioral sciences to help make better policy in their communities and effectively navigate an emergency like the COVID-19 pandemic? To respond to this need, the National Academies of Sciences, Engineering, and Medicine teamed up with NSF to assemble a network of scientists dedicated to helping local leaders translate decades of research into human behavior into clear and helpful guidance for public health and safety. Known as SEAN, the Social Experts Action Network, it's a compilation of accessible resources that local leaders and officials can use to keep their communities informed about COVID-19 and deploy evidence-based approaches for handling the public health emergency.

Members of La Colaborativa, a Massachusetts non-profit that used science to help address vaccine hesitancy in their local community. *Credit La Colaborativa / Darlene DeVita.*

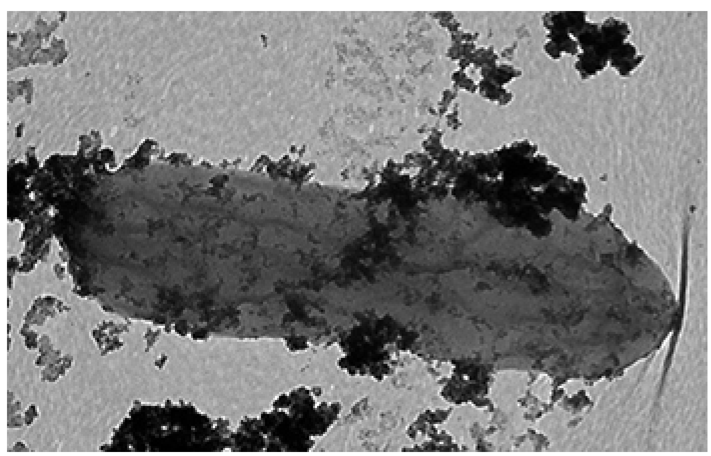
New NSF Long-Term Ecological Research site will study dynamic and diverse relationships between urban nature and people



Scientists affiliated with a new NSF-funded LTER site based in Minneapolis-St. Paul will examine how socioeconomic disparities, pollution, habitat loss and climate change interact to affect the environment in the Twin Cities. *Credit: Michael Hicks.*

Mayors and city councils spend a lot of time thinking about the systems that their towns and cities rely on. It can be an intricate network of infrastructure, from roads and the water supply to electric grids and sewers. But there are also ecological and environmental systems to consider—rivers and streams, parks, waterfronts, green space, and even individual gardens and yards are all part of the anatomy of cities and towns. With funding from NSF, researchers at the Minneapolis-St. Paul Urban Long-Term Ecological Research Program (LTER) are studying urban nature to better understand these environments and how they interact with the complex matrix of infrastructure and social systems that make up urban areas. This research will provide long-term environmental data collection, analysis, and interpretation to examine, among many issues, the interface between climate change and social disparities. Just as civil engineers help local governments improve infrastructure and services that residents depend on, this research is going to expand the understanding of urban ecology to help city planners strengthen the benefits of natural landscapes that are important to the Twin Cities and their residents. All data are publicly accessible across the LTER network and beyond.

How 'Iron Man' bacteria could help protect the environment



This Geobacter cell is speckled with cobalt minerals that would be toxic to many organisms. *Credit: Hunter Dulay.*

Researchers at Michigan State University have shown that microbes found in soil and sediment, known as *Geobacter*, are capable of a feat that could help reclaim a valuable natural resource and soak up toxic pollutants. The researchers found that *Geobacter* microbes were resistant to the toxic effects of cobalt. Cobalt is a metal used in lithium-ion batteries—it is rare and valuable, and toxic to living things, including humans and microbes. When *Geobacter* microbes encountered rust containing cobalt, they were able to extract the cobalt without it penetrating their cells and causing harm. Cobalt nanoparticles instead formed a protective layer around the microbes. The research is an exciting proof-of-concept that *Geobacter* microbes could be an important tool for cleaning up a range of toxic metals and for efficiently reclaiming valuable resources like cobalt.

Dark Energy Survey releases the most precise look at the universe's evolution

DES photographed the night sky using the Dark Energy Camera on the Victor M. Blanco 4-meter telescope at the Cerro Tololo Inter-American Observatory in Chile, a program of NSF's NOIRLab. *Credit: Reidar Hahn, Fermilab.*

Results from the Dark Energy Survey (DES), a collaboration with the U.S. Department of Energy and funded by several U.S. and international partners, are giving researchers new insights into some of the universe's most mysterious phenomena. While we can't see dark energy or dark matter directly, we can watch as it shapes the structure and motion of galaxies through gravitational effects. The DES mapped more than 226 million galaxies over seven years—creating the largest and most precise map of the universe ever made—which is allowing astronomers to see the influence of dark energy and dark matter on a massive scale and with new precision. The DES is part of a new era of astronomy powered by massive surveys of the sky, and with the help of supercomputers (and even artificial intelligence), DES and similar projects are enabling huge leaps forward in our understanding of the structure of the universe.

New filtering method promises safer drinking water

Most people know that adding fluoride to public water systems helps promote healthy teeth and prevent tooth decay. But in some places, the problem isn't too little fluoride in the water, it's too much. Where fluoride occurs naturally in water systems, communities must be careful to limit the level of fluoride in drinking water in order to avoid health problems that can arise from prolonged exposure to excess fluoride. Until now, removing excess fluoride has required expensive high-pressure filtration systems or burdensome water treatment methods. But with funding from NSF's Small Business Innovation Research program—known as America's Seed Fund, researchers at Tufts University have developed a new, inexpensive filtering technology inspired by biology that can separate fluoride with twice the selectivity of other methods. Their novel and affordable polymer membranes can help protect community water systems and support public health throughout the nation and around the globe.

A new filtering method promises safer drinking water for tens of millions of people. *Credit: Jenny Downing.*

SUMMARY TABLES

For definitions of common acronyms used throughout NSF's FY 2023 Budget Request, see the NOTES found at the beginning of the entire document on pages iii-iv.

NATIONAL SCIENCE FOUNDATION
SUMMARY TABLE
FY 2023 BUDGET REQUEST TO CONGRESS
(Dollars in Millions)

NSF by Account	FY 2021 Actual	FY 2021 ARP Actual	FY 2022 Enacted[1]	FY 2023 Request	FY 2023 Request change over: FY 2021 Actual Amount	FY 2021 Actual Percent	FY 2022 Enacted Amount	FY 2022 Enacted Percent
BIO	$817.74	$9.18		$970.23	$152.49	18.6%	N/A	N/A
CISE	1,007.13	35.72		1,150.78	143.65	14.3%	N/A	N/A
ENG	764.43	3.00		940.28	175.85	23.0%	N/A	N/A
GEO	1,004.27	71.04		1,239.05	234.78	23.4%	N/A	N/A
MPS	1,593.31	20.33		1,746.847	153.54	9.6%	N/A	N/A
SBE	282.11	18.16		330.21	48.10	17.0%	N/A	N/A
TIP[2]	369.01	19.87		879.87	510.86	138.4%	N/A	N/A
TIP Programs	*136.73*	*2.00*		*596.81*	*460.08*	*336.5%*	*N/A*	*N/A*
SBIR/STTR, including Operations	*232.28*	*17.87*		*283.06*	*50.78*	*21.9%*	*N/A*	*N/A*
OISE	51.29	1.45		74.04	22.75	44.4%	N/A	N/A
OPP	484.04	14.52		547.10	63.06	13.0%	N/A	N/A
IA[3]	386.42	2.28		545.86	159.44	41.3%	N/A	N/A
U.S. Arctic Research Commission	1.60	-		1.72	0.12	7.5%	N/A	N/A
Research & Related Activities	**$6,761.35**	**$195.54**	**$7,159.40**	**$8,425.987**	**$1,664.63**	**24.6%**	**$1,266.59**	**17.7%**
STEM Education[3,4]	**$1,110.85**	**$23.99**	**$1,006.00**	**$1,377.18**	**$266.33**	**24.0%**	**$371.18**	**36.9%**
Major Research Equipment & Facilities Construction	**$161.27**	**$8.95**	**$249.00**	**$187.23**	**$25.96**	**16.1%**	**-$61.77**	**-24.8%**
Agency Operations & Award Management	**$384.52**	**$12.00**	**$400.00**	**$473.20**	**$88.68**	**23.1%**	**$73.20**	**18.3%**
Office of Inspector General	**$17.61**	**-**	**$19.00**	**$23.393**	**$5.78**	**32.8%**	**$4.39**	**23.1%**
Office of the National Science Board	**$4.43**	**-**	**$4.60**	**$5.09**	**$0.66**	**14.9%**	**$0.49**	**10.7%**
Total, NSF Discretionary Funding	**$8,440.03**	**$240.48**	**$8,838.00**	**$10,492.08**	**$2,052.05**	**24.3%**	**1654.08**	**18.7%**
STEM Education - H-1B Visa	146.51	-	162.47	158.86	12.35	8.4%	-3.61	-2.2%
Donations	25.94	-	10.00	10.00	-15.94	-61.4%	-	-
Total, NSF Mandatory Funding	**$172.45**	**-**	**$172.47**	**$168.86**	**-$3.59**	**-2.1%**	**-$3.61**	**-2.1%**
Total, NSF Budgetary Resources	**$8,612.48**	**$240.48**	**$9,010.47**	**$10,660.94**	**$2,048.46**	**23.8%**	**$1,650.47**	**18.3%**

Totals exclude reimbursable amounts.

[1] Funding amounts below the account level for the FY 2022 Enacted were not available at the time of printing.

[2] FY 2021 funding for TIP is shown for comparability across fiscal years.

[3] In FY 2023, funding for Graduate Research Fellowship Program is requested to be consolidated within STEM Education. FY 2021 funding from IA is shown in EDU for comparability with the FY 2023 Request. FY 2022 Enacted account level funding is not restated to reflect this shift.

[4] NSF proposes to change the name of the Directorate for Education and Human Resources (EHR) to the Directorate for STEM Education (EDU).

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 2021 Actuals	FY 2022 (TBD)	FY 2023 Request Estimate
Statistics for Competitive Awards			
Number of Proposals	43,300	-	49,200
Number of Awards	11,300	-	13,500
Regular Appropriation	10,700	-	13,500
ARP	600		
Funding Rate	26%	-	27%
Statistics for Research Grant Awards			
Number of Research Grant Proposals	35,700	-	44,000
Number of Research Grant Awards	9,100	-	11,500
Regular Appropriation	8,700	-	11,500
ARP	400		
Funding Rate	25%	-	26%
Median Annualized Award Size	$154,100	-	$171,700
Average Annualized Award Size	$201,100	-	$237,200
Average Duration (years)	3.1	-	3.1

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

NUMBER OF PEOPLE INVOLVED IN NSF ACTIVITIES

NSF estimates that in FY 2023 over 365,300 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.

Number of People Involved in NSF Activities

	FY 2021 Actual Estimate	FY 2021 ARP Actual Estimate	FY 2022 (TBD)	FY 2023 Estimate
Senior Researchers	49,459	1,939	-	59,300
Other Professionals	14,611	373	-	17,750
Postdoctoral Associates	6,771	355	-	7,650
Graduate Students	43,085	1,012	-	53,470
Undergraduate Students	38,586	1,206	-	48,750
K-12 Teachers	39,872	343	-	46,300
K-12 Students	112,236	8,623	-	132,100
Total Number of People	**304,619**	**13,851**	**-**	**365,320**

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 30 percent of the U.S. science and engineering graduate students receiving federal funds and about four percent of the science and engineering graduate students in the U.S. overall.[1]

[1] NCSES Survey of Graduate Students and Postdoctorates in Science and Engineering: Fall 2019—Table 1-7: Detailed primary source of federal support for full-time graduate students in science, engineering, and health: 1975–2019 (https://ncses.nsf.gov/pubs/nsf21318/table/1-7); and Table 1-6: Primary source of support for full-time graduate students in science, engineering, and health: 1975–2019 (https://ncses.nsf.gov/pubs/nsf21318/table/1-6)

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.

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 2023

(Millions of Current Dollars)

Click here for complete history

Fiscal Year	Research & Related Activities (R&RA)		STEM Education (EDU)[1]		Major Research Equipment & Facilities Construction (MREFC)[2]		Agency Operations & Award Management (AOAM)[3]		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[4]	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[5]	5,662.96	6,789.80	823.47	942.55	223.23	243.23	336.89	357.75	15.35	16.50	4.10	4.50	7,066.00	8,354.33
2021[6]	6,213.02	6,880.48	930.93	968.00	229.75	241.00	345.64	374.93	17.85	17.85	4.21	4.50	7,741.40	8,486.76
2022 Enacted[7]	8,139.71	7,159.40	1,287.27	1,006.00	249.00	249.00	468.30	400.00	20.42	19.00	4.60	4.60	10,169.30	8,838.00
2023	8,425.99	-	1,377.18	-	187.23	-	473.20	-	23.39	-	5.09	-	10,492.08	-

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

[1] The STEM Education (EDU) account was previously known as Education and Human Resources (EHR) until FY 2022.

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

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

[4] 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.

[5] FY 2020 appropriations include Coronavirus Aid, Relief, and Economic Security Act (CARES Act) supplemental appropriations (P.L. 116-136), which provided NSF $76.0 million in two-year funding ($75.0 million to the R&RA account and $1.0 million to the AOAM account) to prevent, prepare for, and respond to coronavirus, domestically or internationally, including to fund research grants and other necessary expenses. NSF subsequently transferred $5.0 million from the R&RA account to the EHR account for these purposes.

[6] FY 2021 Appropriations exclude the $600.0 million in American Rescue Plan Act of 2021 (ARP) (P.L. 117-2) supplemental two-year appropriations to fund or extend new and existing research grants, cooperative agreements, scholarships, fellowships, and apprenticeships, and related administrative expenses to prepare for, and respond to coronavirus.

[7] FY 2022 Appropriations are Enacted appropriations. MREFC Enacted account level excludes $25.0 million in one-time funding for necessary expenses related to RCRV construction impacted by Hurricane Ida as provided in P.L. 117-43, the "Extending Government Funding and Delivering Emergency Assistance Act." Full information on transfers and reprogrammings were not available at the time of printing.

NATIONAL SCIENCE FOUNDATION
ADMINISTRATION PRIORITIES AND CROSSCUTTING RESEARCH TOPICS SUMMARY
FY 2023 BUDGET REQUEST TO CONGRESS
(Dollars in Millions)

	NSTC Crosscut Clean Energy Technology					NSTC Crosscut U.S. Global Change Research Program				
				Change over FY 2021 Actual					Change over FY 2021 Actual	
	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Amount	Percent	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Amount	Percent
BIO	$45.00	-	$59.28	$14.28	31.7%	$155.00	-	$237.15	$82.15	53.0%
CISE	24.22	-	31.12	6.90	28.5%	-	-	40.00	40.00	N/A
ENG	143.38	-	223.57	80.19	55.9%	-	-	-	-	N/A
GEO	-	-	-	-	N/A	329.00	-	515.37	186.37	56.6%
MPS	132.07	-	128.56	-3.51	-2.7%	9.83	-	34.63	24.80	252.3%
SBE	-	-	-	0.00	N/A	18.25	-	25.14	6.89	37.8%
TIP[1]	37.21	-	52.47	15.26	41.0%	-	-	-	-	N/A
OISE	0.01	-	5.00	4.99	49900.0%	-	-	5.00	5.00	N/A
OPP	-	-	-	-	N/A	56.11	-	56.11	-	-
IA	-	-	-	-	N/A	-	-	-	-	N/A
R&RA	**$381.89**	**-**	**$500.00**	**$118.11**	**30.9%**	**$568.19**	**-**	**$913.40**	**$345.21**	**60.8%**
EDU[2]	**-**	**-**	**-**	**-**	**N/A**	**-**	**-**	**-**	**-**	**N/A**
Total, NSF	**$381.89**	**-**	**$500.00**	**$118.11**	**30.9%**	**$568.19**	**-**	**$913.40**	**$345.21**	**60.8%**

[1] FY 2021 funding for TIP is shown for comparability across fiscal years.

[2] Account known as Education and Human Resources (EHR) has been renamed to STEM Education (EDU).

	Advanced Manufacturing					Advanced Wireless				
				Change over FY 2021 Actual					Change over FY 2021 Actual	
	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Amount	Percent	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Amount	Percent
BIO	$7.16	-	$17.16	$10.00	139.7%	-	-	-	-	N/A
CISE	44.40	-	42.22	-2.18	-4.9%	87.45	-	93.26	5.81	6.6%
ENG	123.65	-	174.37	50.72	41.0%	25.83	-	27.75	1.92	7.4%
GEO	-	-	-	-	N/A	-	-	-	-	N/A
MPS	193.42	-	123.13	-70.29	-36.3%	17.00	-	17.00	-	-
SBE	0.50	-	3.50	3.00	600.0%	-	-	-	-	N/A
TIP[1]	44.30	-	54.63	10.33	23.3%	0.75	-	30.55	29.80	3973.3%
OISE	0.26	-	0.50	0.24	92.3%	-	-	-	-	N/A
OPP	-	-	-	-	N/A	-	-	-	-	N/A
IA	16.24	-	1.00	-15.24	-93.8%	-	-	-	-	N/A
R&RA	**$429.93**	**-**	**$416.51**	**-$13.42**	**-3.1%**	**$131.03**	**-**	**$168.56**	**$37.53**	**28.6%**
EDU[2]	**$22.19**	**-**	**$5.00**	**-$17.19**	**-77.5%**	**-**	**-**	**-**	**-**	**N/A**
Total	**$452.11**	**-**	**$421.51**	**-$30.60**	**-6.8%**	**$131.03**	**-**	**$168.56**	**$37.53**	**28.6%**

[1] FY 2021 funding for TIP is shown for comparability across fiscal years.

[2] Account known as Education and Human Resources (EHR) has been renamed to STEM Education (EDU).

NATIONAL SCIENCE FOUNDATION
ADMINISTRATION PRIORITIES AND CROSSCUTTING RESEARCH TOPICS SUMMARY
FY 2023 BUDGET REQUEST TO CONGRESS
(Dollars in Millions)

	Artificial Intelligence					Biotechnology				
	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual: Amount	Change over FY 2021 Actual: Percent	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual: Amount	Change over FY 2021 Actual: Percent
BIO	$20.00	-	$20.00	-	-	$110.00	-	$130.00	$20.00	18.2%
CISE	344.00	-	369.80	25.80	7.5%	6.92	-	6.00	-0.92	-13.3%
ENG	85.86	-	95.80	9.94	11.6%	86.77	-	101.50	14.73	17.0%
GEO	1.00	-	5.00	4.00	400.0%	10.00	-	10.00	0.00	-
MPS	110.63	-	71.67	-38.96	-35.2%	91.88	-	62.20	-29.68	-32.3%
SBE	15.06	-	19.59	4.53	30.1%	2.04	-	1.50	-0.54	-26.6%
TIP[1]	86.79	-	101.55	14.76	17.0%	11.84	-	69.06	57.22	483.4%
OISE	0.33	-	-	-0.33	-100.0%	-	-	-	-	N/A
OPP	-	-	-	-	N/A	1.60	-	2.00	$0.40	25.0%
IA	9.07	-	1.00	-8.07	-89.0%	1.00	-	1.00	-	-
R&RA	**$672.74**	**-**	**$684.41**	**$11.67**	**1.7%**	**$322.05**	**-**	**$383.26**	**$61.21**	**19.0%**
EDU[2]	**$29.04**	**-**	**$50.00**	**$20.96**	**72.2%**	**$14.41**	**-**	**$9.00**	**-$5.41**	**-37.6%**
Total	**$701.78**	**-**	**$734.41**	**$32.63**	**4.6%**	**$336.47**	**-**	**$392.26**	**$55.79**	**16.6%**

[1] FY 2021 funding for TIP is shown for comparability across fiscal years.

[2] Account known as Education and Human Resources renamed to STEM Education (EDU).

	NSTC Crosscut Quantum Information Science					Microelectronics and Semiconductors				
	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual: Amount	Change over FY 2021 Actual: Percent	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual: Amount	Change over FY 2021 Actual: Percent
BIO	$3.28	-	$3.28	-	-	-	-	-	-	N/A
CISE	20.70	-	24.28	3.58	17.3%	17.95	-	23.46	5.51	30.7%
ENG	21.31	-	32.89	11.58	54.3%	43.07	-	46.00	2.93	6.8%
GEO	-	-	-	-	N/A	-	-	-	-	N/A
MPS	154.03	-	156.13	2.10	1.4%	57.31	-	26.00	-31.31	-54.6%
SBE	-	-	-	-	N/A	-	-	-	-	N/A
TIP[1]	20.53	-	38.42	17.89	87.1%	12.78	-	50.23	37.45	293.0%
OISE	0.09	-	1.00	0.91	1011.1%	-	-	-	-	N/A
OPP	-	-	-	-	N/A	-	-	-	-	N/A
IA	24.60	-	-	-24.60	-100.0%	-	-	-	-	N/A
R&RA	**$244.54**	**-**	**$256.00**	**$11.46**	**4.7%**	**$131.11**	**-**	**$145.69**	**$14.58**	**11.1%**
EDU[2]	**$10.52**	**-**	**$5.00**	**-$5.52**	**-52.5%**	**-**	**-**	**-**	**-**	**N/A**
Total, NSF	**$255.06**	**-**	**$261.00**	**$5.94**	**2.3%**	**$131.11**	**-**	**$145.69**	**$14.58**	**11.1%**

[1] FY 2021 funding for TIP is shown for comparability across fiscal years.

[2] Account known as Education and Human Resources renamed to STEM Education (EDU).

	NSTC Crosscut National Nanotechnology Initiative (NNI)					NSTC Crosscut Networking & Information Technology R&D (NITRD)				
	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual		FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual	
				Amount	Percent				Amount	Percent
BIO	$39.95	-	$39.95	-	-	$79.00	-	$79.00	-	-
CISE	14.67	-	14.05	-0.62	-4.2%	1,007.13	-	1,150.78	143.65	14.3%
ENG	206.45	-	231.75	25.30	12.3%	164.59	-	179.26	14.67	8.9%
GEO	-	-	-	-	N/A	23.00	-	30.00	7.00	30.4%
MPS	340.13	-	133.50	-206.63	-60.8%	298.45	-	226.81	-71.64	-24.0%
SBE	0.40	-	0.40	-	-	34.90	-	30.94	-3.96	-11.3%
TIP[1]	4.00	-	10.05	6.05	151.3%	80.45	-	380.04	299.59	372.4%
OISE	0.10	-	0.10	-	-	0.33	-	-	-0.33	-100.0%
OPP	-	-	-	-	N/A	-	-	-	-	N/A
IA	-	-	-	-	N/A	9.07	-	1.00	-8.07	-89.0%
R&RA	**$605.70**	**-**	**$429.80**	**-$175.90**	**-29.0%**	**$1,696.92**	**-**	**$2,077.83**	**$380.91**	**22.4%**
EDU[2]	**$6.04**	**-**	**$5.00**	**-$1.04**	**-17.2%**	**$17.60**	**-**	**$29.59**	**$11.99**	**68.1%**
Total	**$611.74**	**-**	**$434.80**	**-$176.94**	**-28.9%**	**$1,714.52**	**-**	**$2,107.42**	**$392.90**	**22.9%**

[1] FY 2021 funding for TIP is shown for comparability across fiscal years.

[2] Account known as Education and Human Resources renamed to STEM Education (EDU).

NATIONAL SCIENCE FOUNDATION
DIRECTORATE FOR STEM EDUCATION FUNDING BY DIVISION AND PROGRAM[1]
FY 2023 BUDGET REQUEST TO CONGRESS
(Dollars in Millions)

	FY 2021 Actuals	FY 2022 (TBD)	FY 2023 Request	FY 2023 Request change over FY 2021 Actuals: Amount	Percent
Division of Equity for Excellence in STEM (EES)[2]					
ADVANCE	18.00	-	20.50	2.50	13.9%
Alliances for Graduate Education and the Professoriate (AGEP)	8.00	-	14.00	6.00	75.0%
Big Idea: NSF INCLUDES	20.00	-	50.50	30.50	152.5%
Centers for Research Excellence in Science and Technology (CREST)	24.00	-	41.00	17.00	70.8%
EDU Core Rsrch (ECR): Broadening Participation and Institutional Capacity in STEM	14.61	-	17.99	3.38	23.2%
Excellence Awards in Science and Engineering (EASE)	3.63	-	7.64	4.01	110.7%
Historically Black Colleges and Universities Undergraduate Program (HBCU-UP)	36.50	-	48.50	12.00	32.9%
IUSE: Hispanic Serving Institutions (HSI) Program	23.25	-	30.25	7.00	30.1%
Louis Stokes Alliances for Minority Participation (LSAMP)	49.51	-	70.50	20.99	42.4%
Tribal Colleges and Universities Program (TCUP)	16.50	-	23.00	6.50	39.4%
EES Subtotal	**$214.00**	**-**	**$323.88**	**$109.88**	**51.3%**
Division of Graduate Education (DGE)					
Cybercorps®: Scholarship for Service (SFS)	59.99	-	75.00	15.01	25.0%
EDU Core Research (ECR): STEM Professional Workforce Preparation	18.12	-	21.11	2.99	16.5%
Graduate Research Fellowship Program (GRFP)[3]	284.45	-	355.51	71.06	25.0%
NSF Research Traineeship (NRT)	58.00	-	62.50	4.50	7.8%
STEM Education Postdoctoral Research Fellowships	-	-	5.00	5.00	N/A
DGE Subtotal	**$420.57**	**-**	**$519.12**	**$98.55**	**23.4%**
Division of Research on Learning in Formal and Informal Settings (DRL)					
Advancing Informal STEM Learning (AISL)	$62.50	-	$74.50	$12.00	19.2%
Artificial Intelligence Research Institutes, National	7.60	-	19.59	11.99	157.9%
Computer Science for All (CSforAll)	10.00	-	10.00	-	-
Discovery Research PreK-12 (DRK-12)	95.00	-	99.50	4.50	4.7%
EDU Core Research (ECR): STEM Learning	29.06	-	38.99	9.93	34.2%
DRL Subtotal	**$204.16**	**-**	**$242.58**	**$38.42**	**18.8%**
Division of Undergraduate Education (DUE)					
Advanced Technological Education (ATE)[4]	76.45	-	75.00	-1.45	-1.9%
EDU Core Research (ECR): STEM Learning Environments	14.85	-	23.85	9.00	60.6%
Improving Undergraduate STEM Education (IUSE)	90.00	-	95.50	5.50	6.1%
IUSE: Hispanic Serving Institutions (HSI) Program	23.25	-	30.25	7.00	30.1%
Robert Noyce Teacher Scholarship Program (Noyce)[5]	67.56	-	67.00	-0.56	-0.8%
DUE Subtotal	**$272.12**	**-**	**$291.60**	**$19.48**	**7.2%**
Total, EDU	**$1,110.85**	**-**	**$1,377.18**	**$266.33**	**24.0%**

[1] NSF proposes to change the name of the Directorate for Education and Human Resources (EHR) to the Directorate for STEM Education (EDU).

[2] NSF proposes to change the name of the Division of Human Resource Development (HRD) to the Division of Equity for Excellence in STEM (EES).

[3] The Graduate Research Fellowship Program is consolidated within the EDU Division of Graduate Education in FY 2022 and is restated in prior years for comparability.

[4] Decreases reflected in FY 2023 Request as compared to the FY 2021 Actuals are due to FY 2021 spending, which includes prior year recoveries funding.

[5] Decreases reflected in FY 2023 Request as compared to the FY 2021 Actuals are due to FY 2021 spending, which includes no year recoveries funding and two year funding.

NATIONAL SCIENCE FOUNDATION
CoSTEM INVENTORY AND POSTDOCTORAL FELLOWSHIP PROGRAMS
BY LEVEL OF EDUCATION
FY 2023 BUDGET REQUEST TO CONGRESS
(Dollars in Millions)

		FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	FY 2023 Request change over FY 2021 Actual: Amount	Percent
Minority-Serving Institutions		**$99.51**	**-**	**$132.00**	**$32.49**	**32.7%**
UG	IUSE: Hispanic Serving Institutions (HSI) Program	46.50	-	60.50	14.00	30.1%
UG	Historically Black Colleges and Universities Undergraduate Program (HBCU-UP)	36.50	-	48.50	12.00	32.9%
UG	Tribal Colleges and Universities Program (TCUP)	16.50	-	23.00	6.50	39.4%
Fellowships and Scholarships		**$564.76**	**-**	**$679.16**	**$114.40**	**20.3%**
UG	NSF Scholarships in STEM (S-STEM) (H-1B)	94.70	-	119.15	24.45	25.8%
UG	Robert Noyce Scholarship (Noyce) Program	67.56	-	67.00	-0.56	-0.8%
G	CyberCorps®: Scholarship for Service (SFS)	59.99	-	75.00	15.01	25.0%
G	Graduate Research Fellowship Program (GRFP)	284.45	-	355.51	71.06	25.0%
G	NSF Research Traineeship (NRT)	58.05	-	62.50	4.45	7.7%
Other Grant Programs		**$689.87**	**-**	**$842.89**	**$153.02**	**22.2%**
K-12	Computer Science for All (CSforAll)	24.60	-	24.50	-0.10	-0.4%
K-12	Discovery Research PreK-12 (DRK-12)	95.00	-	99.50	4.50	4.7%
K-12	Innovative Technology Experiences for Teachers and	51.65	-	39.72	-11.93	-23.1%
UG	Advanced Technological Education (ATE)	76.45	-	75.00	-1.45	-1.9%
UG	Emerging Frontiers in Research and Innovation (EFRI)	0.90	-	1.00	0.10	11.1%
UG	Harnessing the Data Revolution (HDR): Data Science Corps (DSC)	7.48	-	3.00	-4.48	-59.9%
UG	Improving Undergraduate STEM Education (IUSE)	99.26	-	108.65	9.39	9.5%
UG	International Research Experiences for Students (IRES)	12.33	-	10.00	-2.33	-18.9%
UG	Louis Stokes Alliances for Minority Participation (LSAMP)	49.51	-	70.50	20.99	42.4%
UG	Research Experiences for Undergraduates (REU) - Sites and Supplements	85.45	-	84.14	-1.31	-1.5%
UG	Research Experiences for Teachers (RET) Sites in ENG, CISE, & BIO[1]	8.24	-	13.20	4.96	60.1%
G	Alliances for Graduate Education and the Professoriate (AGEP)	8.00	-	14.00	6.00	N/A
G	Research and Mentoring for Postbaccalaureates in Biological Sciences (RaMP)	-	-	59.10	59.10	-
G	Training-based Workforce Dev. for Adv. Cyberinfrastructure (CyberTraining)	7.49	-	6.00	-1.49	-19.9%
O&I	Advancing Informal STEM Learning (AISL)	62.50	-	74.50	12.00	19.2%
O&I	EDU Core Research (ECR)[2]	76.63	-	101.94	25.31	33.0%
O&I	Excellence Awards in Science and Engineering (EASE)	3.63	-	7.64	4.01	110.7%
O&I	NSF INCLUDES	20.75	-	50.50	29.75	143.3%
Subtotal, Above Categories (CoSTEM Inventory Programs)		**$1,354.13**	**-**	**$1,654.05**	**$299.92**	**22.1%**
NSF Postdoctoral Programs		**$58.18**	**-**	**$138.59**	**$80.41**	**138.2%**
G	Astronomy and Astrophysics Postdoctoral Fellowships (AAPF)	1.80	-	5.40	3.60	200.0%
G	Engineering Postdoctoral Fellowships	-	-	15.00	15.00	N/A
G	Entrepreneurial Fellowships	-	-	25.00	25.00	N/A
G	Geosciences Postdoctoral Fellowships	9.26	-	17.14	7.88	85.0%
G	Mathematical Sciences Postdoctoral Research Fellowships (MSPRF)	9.15	-	15.15	6.00	65.6%
G	MPS ASCEND Postdoctoral Research Fellowships	9.26	-	20.00	10.74	115.9%
G	Postdoctoral Research Fellowships in Biology (PRFB)	22.79	-	26.90	4.11	18.0%
G	SPRF-Broadening Participation	3.13	-	6.00	2.87	91.5%
G	SPRF-Fundamental Research	2.78	-	3.00	0.22	8.0%
G	STEM Postdoctoral Research Fellowships (STEM Ed PRF)	-	-	5.00	5.00	N/A
K-12 STEM Education Programs (K-12) Subtotal		**$171.25**	**-**	**$163.72**	**-$7.53**	**-4.4%**
Undergraduate STEM Education Programs (UG) Subtotal		**$601.39**	**-**	**$683.64**	**$82.25**	**13.7%**
Graduate and Professional STEM Education Programs (G) Subtotal		**$476.16**	**-**	**$710.70**	**$234.54**	**49.3%**
Outreach and Informal STEM Education Programs (O&I) Subtotal		**$163.51**	**-**	**$234.58**	**$71.07**	**43.5%**
Total, NSF STEM Education		**$1,412.31**	**-**	**$1,792.64**	**$380.33**	**26.9%**

[1] BIO did not fund a RET Sites program in FY 2021. BIO funding for a RET Sites program is included in the FY 2023 Request.

[2] NSF proposes to change the name of the Directorate for Education and Human Resources (EHR) to the Directorate for STEM Education (EDU).

NATIONAL SCIENCE FOUNDATION
RESEARCH INFRASTRUCTURE (RI) FUNDING, BY ACCOUNT AND ACTIVITY
FY 2023 BUDGET REQUEST TO CONGRESS
(Dollars in Millions)

	FY 2021 Actual	**FY 2021 Actual RI Funding**	FY 2021 ARP Actual	**FY 2021 ARP Actual RI Funding**	FY 2022 (TBD)	**FY 2022 (TBD) RI Funding**	FY 2023 Request	**FY 2023 Request RI Funding**	**Change over FY 2021 Actual RI**	
									Amount	**Percent**
BIO	$817.74	**$129.99**	$9.18	-	-	-	$970.23	**$125.11**	-$4.88	-3.8%
CISE	1,007.13	**185.51**	35.72	**6.00**	-	-	1,150.78	**182.09**	-3.42	-1.8%
ENG	764.43	**25.94**	3.00	-	-	-	940.28	**26.43**	0.49	1.9%
GEO	1,004.27	**430.06**	71.04	**2.29**	-	-	1,239.05	**445.82**	15.76	3.7%
MPS	1,593.31	**420.14**	20.33	-	-	-	1,746.85	**402.32**	-17.82	-4.2%
SBE	282.11	**74.93**	18.16	**0.26**	-	-	330.21	**83.96**	9.03	12.0%
TIP[1]	369.01	-	19.87	-	-	-	879.87	-	-	N/A
OISE	51.29	**0.10**	1.45	-	-	-	74.04	**0.10**	-	-
OPP	484.04	**363.23**	14.52	-	-	-	547.10	**411.96**	48.73	13.4%
IA	528.61	**110.74**	2.28	-	-	-	545.86	**128.74**	18.00	16.3%
USARC	1.60	-	-	-	-	-	1.72	-	-	N/A
R&RA	$6,903.54	**$1,740.64**	$195.54	**$8.55**	-	-	$8,425.99	**$1,806.53**	$65.89	3.8%
EDU[2]	$968.66	-	$23.99	-	-	-	$1,377.18	-	-	N/A
MREFC	$161.27	**$161.10**	$8.95	**$8.95**	-	-	$187.23	**$186.23**	$25.13	15.6%
AOAM	$384.52	-	$12.00	-	-	-	$473.20	-	-	N/A
OIG	$17.61	-	-	-	-	-	$23.39	-	-	N/A
NSB	$4.43	-	-	-	-	-	$5.09	-	-	N/A
Total, NSF	**$8,440.03**	**$1,901.74**	**$240.48**	**$17.50**	**-**	**-**	**$10,492.08**	**$1,992.76**	**$91.02**	**4.8%**

[1] FY 2021 and FY 2021 ARP funding for TIP is shown for comparability across fiscal years.

[2] Account known as Education and Human Resources renamed to STEM Education (EDU).

NATIONAL SCIENCE FOUNDATION
RESEARCH INFRASTRUCTURE SUMMARY
FY 2023 BUDGET REQUEST TO CONGRESS
(Dollars in Millions)

	FY 2021 Actual	FY 2021 ARP Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Operations and Maintenance of Major Facilities[1]	**$967.01**	**-**	**-**	**$1,003.10**	**$36.09**	**3.7%**
Major Research Facilities Construction Investments	**$95.68**	**$8.95**	**-**	**$122.41**	**$26.73**	**27.9%**
Construction, Acquisition, and Commissioning (MREFC)[2]	87.06	8.95	-	109.98	22.92	26.3%
Design Stage Activities[3]	8.62	-	-	12.43	3.81	44.2%
Mid-scale Research Infrastructure[4]	**$167.48**	**-**	**-**	**$180.19**	**$12.71**	**7.6%**
MREFC Mid-scale Research Infrastructure	74.04	-	-	76.25	2.21	3.0%
NSF-wide Mid-scale Research Infrastructure (R&RA)	32.45	-	-	50.00	17.55	54.1%
Directorate Midscale Research Infrastructure Programs	60.99	-	-	53.94	-7.05	-11.6%
Major Research Instrumentation (MRI)	**$76.06**	**-**	**-**	**$75.00**	**-$1.06**	**-1.4%**
Polar Logistical and Infrastructure Support[5]	**$132.82**	**-**	**-**	**$157.00**	**$24.18**	**18.2%**
CISE Netwrking & Computatnl Resrces Infrastrctre & Srvces (NCRIS)[6]	**$114.48**	**$6.00**	**-**	**$144.25**	**$29.77**	**26.0%**
Research Resources[7]	**$247.42**	**$2.55**	**-**	**$191.04**	**-$56.38**	**-22.8%**
BIO	62.89	-	-	53.76	-9.13	-14.5%
CISE	51.94	-	-	37.24	-14.70	-28.3%
GEO	85.96	2.29	-	70.06	-15.90	-18.5%
MPS	17.95	-	-	15.10	-2.85	-15.9%
SBE	20.68	0.26	-	9.59	-11.09	-53.6%
OPP	8.00	-	-	5.29	-2.71	-33.9%
Other Research Infrastructure	**$102.30**	**-**	**-**	**$121.71**	**$19.41**	**19.0%**
Subtotal, Research Infrastructure Support	**$1,903.24**	**$17.50**	**-**	**$1,994.70**	**$91.46**	**4.8%**
Research Infrastructure Stewardship Offset	-1.50	-	-	-1.94	-0.44	29.1%
RESEARCH INFRASTRUCTURE TOTAL	**$1,901.74**	**$17.50**	**-**	**$1,992.76**	**$91.02**	**4.8%**

[1] For facility level detail on operations and maintenance, see the Major Facilities Overview within the NSF-wide Investments chapter.

[2] Construction, Acquisition, and Commissioning are for implementation support provided through the MREFC account. MREFC funding is included for the Antarctic Infrastructure Recapitalization (AIR) program, ($3.86 million in FY 2021 and $60.0 million in FY 2023); Vera C. Rubin Observatory ($34.09 million in FY 2021 and $15.0 million in FY 2023); the High Luminosity-Large Hadron Collider Upgrade (HL-LHC) ($28.74 million in FY 2021 and $33.0 million in FY 2023), Regional Class Research Vessels (RCRV) ($10.98 million in FY 2021 and $1.98 million in FY 2023) and Mid-scale Research Infrastructure ($74.04 million in FY 2021 and $76.25 million in FY 2023, shown on the MREFC Mid-scale RI line below). For more information, refer to the MREFC chapter.

[3] Design Stage Activities include support for potential next generation multi-user facilities. This line reflects FY 2021 funding of $7.0 million for the Leadership Class Computing Facility and $1.62 million and $12.43 million in FY 2021 and FY 2023 for the Antarctic Research Vessel (ARV).

[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).

[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 (NCRIS) excludes support for the potential Leadership Class Computing Facility in FY 2021 ($7.0 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

For definitions of common acronyms used throughout NSF's FY 2023 Budget Request, see the NOTES found at the beginning of the entire document on pages iii-iv.

NATIONAL SCIENCE FOUNDATION CURRENT AUTHORIZATIONS

(Dollars in Millions)

LEGISLATION	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Authorization Levels FY 2021	FY 2022	FY 2023
National Science Foundation Act of 1950, P.L. 81-507[1]				*within limits of funds made available for this purpose* *within the limits of available appropriations* *to make such expenditures as may be necessary* *within the limit of appropriated funds* *utilize appropriations available*		
American Innovation and Competitiveness Act, P.L. 114-329				*(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]	$196.04	$199.06	$236.39	*3.2% of research funds in 2020, 2021, and 2022*		
Small Business Technology Transfer (STTR) Program [2]	$31.10	$28.00	$33.25	*0.45% of research funds in 2020, 2021, and 2022*		
The Research Excellence and Advancements for Dyslexia Act (READ Act), P.L. 114-124[3]	$14.56	*		*$5.00*	*$5.00*	*NA*
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 childr en 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] *For each of fiscal years 2016 through 2021, there are authorized out of funds appropriated to the National Science Foundation, $5,000,000.*						

NATIONAL SCIENCE FOUNDATION CURRENT AUTHORIZATIONS
(Dollars in Millions)

LEGISLATION	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Authorization Levels FY 2021	FY 2022	FY 2023
National Earthquake Hazards Reduction Program Reauthorization Act of 2018, P.L. 115-307	$54.29	-	$54.00	*$54.00*	*$54.00*	*$54.00*
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]						
National Quantum Initiative Act, P.L. 115-38					*(Does not authorize appropriations)*	
Authorizes the National Science Foundation to carryout 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.						
National Defense Authorization Act for Fiscal Year 2021, P.L. 116-283						
Sec 5401(f) Establishes the National Science Foundation Pilot Program of Grants for Research in Rapidly Evolving, High Priority Topics to assess the feasibility and advisability of awarding grants for the conduct of research in rapidly evolving, high priority topics using funding mechanisms that require brief project descriptions and internal merit review, and that may include accelerated external review. [6]	*	*	*	*$868.00*	*$911.40*	*$956.97*

NATIONAL SCIENCE FOUNDATION CURRENT AUTHORIZATIONS
(Dollars in Millions)

LEGISLATION	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Authorization Levels FY 2021	FY 2022	FY 2023
H.R. 8810 - National Landslide Preparedness Act, P.L. 116-323	*	*	*	*$11.00*	*$11.00*	*$11.00*
Provide grants, on a competitive basis, to State, territorial, local, and Tribal governments to research, map, assess, and collect data on landslide hazards within the jurisdictions of those governments. For each of fiscal years 2021 through 2024 there is authorized to be appropriated to the National Science Foundation, $11,000,000 to carry out this section.						
H.R. 4704 - Advancing Research to Prevent Suicide Act, P.L. 116-339					*(Does not authorize appropriations)*	
Directs NSF to award competitive, merit-reviewed grants to institutions of higher education (or their consortia) to support multidisciplinary, fundamental research with potential relevance to suicide, including potential relevance to prevention and treatment. *In awarding such grants, the NSF shall encourage applications submitted by early career researchers, including doctoral students and postdoctoral researchers, to promote the researchers' development.*						

[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 2021 Actuals funding includes $6.78 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.
[6] Authorizes appropriation of funds for the Pilot Program of Grants for Research in Rapidly Evolving, High Priority Topics. Outyear funding is $1,004,820,000 for fiscal year 2024; and $1,055,060,000 for fiscal year 2025.

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's Computer Science for All (CSforAll) activities address the national need to build computer science education opportunities and teacher preparation at the preK-12 level, as part of building the U.S. economy. Projects are expected to address equity issues in computer science education, including the participation of girls and women, and other under-represented groups.

NSF launched Computer Science for All: Researcher Practitioner Partnerships (CS for All: RPP) under the (STEM+C) program in 2017 with solicitation NSF 17-525[1]. In 2018, NSF issued an updated solicitation (NSF 18-537)[2] making CSforAll a stand-alone program. In 2020, NSF issued an updated solicitation Computer Science for All (CSforAll: Research and RPPs), NSF 20-539[3]. As the new name suggests, this updated solicitation added a focus on research to serve the goals of the program. Specifically, a new research strand was added to support projects designed to contribute new knowledge to the educational field about the teaching and learning of introductory computer science concepts.

The CS for All: Research and RPPs program synopsis in the program solicitation states that:

> This program aims to provide all U.S. students with 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 both research and 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 (1) high school teachers with the preparation, professional development (PD) and ongoing support they need to teach rigorous computer science courses; (2) preK-8 teachers with the instructional materials and preparation they need to integrate CS and CT into their teaching; and (3) schools and districts with the resources needed to define and evaluate multi-grade pathways in CS and CT.

Metrics

Short-, mid-, and longer-term metrics for success are considered by the program as follows:

- Short-term metrics 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 intended populations to be reached by the awards. CSforAll considers ‘short-term’ metrics to be those which are observable on an annual basis. To date, the program has only reported progress with respect to these short-term metrics.
- Mid-term metrics 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. CSforAll operationalizes ‘mid-term’ as progress that individual projects can reasonably be expected to achieve within three years of award. This is the second report to include an assessment of progress with respect to these mid-term metrics.
- 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 well-aligned requirements of Public Law 114-329. Program staff will work with the Evaluation and

[1] www.nsf.gov/pubs/2017/nsf17525/nsf17525.htm
[2] www.nsf.gov/pubs/2018/nsf18537/nsf18537.htm
[3] www.nsf.gov/pubs/2020/nsf20539/nsf20539.htm

Monitoring Group within NSF's Directorate for STEM Education and the 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 assessing the collective success of the CS for All: RPP projects using these longer-term metrics.

<u>Report on the Success of the Program as Measured by the Short-Term Metrics</u>
During FY 2021, the program funded 30 new projects comprised of 40 awards to proposals submitted pursuant to NSF 20-539. These awards have goals that cover the first three research topics listed in Sec. 310 of the Act as outlined below. Because some awards have goals that span more than one of the research topics addressed in (b)(2) A, B, and C, the number of projects sums to more than 30.

- 24 projects have research goals that address subsection (b)(2) A and (b)(2) B;
- 30 projects have research goals that address subsection (b)(2) C; and
- 5 projects have research goals that address multi-grade pathways to CT and CS.

Examples of CSforAll supported efforts to address the development or adaptation, piloting or full implementation, and testing of models of preservice preparation for teachers who will teach computer science and computational thinking and/or scalable and sustainable models of professional development and ongoing support for these teachers, can be found at the CSforAll program website[4] Taken as a group, these awards consider a range of opportunities to expand CS education and computational literacy. These include methods for concurrent high school / college enrollment, regionally-focused K-12 efforts in Appalachia, Milwaukee and elsewhere around the Nation, and also means for engaging a broader cross-section of students in CS education through connections to the Arts and other topic areas.

With respect to subsection (b)(2) D, all 30 new awards have explicit statements and plans to address at least one underrepresented or underserved group included within their project descriptions. The specific groups addressed by these 30 awards are detailed in the following table. (Because some awards serve more than one underrepresented group, the number of awards sums to more than 30.) In addition, the geographic spread of CSforAll awards can be viewed on NSF's website.[5]

Underrepresented or Underserved Group Served by Backbone Organizations	
Category	Number of awards serving
African- Americans	20
Women/Girls	20
Latino/a	19
Low Socio-Economic Status	19
Persons with Disabilities	12
Native Americans	7
English Language Learners	6
Native Hawaiians & Pacific Islanders	1

[4] Computer Science for All (CSforAll: Research and RPPs) | Beta site for NSF - National Science Foundation; https://beta.nsf.gov/funding/opportunities/computer-science-all-csforall-research-and-rpps
[5] Computer Science For All Active Awards; www.nsf.gov/awards/award_visualization

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

Mid-term metrics assess progress that individual projects can reasonably be expected to achieve within three years of award. Measurement of mid-term metrics is based on information contained in projects' annual reports. Given that the program began in FY 2017, mid-term metrics are possible only for the 48 awards that NSF issued across FY 2017 and FY 2018.

In their annual reports, awardees are requested to provide information about the progress of their individual projects:

- What are the major goals of the project?
- What was accomplished under these goals and objectives? What were the major activities, the specific objectives, significant results, and key outcomes?
- What opportunities for training and professional development has the project provided?
- Have the results been disseminated to communities of interest?
- What do you plan to do during the next reporting period to accomplish the goals?

Based on the responses of the awardees, program staff assessed that 100 percent of projects awarded in FY 2017 and FY 2018 have been making satisfactory progress for each year of the project duration. "Satisfactory progress" refers to criteria such as whether the stated goals of the project are being met; whether the major activities are in line with those planned in the original grant proposal; whether the opportunities for training and professional development are in line with those promised; and whether dissemination is occurring as planned. Projects voluntarily included information about the numbers of schools and teachers reached—the 48 awarded projects from FY 2017 and FY 2018 reported a total of approximately 615 schools and approximately 2,320 teachers reached. This aggregated information from individual projects contributes to the conclusion that CSforAll is successful in the mid-term.

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 2021

This report summarizes fiscal year (FY) 2021 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 details:

(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 integrate the EPSCoR states more fully 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 uses 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's RII programs are instrumental in helping to build jurisdictional capability and capacity. RII Track-1 awards provide up to $4 million per year for up to five years. They are intended to improve the research competitiveness of jurisdictions by improving their academic research infrastructure in areas of science and engineering supported by the National Science Foundation and critical to the particular jurisdiction's science and technology initiative or plan. RII Track-2 Focused EPSCoR Collaborations awards provide up to $1 million per year for up to four years as collaborative awards between two EPSCoR jurisdictions or up to $1.5 million per year for up to four years to a consortium of three or more EPSCoR jurisdictions. These awards build interjurisdictional collaborative teams of EPSCoR investigators in scientific focus areas consistent with NSF priorities. RII Track-4: EPSCoR Research Fellows provides opportunities for non-tenured investigators to further develop their individual research potential through extended collaborative visits to the nation's premier private, governmental, or academic research centers. Through these visits, the EPSCoR Research Fellows learn new techniques, benefit from access to unique equipment and facilities, and shift their research toward transformative new directions. The experience gained through the fellowship is intended to provide a foundation for research collaborations that span the recipient's entire career. These benefits to the Fellows are also expected to in turn enhance the research capacity of their institutions and jurisdictions.

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

EPSCoR's strategies and objectives in FY 2021 remain the same as those described in the FY 2020 report. Specifically, the mission of EPSCoR is "to enhance research competitiveness of targeted jurisdictions (states, territories, commonwealths) by strengthening Science, Technology, Engineering and Math (STEM) capacity and capability." 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 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 affect 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 2021, NSF EPSCoR invested a total of $200.16 million in support of its programmatic activities. Of this, $135.55 million (67.7 percent) was directed to RII, $64.02 million (32.0 percent) to co-funding, and $600,000 (0.3 percent) to outreach activities and workshops. The table below details the investments from EPSCoR resources and EPSCoR investments in co-funding actions.

FY 2021 EPSCoR Funding by Jurisdiction

(Dollars in Millions)

EPSCoR Jurisdiction	RII Program	Outreach & Workshops	EPSCoR Co-funding	EPSCoR Total
AK	$4.03	-	$0.51	$4.54
AL	3.25	-	4.72	7.97
AR	4.94	0.05	7.33	12.33
DE	3.96	-	1.18	5.14
GU	4.62	-	-	4.62
HI	2.47	0.18	1.47	4.11
IA	1.00	-	2.78	3.77
ID	5.58	-	6.80	12.38
KS	10.76	-	1.18	11.94
KY	2.60	-	3.01	5.61
LA	12.39	-	3.50	15.89
ME	8.18	-	1.26	9.44
MS	5.04	-	2.47	7.51
MT	0.60	0.01	4.18	4.79
ND	12.11	-	0.99	13.09
NE	7.67	-	1.79	9.46
NH	1.74	-	0.15	1.89
NM	0.13	0.10	3.19	3.42
NV	1.23	0.01	2.38	3.62
OK	4.84	-	2.59	7.43
PR	3.51	-	5.08	8.59
RI	5.26	-	0.89	6.15
SC	5.25	-	2.84	8.09
SD	6.45	-	0.39	6.84
VI	4.76	-	-	4.76
VT	1.79	-	0.43	2.21
WV	1.75	-	1.27	3.02
WY	4.19	-	0.87	5.06
Admin	5.46	0.25	0.79	6.49
Total	**$135.55**	**$0.60**	**$64.02**	**$200.16**

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

In FY 2021, NSF invested a total of $1,041.25 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 2021 NSF Funding Made Available to All EPSCoR Jurisdictions
(Dollars in Millions)

EPSCoR Jurisdiction	NSF Funding
AK	$56.05
AL	63.48
AR	33.84
DE	46.51
GU	5.46
HI	57.27
IA	57.91
ID	34.79
KS	40.41
KY	38.57
LA	62.14
ME	26.07
MS	31.26
MT	39.67
ND	25.07
NE	39.22
NH	33.28
NM	55.25
NV	29.94
OK	41.67
PR	18.98
RI	60.55
SC	68.96
SD	16.32
VI	8.84
VT	12.10
WV	19.92
WY	17.72
Total	**$1,041.25**

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. In these meetings, the EPSCoR participants are provided with information on NSF strategic priorities and funding opportunities.

In FY 2021, EPSCoR staff promoted engagement of the EPSCoR community in NSF and other national activities. Examples are:

- Communicated extensively regarding the Office of Management and Budget's (OMB) and NSF guidelines about COVID-19 flexibilities for funded awards.
- Hosted its 2021 EPSCoR Annual Principal Investigator (PI) Meeting virtually during the week of May 17-21. The EPSCoR community and NSF program officers shared effective practices in research, strategic planning, diversity, communication, evaluation, and other areas of importance to EPSCoR jurisdictions and NSF. In addition to presentations and breakout sessions, there were Track-specific symposia that showcased successful projects and offered valuable insight to potential future PIs. The agenda also included 33 open houses for PIs to meet with Program Officers from all NSF Directorates to discuss program-specific funding opportunities. Every EPSCoR jurisdiction was represented at this meeting, which had approximately 300 participants.
- Committed $13.20 million in support of three new awards led by EPSCoR institutions in the FY 2021 Mid-scale RI-1 competition. These awards went to the University of Arkansas, the University of Idaho, and the University of Kentucky.
- Provided $5.0 million to the new Center for Advanced Radio Sciences and Engineering led by the University of Puerto Rico Mayaguez, part of NSF's response to the collapse of the Arecibo Observatory.
- Contributed $831,000 to enable the award of a new NSF INCLUDES Alliance led by Auburn University focused on improving opportunities in STEM for students with disabilities.
- Provided $1.0 million to a new Sustainable Regional Systems Research Network led by the University of New Mexico, with a focus on rural-urban systems in the Intermountain West.
- 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. In FY 2021,

proposals were invited on the topic of "Advancing research toward Industries of the Future to ensure economic growth for EPSCoR jurisdictions," aligned with NSF's emerging industries initiative. Ten awards were made in FY 2021, representing a total EPSCoR investment of $45.70 million over their four-year award duration.

- Committed $10.0 million in supplemental funding to 19 existing RII Track-2 awards to support individuals and institutions that are adversely affected by the COVID-19 pandemic. The supplements are specifically focused on further building EPSCoR's RII Track-2 networks by providing support to broaden the engagement of researchers from minority-serving institutions (MSIs).
- Continued the RII Track-4, EPSCoR Research Fellows solicitation and 35 awards were made, representing a total EPSCoR investment of $7.0 million over their two-year award duration.
- Debuted the Track-4 Fellows Advancing Science and Technology (FAST) funding opportunity, a collaboration with NASA-EPSCoR. Track-4 FAST allows for PIs from MSIs to further develop their individual research potential through extended collaborative visits to NASA research facilities located at NASA Centers throughout the United States. A total of two out of the 35 awards made for the FY21 RII Track-4 competition were made through the Track-4 FAST mechanism.
- Convened two meetings with the EPSCoR Interagency Coordinating Committee (EICC) to share relevant program information and identify opportunities for coordination. Representatives from the EICC also presented information on their programs at a panel session during the annual PI meeting and held breakout sessions for PIs interested in learning more about leveraging funding opportunities.

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

Demographics of all reviewers who evaluated EPSCoR proposals or the program in FY 2021 are as follows: of the 212 reviewers, 19.8 percent were underrepresented minorities, 53.8 percent were female, 9.9 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. Though funding is awarded to a primary institution, there are always several subaward institutions involved in RII Track-1 and Track-2 awards. Subaward funding is not reflected in the tables provided earlier in this report but does help to enhance jurisdictional competitiveness. Data on research progress and outcomes are collected from subawards as well as the primary institution. In addition to subaward partnerships, RII awards require institutional collaborations, which are defined as collaborations among researchers at a RII awardee or sub-awardee and those at institutions not receiving any RII funds.

In FY 2021, RII Track-1 participants developed 333 institutional collaborations within EPSCoR jurisdictions; 284 institutional collaborations between EPSCoR jurisdictions and non-EPSCoR jurisdictions; and 118 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 Track-1 projects.

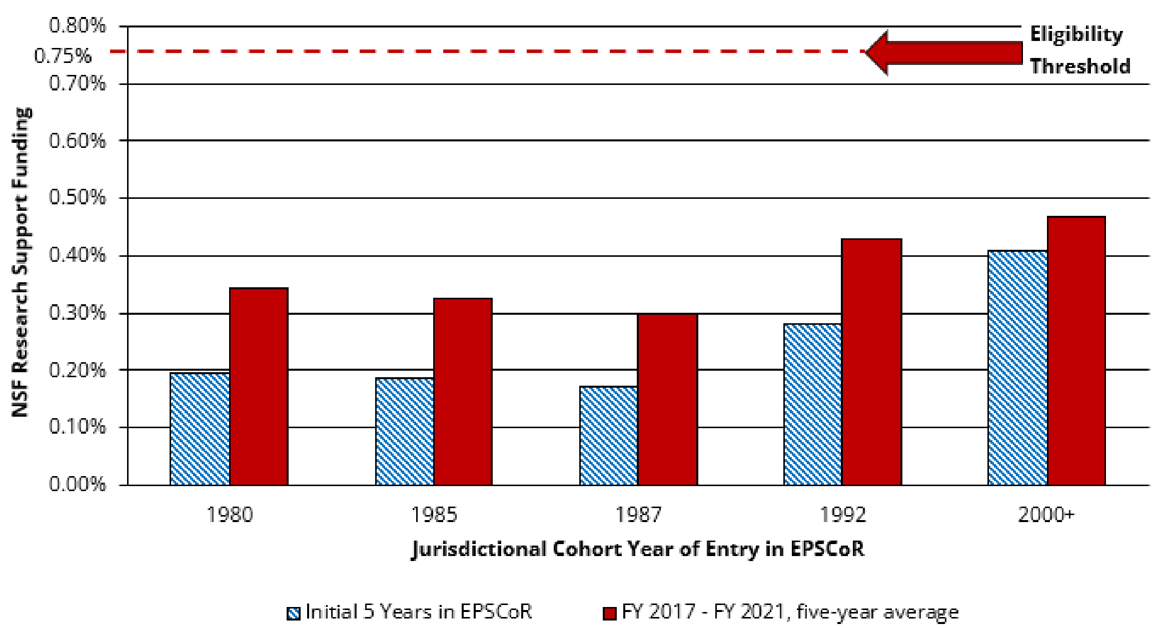
Among the 219 awards co-funded by EPSCoR in FY 2021, 173 involved collaborative research between multiple institutions. Of those 173 collaborative awards, 98 (57 percent) were collaborations between investigators from institutions in EPSCoR and non-EPSCoR jurisdictions.

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 budget over the most recent five-year period, excluding NSF funding to other federal agencies and EPSCoR RII and workshop/conference funding. Jurisdictions above 0.75 percent but less than 0.80 percent are allowed to remain EPSCoR-eligible for up to five years. 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.

Figure 1 (below) shows the average annual amount of NSF research funds given to each 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, Iowa, New Hampshire, New Mexico, Rhode Island, and the U.S. Virgin Islands. Former EPSCoR jurisdictions Missouri, Tennessee, and Utah are excluded because they were not EPSCoR-eligible in FY 2021.

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



Each cohort shows an increase in competitiveness over the periods of participation. For example, the

1980 cohort shows a 76 percent increase in NSF research funding over the past 41 years of EPSCoR activity. The 1985 cohort (Alabama, Kentucky, Nevada, North Dakota, Oklahoma, Puerto Rico, Vermont, and Wyoming) demonstrates a 74 percent increase during its 36 years of participation in EPSCoR. The 1987 cohort (Idaho, Louisiana, Mississippi, and South Dakota) shows a 73 percent increase over the past 34 years, whereas the 1992 cohort (Kansas and Nebraska) has a 54 percent increase in competitiveness over its 29 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 15 percent increase in research funding.

Percentage of NSF Funding, by Jurisdiction and EPSCoR Cohort

	Initial 5 Years in EPSCoR*	Most Recent 5 Year Period (FY 2017-2021)**
1980 Cohort	0.19%	0.34%
Arkansas	0.10%	0.28%
Maine	0.27%	0.27%
Montana	0.13%	0.41%
South Carolina	0.41%	0.58%
West Virginia	0.07%	0.17%
1985 Cohort	0.19%	0.33%
Alabama	0.33%	0.74%
Kentucky	0.22%	0.40%
Nevada	0.14%	0.32%
North Dakota	0.06%	0.16%
Oklahoma	0.30%	0.42%
Puerto Rico	0.15%	0.21%
Vermont	0.10%	0.13%
Wyoming	0.20%	0.22%
1987 Cohort	0.17%	0.30%
Idaho	0.08%	0.28%
Louisiana	0.36%	0.52%
Mississippi	0.16%	0.26%
South Dakota	0.09%	0.13%
1992 Cohort	0.28%	0.43%
Kansas	0.34%	0.46%
Nebraska	0.22%	0.40%
2000+ Cohort	0.41%	0.47%
Alaska	0.55%	0.67%
Delaware	0.41%	0.46%
Guam	0.02%	0.01%
Hawaii	0.56%	0.63%
Iowa***	N/A	0.69%
New Hampshire	0.44%	0.44%
New Mexico	0.58%	0.63%
Rhode Island	0.70%	0.63%
Virgin Islands	-	0.04%

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

**Percentages based on current eligibility guidelines.

***Iowa reentered EPSCoR eligibility in FY 2019; data for the initial five years not

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. 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 active projects.

RII Track-1 Aggregate of EPSCoR Outputs

	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	Total
Number of Active Awards*	27	28	27	26	26	
Publications	985	1,044	732	638	720	**4,119**
Grants Awarded	455	505	451	326	334	**2,071**
Value of Grants Awarded (Dollars in Millions)	$492.10	$269.13	$314.40	$146.87	$182.66	**$1,405.16**
Patents Awarded	17	8	17	10	12	**64**
Patents pending	29	15	44	38	20	**146**

*The outputs for the active RII Track-1 awards are not comparable from year-to-year due to the influx of new and expiring awards over the time period. Data is self-reported by each project through annual reports and aggregated for the program, by year.

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 these projects signifies strong commitment by NSF and the jurisdictions in strengthening jurisdictional human capital in science and engineering research and education.

RII Track-1 Human Resource Development

	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	Total
Faculty Supported	1,183	1,126	1,062	891	975	**N/A***
Post-Docs Supported	156	179	165	170	196	**N/A***
Graduate Students Supported	1,056	1,128	992	834	916	**N/A***
Undergraduates Supported	1,220	1,187	1,168	870	972	**N/A***
New Faculty Hired	54	27	40	35	45	**201**
Graduate Degrees Conferred	254	262	202	166	162	**1,046**
Undergraduate Degrees Conferred	634	357	297	183	242	**1,713**

*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.
Data is self-reported by each project through annual reports and aggregated for the program, by year.

NSF EPSCoR is continuing to refine and implement a cohesive research competitiveness evaluation framework for the program. The framework draws upon recommendations from a study completed in FY 2020 that helped to develop a flexible framework to explore, define, and measure research competitiveness. The evaluation framework will also be informed by the Future of NSF EPSCoR Committee, a subcommittee of the Committee on Equal Opportunities in Science and Engineering (CEOSE) at NSF. The subcommittee's charge is to address the questions:

a. What does the available evidence tell us about the effectiveness of NSF EPSCoR's current investment strategies, both individually and collectively, in advancing scalable, jurisdiction-wide solutions and best practices to achieve the program's goals?

b. Based on the answers to the question above, are there novel strategies or changes to the current strategies that would enable NSF EPSCoR and its jurisdictional partners to more effectively achieve its mission?

The committee's report is expected to be completed in May 2022. The report and evaluation framework will: (1) help identify potential impactful programmatic changes with respect to achieving the overall mission and increasing academic research competitiveness, and (2) produce a revised set of strategic priorities and an implementation plan that will leverage the current staffing capacity.

NSF-WIDE INVESTMENTS

For definitions of common acronyms used throughout NSF's FY 2023 Budget Request, see the NOTES found at the beginning of the entire document on pages iii-iv.

CLIMATE AND CLEAN ENERGY TECHNOLOGY

Description and Rationale

As the climate crisis intensifies and the need for reliable, sustainable energy grows, NSF investment in Climate and Clean Energy are essential for enhancing scientific knowledge and developing the solution needed for the future health and economic prosperity of our society. In the FY 2023 Request, NSF investments total over $1.50 billion to address the challenges of climate change and to develop novel clean energy solutions.

The magnitude of these challenges calls for a whole of NSF approach to engage scientists and engineers across disciplines through convergence research that addresses societal needs and integrates research and education to prepare a diverse climate and clean energy workforce. Investments will support community engagement, partnerships, and lab-to-market opportunities to expand research and education impacts. NSF will invest strategically in emerging areas to deliver tangible societal benefits and enable U.S. leadership for a sustainable, equitable future. These investments will primarily align with the goals of the USGCRP and Clean Energy Technology crosscuts with support beyond those investments further enhancing NSF's efforts to address the climate imperative.

Goals of Investments

NSF will invest in fundamental research to better understand the drivers of climate change and their interdependencies, and how climate change and extreme events impact communities, natural environments and hazards, and engineered systems. New models and methods will help to quantify and predict the impacts of climate change and to understand the consequences and impacts on both societal and environmental vulnerability and resilience. These investments will help design integrated systems approaches for intervention, mitigation, and adaptation strategies across multiple social and natural sectors, and scales ranging from local to global levels.

Climate change disproportionally affects low-income communities who can least afford to mitigate or migrate to avoid impacts to their economic condition. NSF will support climate equity through investments that encourage inclusivity, broadening participation, and leadership development, with the goal of addressing climate impacts and the sustainability of local/regional communities.

Research on climate change mitigation and adaptation systems that include environmental, educational, infrastructural, health, and community elements will create sustainable and resilient strategies to manage and engineer the changing world. Some climate change mitigation and adaptation strategies may be independent of or indirectly related to clean energy solutions, such as, but not limited to, greenhouse gas (GHG) capture; resilient and sustainable food-energy-water systems, for example to mitigate the impacts in the drought-stricken Western U.S; lowering GHG release from manufacturing and agriculture; and designing built environments for extreme weather.

NSF's clean energy investment will focus on advancing the transformation of energy systems for the future, including new energy sources, energy-efficient technologies, energy storage and transmission, and secure and sustainable energy systems. These investments will advance fundamental physics, chemistry and materials science research pertaining to energy, as well as research related to social, cultural, and individual acceptance of energy system transitions.

Some NSF clean energy research investments will also yield new climate change mitigation and adaption strategies. Examples include research for redesigning energy-intensive industries, low-power microelectronics, converting climate change drivers to clean chemicals and fuels, integrating renewables into a resilient, secure, equitable energy grid, sustainable resourcing of hydrogen and critical minerals needed for clean energy technology, and the electrification of the manufacturing, transportation, and chemical processing industries. Similarly, some NSF climate research investments will drive the development of optimized clean energy approaches. For example, understanding the impacts of rising temperatures, wildfires, drought, and severe weather on the social, natural, and built environments could directly inform the design of clean energy mitigation and adaptation methods.

NSF investments in cyberinfrastructure, computing, communications, and information systems will support the interconnected climate change and clean energy portfolios. Likewise, preparing a future workforce that understands the complex interdependencies of the climate, human, and other earth systems and that can innovate in clean energy and related green industries is critical for the U.S. to manage, mitigate, and adapt to climate change.

These NSF investments in Climate and Clean Energy research and education across the science and engineering spectrum will improve our understanding of climate change, increase innovative energy technologies, enhance sustainability, mitigate climate change, and lead to other societal benefits.

Potential Impact for Urgency and Readiness

Accelerating climate research and understanding impacts of climate change and clean energy technologies, requires bold thinking, convergent approaches, and an overarching commitment to equity, justice, and education. NSF will take concrete actions to advance knowledge, empower communities, and generate innovative solutions.

As indicated in the National Academies of Sciences, Engineering, and Medicine (the National Academies) report on *Accelerating Decarbonization of the U.S. Energy System*,[1] bold and decisive action is urgently required to address the need for clean energy. New resources are necessary to both initiate and accelerate new discovery, insights, and translation research pathways from exploratory concepts to technological solutions. The discovery, development, and deployment of clean energy technology solutions remain a primary direct and indirect mechanism to attenuate the current impacts of climate change and provide the path forward to thriving in an ever-advancing technological world that is increasingly reliant on dependable, cost-effective, and on-demand energy.

Climate observations and modeling, as well as in-depth understanding of the impacts of climate change on both environmental and societal systems, are fundamental to our ability to predict and address drivers and feedbacks of the climate system. Integrated observation systems and advanced modeling and computation are essential to quantify, predict, and forecast the consequences of climate change on people, communities, and ecosystems. Predictive capabilities at temporal and

[1] www.nationalacademies.org/our-work/accelerating-decarbonization-in-the-united-states-technology-policy-and-societal-dimensions

spatial scales relevant for decision-making (e.g., risk assessment of floods or heat waves) and societal adaptation are necessary for the implementation of sound mitigation, adaptation, and resilience strategies, as well as for the development of effective local, state, and federal policies. NSF investments in research, research infrastructure, and workforce development will advance our predictive capabilities to inform mitigation and adaptation practices.

NSF's support of all fields of science and engineering make it uniquely capable of advancing the integrated, interdisciplinary research needed to characterize and quantify climate thresholds and tipping points. This work is paramount to projections of future climate change and its compounding and cascading impacts on people, socio-economic, built, and environmental systems. NSF is poised to lead coordinated efforts to take on this global challenge through the Foundation's unique ability to implement a "whole of science and engineering" approach.

Budget Justification

A distinct advantage of NSF is the natural and inherent integration of research with education, which helps to ensure that the next generation of researchers and technical workforce—including those from groups traditionally underrepresented in STEM careers—are trained and able to bring their fresh perspectives and ideas to the table.

NSF is ideally suited to enable innovative climate and clean energy solutions due to the ease of collaboration across an expansive range of research disciplines. NSF can consider proposals in multiple emphasis areas from a wide swath of the research community, with the NSF merit review process ensuring that the best research ideas in those areas receive funding. The newly formed TIP directorate will strengthen and scale up the integration of foundational research, use-inspired research, and translational research, accelerating the impact of NSF investments.

At the FY 2023 Request level, investments in Climate and Clean Energy include high-risk, high-reward ideas from researchers across the science and engineering spectrum that will create broad new understanding and innovations that will increase energy efficiency, enhance sustainability, mitigate climate change, or lead to other societal benefits. NSF's investments will bolster the President's plan to advance climate science and sustainability research. Funding will further spur innovation, commercialization, and deployment of clean energy technologies and infrastructure as well as advance America's ability to lead and compete in key global markets.

This request will allow NSF to make climate investments within interconnected themes, informed by multiple USGCRP and National Academies reports. These areas highlight where NSF's multidisciplinary approach can coalesce to produce actionable knowledge as well as tools and technologies for decision makers.

In summation, FY 2023 investments will support:

1. **Fundamental Research:** To promote foundational, interdisciplinary, use-inspired, and convergent research to discover new science and engineering knowledge that advances our understanding of the climate system and the impacts on the social, natural, and built environments. Fundamental research on the thermodynamic, fluid dynamic, kinetic, electronic, metabolic, and system-level phenomena are the foundation of the next generation of energy

technologies that can help in tackling clean energy challenges and in creating sustainable and equitable societies and environments.

2. **Resilience and Sustainability:**
   - To further our understanding of the interdependencies of climate change and clean energy to ensure sustainable and equitable social, engineered, and natural systems.
   - To further our understanding of infrastructure essential for strengthening the Nation's resilience, security, and the stability of our energy supplies, Research encompasses the intelligent interconnection of built infrastructure, energy infrastructure, and cyberinfrastructure for overall resilience and efficiency.
   - To understand energy use as a sociotechnical system and enable ways to use energy more efficiently and increase the use of clean energy.
   - To enable development of a new generation of energy technologies, materials, and manufacturing processes in a sustainable manner while improving long-term impacts on human health and the environment.

3. **Integration of Fundamental and Translational Research:** To strengthen the integration throughout the NSF-funded research and innovation ecosystem, including the unique NSF Lab-to-Market Platform. to accelerate discovery, understanding, and translation of sustainable climate change adaptation and mitigation strategies and advanced energy technologies and systems.

4. **Community Equity:** To build knowledge that enables scientific and technological solutions that benefit society equitably and without disproportional impacts on underserved communities.

5. **Workforce Development:** To develop the workforce needed to address emerging climate challenges and to support the research and development of the next generation of energy technologies.

6. **Facilities essential for enabling research**: To provide state-of-the-art tools for research and education. Investments in NSF's major facilities, such as the National Center for Atmospheric Research (NCAR) and the National Ecological Observatory Network (NEON), enable the advancement of climate research.

CLEAN ENERGY TECHNOLOGY

Clean Energy Technology Funding

(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request[2]
BIO	$45.00	-	$59.28
CISE	24.22	-	31.12
ENG	143.38	-	223.57
MPS	132.07	-	128.56
OISE	0.01	-	5.00
TIP[1]	37.21	-	52.47
Total	**$381.89**	**-**	**$500.00**

[1] FY 2021 funding for TIP is shown for comparability across fiscal years.

[2] Funding includes resources for agency-wide initiatives.

Overview

Energy is essential, and our future as a people and a Nation depends on our leadership in the transition to clean energy. That leadership depends on winning the research, innovation, and education race to transform the energy sector and ensuring the global competitiveness of our energy workforce. NSF will advance the clean energy future through investments in fundamental research to transform energy systems and develop new energy industries; innovation and translation to move discoveries to the market and society; and education and workforce development, with a focus on preparing for the energy jobs of the future. Clean energy investments complement and align with NSF investments to advance climate change understanding, adaptation, and mitigation.

Energy production and use in the United States continues to grow, supporting our residential, commercial, and industrial sectors. Expanding sources of renewable energy (such as solar, wind, geothermal, hydro, tidal and biomass) are enabled by new discoveries, new technologies and the translation of those discoveries and technologies to practical solutions (for example, energy conversion technologies like fuel cells, and energy distribution technologies like the smart grid). Increased energy-efficiency and energy-use management tools support the U.S. economy as industries and households transition to clean-energy solutions, while supporting increased energy demands associated with computing and communication systems. Advances in designing and producing chemicals and materials for clean energy and energy efficiency technologies, as well as electrification of the chemical industry and transportation sectors, are critical to the transition to a carbon neutral world, with reduced impacts of energy systems on the global climate. Advances in plasma science, thermoelectrics, catalysis, and semiconductors provide new opportunities for energy system transformations. Integration of advances in biotechnology and bio-inspired systems into energy research will propel discovery and applications that create new industries. Leveraging artificial intelligence and optimization across energy systems will shape the energy sector of the future. Current and planned future NSF's investments across these research areas, from clean energy sources to clean energy uses (transportation, industry, cyberinfrastructure), will support U.S. leadership in the transition to clean energy.

NSF's clean energy investments span longstanding programs as well as focused solicitations. Research funding opportunities in clean energy enable partnerships of investigators in the economic and social sciences, educational research, biological sciences, physical sciences, computing and information sciences, and engineering disciplines to build fundamental knowledge and overcome technological barriers. NSF continues to make long-term investments in multidisciplinary research centers through the Centers for Chemical Innovation, Expeditions in Computing, Engineering Research Centers, and Industry-University Cooperative Research Centers programs. NSF also supports research infrastructure such as the Grid-Connected Testing Infrastructure for Networked Control of Distributed Energy Resources (DERConnect).

Goals

Clean Energy Technology investments at NSF are designed to identify and support transformative research to advance U.S. leadership in the clean energy transition. Goals include:

- *Support fundamental research* in science and engineering to change paradigms and spawn innovations in clean energy supply, distribution, and use;
- *S*upport *convergent research engaging teams* of scientists and engineers to address interconnected problems inspired by the need to reshape the energy sector and related emerging industries;
- *Develop energy research infrastructure*, as well as the associated computing and communications infrastructure, necessary to generate fundamental knowledge and technologies for clean energy;
- *Translate innovations* through unique funding opportunities and partnerships that foster co-design, co-creation, piloting, and prototyping*;* and
- *Develop the workforce of the future* to attract, inspire, educate, train and reskill/upskill individuals, from K-12 to college and industry, to support a diverse and engaged clean-energy workforce.

FY 2023 Investments

The cross-NSF investments in Clean Energy Technology in FY 2023 support high-risk, high-reward research ideas across the science and engineering spectrum that create broad new understanding and innovations to support energy efficiency, enhance sustainability, adapt to and mitigate climate change, spawn new industries, and support translation and partnerships for innovation, as well as education and workforce development.

Fundamental and Convergent Research: NSF will invest in fundamental, convergent clean-energy research to support: improvements in generation, conversion, storage, and distribution of electricity and fuels; advancements in renewable clean-energy sources; development of new energy materials; more efficient energy usage; as well as research related to infrastructure and systems, such as sustainable transit/vehicle technologies, building efficiency, sustainable computing, decarbonized manufacturing, and interconnected natural, human-built, and social systems.

Energy Research Infrastructure: Investments in energy research infrastructure will allow for the creation of more energy-efficient energy systems, from generation to distribution, for industry, transportation, buildings, and other uses. Investments in computing and communication research infrastructure will enable the creation of more efficient and sustainable hardware, software, and systems for computing and communication—a significant and growing component of U.S. electricity consumption. Energy research infrastructure investments will also afford piloting and prototyping of research-based solutions.

Innovation and Translation: NSF accelerates the translation of research results to the market and society, catalyzing a broad spectrum of advanced energy technologies and systems. NSF speeds translation of fundamental discoveries in clean energy into technologies and systems through its Centers for Chemical Innovation, Expeditions in Computing, Engineering Research Centers, and Industry-University Cooperative Research Centers, as well as through the NSF Lab-to-Market Platform comprising Partnerships for Innovation, NSF Innovation Corps, and the Small Business Innovation Research and Small Business Technology Transfer programs. In addition, NSF partners and coordinates with other agencies such as the Department of Energy and the Department of Defense to transition fundamental research further towards application.

Education and Workforce Development: To prepare a diverse clean energy workforce across the Nation, NSF invests in the Advanced Technological Education, NSF Research Traineeship, Faculty Early Career Development, Research Experiences for Undergraduates Sites and Supplements, and Research Experiences for Teachers in Engineering and Computer Science programs, as well as clean energy education in research projects. NSF support for Non-Academic Research Internships for Graduate Students (INTERN) provides students with relevant experience beyond academia, including in government and industry settings. The Innovative Technology Experiences for Students and Teachers (ITEST) program provides support for projects that involve k-12 students in innovative use of technologies, including those related to clean energy.

U.S. GLOBAL CHANGE RESEARCH PROGRAM (USGCRP)

U.S. Global Change Research Program
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request[1]
BIO	$155.00	-	$237.15
CISE	-	-	40.00
GEO	329.00	-	515.37
MPS	9.83	-	34.63
SBE	18.25	-	25.14
OISE	-	-	5.00
OPP	56.11	-	56.11
Total	**$568.19**	**-**	**$913.40**

[1]Funding includes resources for agency-wide initiatives.

Overview

NSF investments in climate and global change research span climate science, impacts, adaptation and mitigation strategies, and solutions. As part of NSF's holistic approach to addressing global change, NSF's investments aligned with USGCRP are complemented by investments in research to advance America's clean energy future—from foundational and use-inspired knowledge in physics, chemistry, biology, materials science, and computing to large-scale systems engineering computation, and advanced cyberinfrastructure. More information on these complementary investments can be found in the Clean Energy Technology narrative in this chapter.

NSF addresses climate and 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 climate and 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 and integrated 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 invests in the fundamental research at the heart of global change issues. 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 and sensing 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 environment.

Past investments have helped inform the National Climate Assessment and several other technical reports mandated by the Global Change 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-built system are critical in developing effective solutions to these challenges and capitalizing on opportunities.

Goals

1. Advance scientific knowledge of the integrated natural and human components of the earth system; and
2. Inform decisions: provide the scientific basis to enable decisions on adaptation and mitigation.

FY 2023 USGCRP Funding

Several investments of note are planned in FY 2023. NSF will develop regional climate impact integration hubs, focused on climate innovation, mitigation, adaptation, and equity. Hubs will have a regional focus, providing innovative solutions to relevant regional climate impacts that draw on all fields of science and engineering as well as local knowledge. A networked structure will connect, inspire, and include diverse scientific talent from across the Nation while a strong focus on outcome-oriented research will help to address the climate imperative.

A fundamental step in implementing the impact integration hubs is creating a National Discovery Cloud (NDC) for Climate. The NDC for Climate will federate access to advanced compute, data, software, and networking resources from multiple sources, including NSF-funded advanced computing resources, edge resources located at NSF major facilities, and capabilities deployed at other compute- and data-intensive NSF research facilities, as well as commercial cloud computing resources. In addition, the NDC for Climate will incorporate systems to curate, federate, and provide access to data from multiple sources. These approaches will enable new scientific discoveries by supporting the broad examination and reexamination of collected data, and by supporting scientific analysis of combinations of data from different sources. The NDC for Climate will further NSF's commitment to equity by democratizing access to research resources and necessary support services.

At a smaller scale, additional new and expanded climate activities are planned in FY 2023. Key investments include:

- A new investment through GEO on large-scale interdisciplinary work on climate change. Building on the strong foundation of fundamental research supported across GEO, this investment will transcend disciplinary boundaries and focus on topics of direct national importance at resolutions and scales needed by decisionmakers such as forecasting drought and water availability on timescales of months to years at local and regional scales.
- Expanded support for computation and cyberinfrastructure development, focused on revolutionizing data structures and architectures through an Open Science Initiative. This initiative will develop the data infrastructure necessary to address critical questions on climate and its impacts, enable an open science framework which is more accessible to artificial intelligence and machine learning systems, and support a scientific community and workforce trained to use these resources.
- Expanded education, equity, and workforce development opportunities will emphasize climate equity and the inclusion of all Americans in the growing green economy and research enterprise.
- In FY 2023, NSF will expand support for greenhouse gas (GHG) measurement and monitoring. NSF-supported projects examine GHG flux measurements as well as work on emerging technologies

that are essential in enhancing GHG monitoring and measurement capabilities.

Investments by Program Component Area (PCA)

USGCRP Funding by Program Component Area
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request
Integrated Observations	$177.94	-	$194.71
Multidisciplinary Earth and Human System Understanding	331.47	-	597.70
Integrated Modeling	47.24	-	67.29
Information Management and Sharing	-	-	40.00
Science of Adaptation and Science to Inform Adaptation Decisions	11.53	-	13.70
Total	**$568.19**	**-**	**$913.40**

Integrated Observations: NSF supports 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 and monitor important variations, trends, and feedback processes between natural and human systems.

Multidisciplinary Earth and Human System Understanding: NSF improves our knowledge of the Earth's past and present climate variability and change through activities to document and understand 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 that advance our understanding of the complex interactions between, within and among the components of integrated socio-environmental systems, such as improving our understanding of the frequency and intensity of extreme climate events and the impacts of these events on natural and human systems.

Integrated Modeling: NSF will continue to devote significant resources to advancing climate and integrated modeling capabilities. 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 and processes, ecosystems, biogeochemical cycling, and integrated socio-environmental systems.

Information Management and Sharing: NSF will invest in activities that advance our capability to collect, store, access, visualize, and share data and information about the integrated Earth system, the vulnerabilities of integrated human-natural systems to global change, and the responses to these vulnerabilities.

Science of Adaptation and Science to Inform Adaptation Decisions: 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 and Antarctic. In addition to supporting research that will inform mitigation and adaptation decisions, NSF will support fundamental research regarding the science of adaptation, defined as the adjustment in natural and/or human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects.

EQUITY FOR UNDERSERVED COMMUNITIES

Description and Rationale

Equal opportunity is a fundamental promise of our Nation. Yet far too many people who have been historically underserved, marginalized, and adversely affected by persistent poverty and inequality have not achieved full participation in all aspects of our society. Their contributions and diverse perspectives are essential to the economic wellbeing, health, and security of our Nation and of the world. In January 2021, the President signed Executive Order (EO) 13985, *Advancing Racial Equity and Support for Underserved Communities*, with the goal of promoting equity to provide everyone in the U.S. the chance to achieve their full potential. NSF is currently supporting this EO through increased engagement with and support of Historically Black Colleges and Universities (HBCUs), Hispanic-Serving Institutions (HSIs), and Tribal Colleges and Universities (TCUs) as well as with those communities that are historically underrepresented and underserved.

NSF has long been committed to identifying and addressing barriers to equity, both within our agency and in how we deliver programs to the thousands of institutions we support. In recent years, NSF has invested over $1 billion each year in its Broadening Participation programs and projects at institutions across the country. National support for these programs is broad. For example, the National Science Board (NSB) in its *Vision 2030*[1] report states, "Faster progress in increasing diversity is needed to reduce a significant talent gap" and they name that talent gap the "Missing Millions." In an address to the American Association for the Advancement of Science (AAAS) in February 2021, the NSF Director, Dr. Sethuraman Panchanathan, stated that finding and addressing the gap between the demographics of the research community and the demographics of the whole Nation—or the "missing millions"—is paramount.

Today, we know that there is unrealized Science, Technology, Engineering and Mathematics (STEM) potential across the Nation. The National Science Board estimates that, in order for the Nation's science and engineering workforce to be representative of the U.S. population in FY 2030, the number of women in STEM must nearly double, Black or African Americans must more than double, and Hispanic or Latinos must triple the number who are in the 2020 U.S. S&E workforce. These estimates are based on projections from the U.S. Census and Bureau of Labor Statistics, together with data from the National Center for Science and Engineering Statistics (NCSES).

NSF believes in inspiring, nurturing, and advancing domestic talent wherever it is found. Increasing equity in underserved communities must cover a wide set of stakeholders, from *individuals* traditionally identified as underrepresented or underserved, to *institutions of higher education* that serve groups underrepresented in STEM, to those *communities, lands and jurisdictions* across the country that currently lack resources and opportunities for robust education, workforce development, and regional innovation.

In FY 2023, NSF intends to build on existing programs and develop new ones to strengthen and scale equity investments. For individuals, NSF will focus on groups that are underserved and underrepresented in STEM, but especially those who are extremely underrepresented in STEM (those with low presence and/or low visibility in NSF programs) as well as the relevant intersections or

[1] www.nsf.gov/nsb/publications/2020/nsb202015.pdf

configurations of gender, race, ethnicity, and geographical location that comprise identity. For institutions, NSF will be more intentional in how we engage Minority Serving Institutions (MSIs) in our programs, starting with those classified as MSIs, but also focusing on the importance of MSI-bridge programs (funding open to all institutions that encourage participation by MSIs). For jurisdictions, NSF will expand support for individuals and institutions in EPSCoR jurisdictions to ensure geographic diversity.

Goals of Investments

- **Accelerate Student Success in STEM**: Increase K-12, undergraduate, graduate, and post-doctoral success in STEM disciplines among those from racial, ethnic, and other groups who have been historically underrepresented in STEM disciplines and careers.

- **Strengthen Educational Institutions through Collaborative Programs and Partnerships**: Strengthen leadership development and advancement opportunities for faculty at minority-service institutions to foster PI and institutional success in STEM and STEM education research.

- **Accelerate Inclusion and Access in NSF's Research Portfolio**: Increase and strengthen institution and faculty engagement in disciplinary fundamental research programs and activities from those institutions not currently well represented in NSF's research programs, including those from EPSCoR jurisdictions.

Achieving these goals will strengthen the capacity and capabilities of those that are currently underrepresented and underserved. This will reduce the barriers to full participation and provide access to all science and engineering research and education resources with new scientific fields, new technologies, and new modes of employment, all of which are crucial to American prosperity.

Potential for Impact, Urgency, and Readiness

The Nation is at a defining moment in support of equity, providing an opportunity to transform the U.S. scientific workforce so that it benefits from the talents of all Americans. The impact of these efforts will be to support U.S. global leadership in STEM and to address longstanding goals to promote social justice and to find talent that leads to a well-paid workforce and a vibrant U.S. economy

Although the Nation has made progress in promoting STEM education and a STEM workforce that includes all Americans (*Women, Minorities, and Persons with Disabilities in Science and Engineering*, NCSES, 2021),[2] persistent inequities remain and are at risk of worsening in the post-pandemic environment. Along with other inequities, those in education and employment are extremely salient. NSF will accelerate its efforts in improving equity in STEM.

FY 2023 investments will build on NSF's agency-wide $1 billion annual investment in broadening participation in STEM, which has already created new knowledge and established broad community readiness. NSF is unique in that it supports all areas of science and engineering as well as encourage interdisciplinary science, engineering, and education in the many programs that it supports. The

[2] *Women, Minorities, and Persons with Disabilities in Science and Engineering*, NSF/SBE/NCSES. NSF 21-321, April 29, 2021. https://ncses.nsf.gov/pubs/nsf21321

science and engineering research communities are supportive and ready to tackle these challenges, as evidenced by the biannual Committee on Equal Opportunity in Science and Engineering (CEOSE) reports to Congress.[3] NSF is ready for a surge of investments targeting equity in STEM education and the STEM workforce as never before.

Budget Justification

The FY 2023 Request presents an intentional and multi-faceted strategy addressing equity within the U.S. science and engineering enterprise to support activities at the intersections of identity as well as underrepresented communities. Building on prior investments, focused funding in FY 2023 of almost $400.0 million will support programs that aim to reduce barriers to and increase participation in science and engineering from groups traditionally underrepresented in these fields. Additional funding is also provided to increase fellowship support among these same groups. Lastly, EPSCoR funding is provided at $247.25 million, or $47.25 million over the FY 2021 Enacted.

These resources will provide more opportunities to enhance student success in STEM, strengthen educational institutions, and promote equity in underserved communities by creating synergies across Administration and NSF priority investment areas. NSF's commitment to finding talent provides opportunities that build strong STEM pathways that lead to a well-paid workforce and support the U.S. economy. To that end, the following programs are increased in NSF's FY 2023 Budget Request.

- **Growing Research Access for Nationally Transformative Equity and Diversity (GRANTED)** ($50.0 million) is a new initiative that will improve the Nation's research support and service capacity at emerging and underserved research institutions. GRANTED will use a variety of mechanisms and programs to further NSF's reach in advancing the geography of innovation and engaging the Missing Millions. GRANTED activities will support the enhancement of research administration and post-award management, as well as the implementation of effective practices for competitive proposal development, through mechanisms such as research-coordination networks (RCNs) and institutional partnership grants, ideas labs, and research enterprise hubs in different geographic regions. GRANTED funding in FY 2023 will focus on minority-serving institutions and aim to mitigate the barriers to competitiveness at underserved institutions within the Nation's research enterprise as NSF contributes to the Administration's priority on equity.

- **Alliances for Graduate Education and the Professoriate (AGEP)** ($14.0 million) aims to increase the number of African American, Hispanic American, Native American Indian, Alaska Native, Native Hawaiian and Native Pacific Islander (or AGEP population) faculty in STEM at all types of institutions of higher education. The program funds projects that increase the understanding of institutional policies and practices to help doctoral candidates, postdoctoral scholars, and faculty improve their academic pathways to tenure and promotion in the STEM professoriate.

- **Centers of Research Excellence in Science and Technology (CREST)** ($41.0 million) enhance the research capabilities of minority-serving institutions (MSI) through the establishment of centers that effectively integrate education and research. CREST promotes the development of new knowledge, enhancements of the research productivity of individual faculty, and an expanded presence of students historically underrepresented in STEM disciplines.

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[3] CEOSE, www.nsf.gov/od/oia/activities/ceose/index.jsp. NSB, www.nsf.gov/nsb/NSBActivities/vision-2030.jsp

- The **Hispanic-Serving Institutions Program (HSI)** ($60.50 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.

- **Historically Black Colleges and Universities Excellence in Research (HBCU-EiR)** ($37.93 million) program supports projects that enable STEM and STEM education faculty to further develop research capacity at HBCUs and to conduct research.

- **Historically Black Colleges and Universities Undergraduate Program (HBCU-UP)** ($48.50 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 approaches for improving the success of HBCU undergraduates so that they may pursue STEM graduate programs and/or careers.

- The **Louis Stokes Alliances for Minority Participation (LSAMP)** ($70.50 million) is an alliance-based program that works to increase the number of STEM baccalaureate and graduate degrees awarded to populations historically underrepresented in STEM disciplines.

- **NSF INCLUDES** ($50.50 million) is a comprehensive national initiative to enhance U.S. leadership in STEM discoveries and innovations focused on NSF's commitment to diversity, inclusion, and broadening participation in these fields. The vision of NSF INCLUDES is to catalyze the STEM enterprise to work collaboratively for inclusive change, resulting in a STEM workforce that reflects the population of the Nation.

- The **Tribal Colleges and Universities Program (TCUP)** ($23.0 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.

- **Established Program to Stimulate Competitive Research (EPSCoR)** ($247.25 million) 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 and geographic diversity.

- Expand support for **fellowship programs.** Some of this increase will support activities dedicated to promoting equity in underserved communities. Touching all NSF directorates, this funding will invest in programs across the agency, such as Research and Monitoring for Postbaccalaureates in Biological Sciences (RaMP), Entrepreneurial Fellows, Atmospheric and Geospace Sciences Postdoctoral Research Fellowships (AGS-PRF), and MPS-ASCEND External Mentoring. In addition to the Equity theme, this funding includes, but is not limited to, support for the goals described in the Discovery Engine theme.

The Broadening Participation table on the following pages gives a visual snapshot of the majority of NSF's equity programming.

NATIONAL SCIENCE FOUNDATION
PROGRAMS TO BROADEN PARTICIPATION
FY 2023 BUDGET REQUEST TO CONGRESS
(Dollars in Millions)

	Amount of Funding Captured	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Percent
Total, NSF Broadening Participation Programs		$1,188.43	-	$1,536.47	$348.04	29.3%

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.

NATIONAL SCIENCE FOUNDATION
PROGRAMS TO BROADEN PARTICIPATION
FY 2023 BUDGET REQUEST TO CONGRESS
(Dollars in Millions)

	Amount of Funding Captured	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Focused Programs						
ADVANCE	100%	$18.13	-	$20.50	$2.37	13.1%
Alliances for Graduate Education & the Professoriate (AGEP)	100%	8.00	-	14.00	6.00	75.0%
AGEP Graduate Research Supplements (AGEP-GRS)	100%	8.20	-	4.64	-3.56	-43.4%
Broadening Participation in Biology Fellowships	100%	4.70	-	10.50	5.80	123.4%
Broadening Participation in Engineering (BPE)	100%	6.55	-	9.00	2.45	37.4%
Career-Life Balance (CLB)[1]	100%	2.03	-	0.28	-1.75	-86.2%
Centers of Research Excellence in Science & Technology (CREST)	100%	24.00	-	41.00	17.00	70.8%
CISE Education and Workforce	100%	13.65	-	12.75	-0.90	-6.6%
CISE-MSI Research Expansion Program	100%	-	-	7.00	7.00	N/A
Coastlines and People (CoPe)	100%	32.59	-	28.00	-4.59	-14.1%
Disability and Rehabilitation Engineering (DARE)	100%	-	-	6.00	6.00	N/A
Excellence Awards in Science & Engineering (EASE)[2]	100%	3.63	-	7.64	4.01	110.7%
Growing Resrch Access for Nationally Transformative Equity & Diversity (GRANTED)	100%	-	-	50.00	50.00	N/A
Historically Black Colleges & Universities Undergraduate Program (HBCU-UP)	100%	36.50	-	48.50	12.00	32.9%
HBCU Excellence in Research (HBCU-EiR)	100%	21.25	-	37.93	16.68	78.5%
IUSE: Hispanic Serving Institutions (HSI) Program	100%	46.50	-	60.50	14.00	30.1%
NSF INCLUDES	100%	20.75	-	50.50	29.75	143.3%
Louis Stokes Alliances for Minority Participation (LSAMP)	100%	49.51	-	70.50	20.99	42.4%
MPS Ascending Postdoctoral Research Fellowships (MPS-Acend)	100%	9.26	-	20.00	10.74	115.9%
NSF Scholarships in STEM (S-STEM)[3]	100%	94.70	-	119.15	24.45	25.8%
Partnerships for Research & Education in Materials (PREM)	100%	8.95	-	9.00	0.05	0.6%
Partnerships in Astronomy & Astrophysics Resrch Ed (PAARE)	100%	-	-	1.50	1.50	N/A
SBE Build and Broaden	100%	6.30	-	8.00	1.70	27.0%
SBE Postdoctrl Resrch Fellwshps-Broadening Participatn (SPRF-BP)	100%	3.13	-	6.00	2.87	91.5%
Science of Broadening Participation	100%	1.50	-	1.50	-	-
Tribal Colleges & Universities Program (TCUP)	100%	16.50	-	23.00	6.50	39.4%
Subtotal, Focused Programs		**$436.34**	**-**	**$667.39**	**$231.05**	**53.0%**

[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).

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

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.

NATIONAL SCIENCE FOUNDATION
PROGRAMS TO BROADEN PARTICIPATION
FY 2023 BUDGET REQUEST TO CONGRESS
(Dollars in Millions)

	Amount of Funding Captured	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Emphasis Programs						
Advancing Informal STEM Learning (AISL)	58%	$36.25	-	$43.21	$6.96	19.2%
Computer Science for All (CSforAll)	62%	15.25	-	15.19	-0.06	-0.4%
CyberTraining	51%	3.82	-	3.06	-0.76	-19.9%
Discovery Research PreK-12 (DRK-12)	56%	53.20	-	55.72	2.52	4.7%
EDU Core Research	62%	47.51	-	63.20	15.69	33.0%
Graduate Research Fellowship Program (GRFP)	67%	189.44	-	236.77	47.33	25.0%
Improving Undergraduate STEM Education (IUSE)	64%	63.52	-	69.54	6.01	9.5%
Innovative Tech. Exp. for Students and Teachers (ITEST)[3]	74%	38.34	-	29.39	-8.96	-23.4%
International Research Experiences for Students (IRES)	54%	6.66	-	5.40	-1.26	-18.9%
Research Exp. for Teachers (RET) in Engr. and Computer Sci.	72%	5.94	-	9.50	3.57	60.1%
Research Exp. for Undergrad. (REU) - Sites and Supplements	61%	52.12	-	51.33	-0.80	-1.5%
Robert Noyce Teacher Scholarship Program (NOYCE)	59%	39.86	-	39.53	-0.33	-0.8%
Subtotal, Emphasis Programs		**$551.93**	**-**	**$621.83**	**$69.91**	**12.7%**

[3] 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.

NATIONAL SCIENCE FOUNDATION
PROGRAMS TO BROADEN PARTICIPATION
FY 2023 BUDGET REQUEST TO CONGRESS
(Dollars in Millions)

	Amount of Funding Captured	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Geographic Diversity Program						
EPSCoR	100%	$200.16	-	$247.25	$47.09	23.5%
Subtotal, Geographic Diversity Program		**$200.16**	**-**	**$247.25**	**$47.09**	**23.5%**

NSF'S RESEARCH PORTFOLIO: THE DISCOVERY ENGINE

Description and Rationale

NSF funds research on vital problems and challenges that serve to advance science to benefit the Nation. NSF's support for innovative research helps to improve quality of life, enhance national security, and fuel American leadership in a wide range of technological and industrial sectors. NSF supports all fields of science and engineering, starts and fuels dynamic collaborations, supports innovation in all areas of STEM education, and broadens opportunity and participation in America's science and engineering enterprise. Because NSF does all this simultaneously, it can integrate these approaches in its research portfolio where and when it is needed.

NSF's research portfolio, through which both research and education opportunities are funded, is the endeavor for which the agency is best known. This research portfolio refers broadly to foundational research whose topics and goals are identified and driven by research communities and individual investigators. Resulting disciplinary or interdisciplinary proposals are submitted to a rigorous peer-review process through which NSF identifies and supports groundbreaking research concepts that are then implemented by tens of thousands of students and researchers in nearly 2,000 research institutions.

Over the past seven decades, NSF's research portfolio—the **Discovery Engine**—has funded research and researchers, innovations and innovators, and world-class research infrastructure that have helped to transform America. While it is foundational in nature, it produces strong societal dividends in diverse areas and on many timescales. NSF investments have produced science and technology with deeply impactful and visible results. The Internet, Google, Qualcomm, 3D printing, the economic theory underpinning spectrum auctioning and kidney exchanges, and the polymerase chain reaction (PCR) testing technique that is critical in the fight against COVID-19 were all supported NSF investments.[1] Of Nobel Prize winners, 253 have received funding from NSF. For Computing's analog to the Nobel Prize, the Turing Award, nearly two-thirds of all recipients (43 out of 71) have received funding from NSF.

NSF is looking ahead, seeking to build on past successes in supporting foundational discoveries, impactful technologies, and tomorrow's emerging industries. Across all STEM areas, and comprising both research and education, NSF is supporting potentially groundbreaking work in climate change adaptation and mitigation, artificial intelligence, quantum information science, advanced manufacturing, advanced wireless, biotechnology, new educational technologies, stronger infrastructure, bias reduction, greater equity, better jobs, and much more.

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[1] National Academies. Information Technology Innovation: Resurgence, Confluence, and Continuing Impact. www.nap.edu/read/25961/chapter/1

Goal of Investment

NSF's research portfolio advances science and engineering discovery in many ways, and notably overlaps with key Administration priorities with investments in Climate and Clean Energy, Equity for Underserved Communities, and Emerging Industries. At the FY 2023 Request level, NSF's research portfolio will promote American leadership in these and other vital areas while laying the foundation for future advances for decades to come. NSF will pursue these goals in three complementary ways:

- **High-Value Strategic Investments in Research.** These investments seize new opportunities for making substantial advancements. They combine the potential for meaningful breakthroughs now with dynamic opportunities for long-term innovation. These investments prompt and accelerate the formation of new industries and evolve in response to urgent national needs.

- **Integrating Research and Education.** In NSF's research portfolio, research and education inform and strengthen one another, creating a feedback loop that advances science and engineering while building a workforce fluent in state-of-the-art science and technology topics. NSF programs are based on the premise that interweaving research and education creates opportunity at greater scale than either activity on its own. Integrating research and education strengthens American leadership in a wide range of scientific and technological domains.

- **Broadening Opportunity and Participation in STEM.** Every demographic and socioeconomic group in every geographic region of the country has talent to contribute. NSF seeks to inspire, motivate, and support more people to contribute to, and benefit from, America's science and engineering enterprise. For NSF, broadening participation is both an emphasis of specific programs, as indicated in the portion of this document that focuses on equity, and is increasingly integrated into all research activities.

Potential for Impact, Urgency, and Readiness

America faces a time of great challenges and greater opportunities. We seek to improve quality of life for everyone. We seek to strengthen communities and create well-paying jobs. We seek to lead the world in innovation and to translate that innovation to empower an America that is more secure, more resilient, more sustainable, and more just. These are the principles by which NSF's research portfolio operates, and the Administration's policy framework further strengthens NSF's resolve to promote these ideals in the groundbreaking work that NSF funds.

<u>Building on a Groundbreaking Strategy</u>
For decades, NSF has helped fuel American leadership in vital areas of science and engineering and in the economic, environmental, social, and military domains that science can advance.

Because of the way in which NSF's component parts work together and coordinate, the NSF approach is capable of finding and supporting groundbreaking ideas. When NSF receives outstanding proposals that do not fit squarely into a single academic discipline, different parts of NSF work together to evaluate and support them.

NSF has broad reach and deep relationships with many academic communities, representing approximately 24 percent of the total federal budget for basic research conducted at U.S. colleges and universities. In many fields such as mathematics, computer science, and the social sciences, NSF is the largest source of federal backing. These relationships and the all-of-STEM reach of its research portfolio give NSF the ability to draw, identify, and support forward-looking proposals that might otherwise "fall between the cracks". In many cases, this support generates unexpected early discoveries and allows researchers to turn their attention toward significant new opportunities to serve the Nation. When that happens, NSF can further realign its research portfolio to help American science seize these moments.

For example, support of early discoveries and subsequent realignments were key to the development of CRISPR, a transformative biotechnology that revolutionizes our ability to edit the genetic code of any living organism. The discovery of CRISPR emerged from a combination of NSF research funding programs over many years and exemplifies the elongated time scale on which benefits from fundamental research can occur. CRISPR is now accelerating discovery across many fields of biology, medicine, and even material science. One exciting application is correcting human genetic diseases such as sickle cell anemia, and it is worth noting that the 2020 Nobel Prize in Chemistry was awarded to CRISPR's NSF-supported discoverers.

From its beginning, NSF has pioneered a world-leading approach for supporting research, an approach that other countries have admired and attempted to emulate. By applying its Merit Review,[2] NSF leverages expertise from all over the country to respond effectively to each successive wave of new ideas. For funding decisions made in FY 2020, the most recent year for which complete data is publicly available, over 30,000 individuals reviewed proposals, served on panels, or both. Working together, these groups and individuals help NSF support the cutting-edge of innovation in science.

Supporting the Nation's Full Range of Talent

In FY 2023, NSF expects to support almost 140,000 students and researchers via awards to nearly 2,000 organizations and institutions, in all states and territories. For many STEM topic areas, NSF represents the area's largest federal funder of academic research, including artificial intelligence, environmental sciences, mathematics, social and behavioral sciences, biology, and computer and information science. NSF's deep and vigorous relationships with the Nation's researchers and research institutions give it profound convening power to identify scientific challenges, advance on technical opportunities, and solve societal problems.

For example, NSF's support of early-stage economics research on poverty over five decades has transformed how governments and other organizations around the world tackle the problem. These researchers, many of whom have won Nobel Prizes, have helped to lift millions of people out of poverty.[3]

Operating with Urgency and Strategy

To accomplish its science, technology, economic, and societal goals requires that America excel at both the "short game" and the "long game." The "short game" is the ability to transform the knowledge that we have into products, practices, and instruments that we can use to solve problems, create change, and empower people right now. The "long game" is making sure that the knowledge base from which our country will need to draw in the future is as strong as possible—with the imperative

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[2] www.nsf.gov/bfa/dias/policy/merit_review/

[3] www.nsf.gov/news/special_reports/nobelprizes/eco.jsp

that continuing American leadership will require this knowledge base to remain at the forefront of scientific advancement. NSF's research portfolio offers benefits at a range of timescales. This approach has fueled generations of innovators and innovations and created societal opportunities. NSF's strategic focus not just on supporting the best science today, but also on planting seeds for future generations of research, has helped America build back better generation after generation.

For example, outcomes from NSF's early-stage investments in core areas of science and research—that is, outcomes from prior research portfolio investments—are seen in many places, including the polymerase chain reaction (PCR) testing technique that has been critical in the fight against COVID-19 and the synthetic biology findings that yielded vital components of the COVID-19 vaccines. Connectivity has also been of crucial importance during the pandemic, and over recent decades NSF-funded researchers have developed technologies that help the internet traffic stay scalable globally and have discovered innovative approaches that improve connectivity in rural areas, including Navajo Nation lands.

Another example can be seen in an interdisciplinary program, Predictive Intelligence for Pandemic Prevention (PIPP), which was created in FY 2021 in response to the COVID-19 pandemic. This initiative focuses on fundamental research and capabilities needed to tackle grand challenges in infectious disease pandemics through prediction and prevention. Projects must identify an innovative interdisciplinary grand challenge that engages integrated computational, biological, engineering, and social/behavioral approaches to formulate and solve critical problems relating to predictive intelligence for pandemic prevention. PIPP activities place great emphasis on high-risk/high-payoff convergent research that has the potential for large societal impact, and funded teams are expected to work across scientific, disciplinary, geographic, and organizational divides, push conceptual boundaries, and build new theoretical framings of the understanding of pandemic predictive intelligence.

Budget Justification

Scientific research is NSF's most fundamental and universal activity. At the FY 2023 Request level, NSF's investments in such research—the Discovery Engine—represent an ongoing commitment to federally funded R&D and allow the Foundation to support a broad range of programs in all NSF directorates and offices. All NSF directorates participate, supporting over 400 disciplinary and interdisciplinary programs across the Foundation.

The requested research funding in FY 2023 will serve and empower American researchers to lead the world in vital scientific advances for decades to come. The increases requested in this budget will serve to reduce the number of high-quality curiosity driven research proposals that are not funded. If the requested funding is not provided, the discoveries and societal benefits this lost research offers will be delayed, deferred, or lost entirely. The increased funding for research in this budget will accelerate the pace of discovery, tighten the cycle from idea to funding to results, and support national competitiveness in the most important areas of science and engineering. Just as today's artificial intelligence revolution has its roots in NSF research portfolio investments going back over many decades,[4] the opportunity for future revolutions rests with this additional investment in the portfolio going forward.

At the FY 2023 Request level, through the Discovery Engine rubric, NSF will:

- Evaluate almost 50,000 proposals through the competitive merit review process and make over 13,400 new competitive awards, of which almost 11,500 are expected to be new research grants.

- Fund over 77,000 researchers and postdoctoral associates plus over 50,000 graduate students and almost 49,000 undergraduate students.

- Expand support for **fellowship programs**. Touching all NSF directorates, this funding will invest in programs across the agency such as CISE Graduate Fellowships, ENG Postdoctoral Fellowships, SBE Postdoctoral Research Fellowships, and STEM Education Postdoctoral Research Fellowships. In addition to the Discovery Engine theme, this funding includes, but is not limited to, support for the goals described in the Equity theme.

- Provide leadership through NSF's **National Center for Science and Engineering Statistics** (NCSES) in government-wide evidence building activities and initiatives, including standing up the first-ever standard application process for applying to access restricted-use data from statistical agencies and units, as well as implementing the proposed National Secure Data Service through the expansion of America's DataHub.

[4] National Academies. Information Technology Innovation: Resurgence, Confluence, and Continuing Impact. www.nap.edu/read/25961/chapter/1

EMERGING INDUSTRIES THEME

For definitions of common acronyms used throughout NSF's FY 2023 Budget Request, see the NOTES found at the beginning of the entire document on pages iii-iv.

EMERGING INDUSTRIES

Description and Rationale

For more than 70 years, NSF has supported fundamental research across a broad range of science and engineering fields. NSF investment in high-risk, high-reward research has given rise to autonomous vehicles, revolutionary next-generation wireless networks and systems, novel computational platforms, life-saving medical devices, advanced manufacturing, and precision agriculture. As the U.S. faces intensifying global competition for science and technology leadership, NSF is ready to strengthen and scale up investments in breakthrough technologies, innovation, and translation. A foundation of NSF's investment in Emerging Industries is also a focus on nurturing diverse talent, which leverages NSF's deep relationships with over 2,000 of America's leading research institutions.

At the FY 2023 Request level, NSF will accelerate advances in Emerging Industries by strengthening a dynamic, diverse, and well-coordinated portfolio of investments. As outlined below, these investments will scale up existing investments to accelerate outcomes and increase impacts, while also launching new programs that will empower researchers and innovators to collaborate. Support for Emerging Industries will come from across NSF, with the Directorate for Technology, Innovation, and Partnerships (TIP) closely coordinating across all directorates and offices, including the EPSCoR program. TIP's ability to work across all parts of NSF, while also stimulating partnerships with America's leading researchers and prospective innovators, creates an important opportunity to support innovation that can more quickly be brought to market or otherwise translated to improve economic opportunity and quality of life.

Goal of Investment

NSF's Emerging Industries portfolio will align with NSF's broader goals to energize the Nation's economic competitiveness, sustain our global leadership and resilience, expand the geography of innovation, and improve quality of life for everyone. Specifically, NSF will:

- advance science and engineering research and innovation that could lead to breakthrough technologies as well as solutions to national and societal challenges.

- accelerate the translation of fundamental discoveries from lab to market, helping to advance the U.S. economy.

- create equitable education pathways to help ensure every American can pursue high-wage, good-quality jobs.

Building on NSF's longstanding leadership in science and engineering research and education, a key focus will be to help Americans in all regions of the country develop and build new innovation ecosystems that strengthen communities and address vital national needs. NSF will strengthen and scale up use-inspired, solution-oriented research and innovation in a range of technology areas including advanced manufacturing, advanced wireless, artificial intelligence, biotechnology, microelectronics and semiconductors, and quantum information science. These industries will expand the national capacity to advance key Administration and Congressional goals such as managing challenges associated with climate change and increasing equity throughout society. A key focus of these innovation ecosystems will be to develop strategic partnerships that link academia, industry, government, philanthropy, investors, and civil society.

Potential for Impact, Urgency, and Readiness

The Nation faces a defining moment. Global competition for leadership and talent in science, engineering, and technology is at an all-time high. For the United States to remain a global leader, we must recommit to investing in breakthrough technologies and innovation, fostering dynamic new partnerships, and nurturing talent throughout the country. The Internet, Google, Qualcomm, 3D printing, and economic theory underpinning spectrum auctioning and kidney exchanges were all supported by NSF investments. The COVID-19 pandemic has only reinforced the importance of science and technology in meeting emerging needs; the polymerase chain reaction (PCR) technique, pioneered through NSF investment, has been critical in the fight against COVID-19. The technologies and industries that are the focus of national conversations around competitiveness today, and the ones that will emerge in the future, are rooted in sustained NSF support for research and innovation at the frontiers of science and engineering.

At the FY 2023 Request level, NSF will catalyze research and innovation in emerging technologies through investments in Emerging Industries that address the following research priorities:

- **Advanced Manufacturing.** Accelerate breakthroughs in manufacturing materials, technologies, and systems through fundamental, multidisciplinary research with the potential to transform manufacturing capabilities, methods, and practices.

- **Advanced Wireless.** Fill knowledge gaps and advance innovations 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, while ensuring innovation and security for all users.

- **Artificial Intelligence.** Bring together numerous fields of scientific inquiry—including computer and information science; cognitive science and psychology; economics and game theory; education research; engineering and control theory; ethics; linguistics; mathematics; and philosophy—to advance the frontiers of trustworthy artificial intelligence and robotics, including advancing perception, learning, reasoning, recommendation, and action in the context of specific fields and economic sectors.

- **Biotechnology.** Further advances in genomics, bioinformatics and data analytics, structural and computational biology, biophysics, synthetic biology, tissue engineering, and development of new types of biomaterials, bio-inspired data storage and microelectronics, and biomanufacturing, accelerating the ability to harness biological systems to create goods and services that can contribute to advances in agriculture, health, security, manufacturing, and the climate.

- **Microelectronics and Semiconductors.** Address the semiconductor challenges facing our Nation due to technological and global trends, such as the end of Moore's Law and offshoring of semiconductor fabrication and manufacturing, by supporting future semiconductor discovery, development and fabrication, which can lead to future domestic and related electronics foundries.

- **Quantum Information Science.** Pioneer the development of quantum computing, communication, sensing, and networking to advance information processing, transmission, and measurement in ways that classical approaches can only do much less efficiently, or not at all.

In addition, NSF investments in Emerging Industries would:

- **Innovate for Equity.** Increase equity and help America build back better by showing how innovators and entrepreneurs can create opportunity for Americans from diverse backgrounds and circumstances. Technological transitions can be especially difficult for communities that face structural inequalities. Research that shows how to innovate effectively with the broadest possible participation is a way to draw more Americans to Emerging Industries. Research that reveals more effective ways to support and mentor diverse populations can improve educational outcomes and employment prospects in underserved communities.

- **Strengthen and Scale Up Technology Translation.** Advance understanding of economic incentives, customer discovery, research usability, industrial organization, and supply chains that can increase the rates at which research discoveries are translated into successful companies. By empowering the Nation's next generation of innovators and entrepreneurs, we can increase the rate at which technological discoveries become successful companies.

- **Protect National Security and Economic Resilience.** Support research and education activities that protect U.S. security and strengthen our economic resilience. Notably, NSF investments in cybersecurity research will address the need to protect digital assets and activities; anticipate, deter, detect, resist, and tolerate cyber-attacks; understand and predict cyber risks; and respond and recover effectively at all levels. In addition, NSF investments in cybersecurity education will nurture a future workforce of cybersecurity professionals. NSF investments in economic resilience will additionally advance research ensuring safe, clean, and reliable access to critical products, materials, and minerals, in turn supporting other Emerging Industries like Advanced Manufacturing.

Budget Justification

At the FY 2023 Request level, NSF will support an Emerging Industries portfolio that consists of a broad suite of programs funded from across all NSF directorates and offices. As noted above, investment priorities include Advanced Manufacturing ($421.51 million), Advanced Wireless ($168.56 million), Artificial Intelligence ($734.41 million), Biotechnology ($392.26 million), Microelectronics and Semiconductors ($145.69 million), and Quantum Information Science ($261.0 million). In addition, FY 2023 Request funding for the new Directorate for Translation, Innovation, and Partnerships (TIP) ($879.87 million) will specifically open new possibilities for research and education by catalyzing strategic partnerships linking academia, industry, government, philanthropy, investors, civil society, and communities of practice that in turn cultivate 21st-century local, regional, and national innovation ecosystems. TIP will serve as a cross-cutting platform: by working in close collaboration with all of NSF's other directorates and offices on these priority investments, TIP will work to rapidly bring to the market and to society the innovations that result from all of NSF's investments in Emerging Industries.

Investments made possible by the FY 2023 Request level include:

- The **Future of Semiconductors (FuSe)** activity will invest in new materials, materials processing and characterization, fabrication, devices and systems, and computing, sensing, and communication systems answering both near-term supply chain concerns and longer-term Post-Moore's Law challenges. FuSE will invest in research opportunities in semiconductor-related areas including new materials, fabrication and manufacturing, electronics, and computer systems. FuSE will also consider research infrastructure needs in this domain, particularly improving semiconductor fabrication foundry access for NSF-funded researchers, and how potential partnerships with industry may facilitate such access. Educational needs and opportunities, particularly those coupled to foundries as experiential learning, are also of interest.

- The **Quantum Information Science and Engineering (QISE) National Virtual Laboratory (NVL)**, which will serve as a national, community-driven effort that supports the smooth integration and translation from fundamental science and engineering to use-inspired applications. Building on the continued and sustained support of fundamental research from existing NSF programs, the NVL will draw together expertise and talent from a broad range of disciplines to enable the creation and application of functional quantum devices and systems. Coordination will be provided through a virtual infrastructure that serves much like a laboratory to identify roles and resource needs and establish mechanisms to enable all members of the laboratory to communicate and function together as a whole. In this way, the NVL enables anyone to become engaged and contribute to advances in QISE. A key focus of the activity will be to promote broad participation, diversity, equity, and inclusion in QISE.

- The **NSF Regional Innovation Engines (NSF Engines)** program will simultaneously address major scientific and technological goals while ensuring broad societal benefits and global leadership. The NSF Engines will advance use-inspired, solution-oriented research and innovation in a range of technology areas (e.g., advanced manufacturing, advanced wireless, artificial intelligence, biotechnology, QISE, semiconductors) as well as in a diverse set of national issues (e.g., the bioeconomy and climate change). The NSF Engines will incentivize partnerships that bring together multiple disciplines, institutions, and sectors, to include academia, industry, nonprofits, state and local governments, and venture capital. The NSF Engines will span the Nation's geography and be responsive to regional strengths and needs. They will simultaneously focus on technology and workforce capabilities while contributing to broad societal benefits and global leadership and will serve as hubs for NSF's broader portfolios of investment in their respective areas of focus, including the investments described above.

- The **NSF Lab-to-Market Platform** will be strengthened and scaled by: (i) increasing funding for the highly successful NSF Partnerships for Industry (PFI) program, which offers researchers with prior NSF-funded research the opportunity to explicitly enter into partnerships, especially with industry, to accelerate the transition of discoveries from the laboratory to the marketplace for societal benefits; (ii) increasing funding for the NSF Innovation Corps (NSF I-Corps™) program, building out the I-Corps™ Hubs and Teams, supporting a Coordination Entity to enable coordination across the Hubs, and supporting partnerships with other NSF programs such as the NSF Convergence Accelerator and RIEs; and (iii) increasing flexibilities for the NSF Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs. NSF will also explore new pathways for translation, e.g., offering education and training as well as open-source innovation research grants through the Pathways to enable Open-Source Ecosystems (POSE) program to spur open-source ecosystems.

- Emerging industries such as artificial intelligence, data science, and quantum information science have the significant opportunity to establish equity and inclusion from the outset and should be synonymous with opportunity for all. The new **Technology and Innovation Internships for Experiential Learning (TIIEL)** will work with industry, government, and educational partners to support internships and other experiences, training, and credentialing for diverse learners at every stage of education, from first-time job seekers to experienced workers looking for new opportunities. Complementing NSF's broader portfolio of investments to train a diverse future workforce in Emerging Industries, the TIIEL program will specifically offer students from groups long underrepresented or underserved with opportunities to be prepared for jobs on day one.

ADVANCED WIRELESS RESEARCH

Advanced Wireless Research Funding[1]
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request
CISE	$87.45	-	$93.26
ENG	25.83	-	27.75
MPS	17.00	-	17.00
TIP[2]	0.75	-	30.55
Total	**$131.03**	**-**	**$168.56**

[1] Funding displayed may have overlap with other topics and programs.
[2] FY 2021 funding for TIP is shown for comparability across fiscal years.

Overview

Advanced wireless networks and systems will provide the backbone that connects users, devices, applications, and services that will continue to enrich America's economy. NSF has a proven track record of investing in fundamental research on wireless technologies. For example, today's fifth-generation ("5G") wireless networks and systems have been enabled by ground-breaking NSF-funded research on millimeter-wave capabilities, advanced antenna systems, and other novel algorithms and protocols dating back to 2004. NSF partners with other federal agencies and industry on such research. Looking forward, NSF-supported research will innovate in areas critical to future generations of wireless networks and systems, such as new wireless devices, circuits, protocols, and systems; security and resilience; mobile edge computing; distributed machine learning, and inferences across mobile devices; and fine-grained and real-time dynamic spectrum allocation and sharing. This research will offer new insights capable of making wireless communication faster, smarter, more affordable, and more robust and secure.

In addition, by deepening public and private partnerships through programs like the Resilient & Intelligent Next-Generation Systems (RINGS) and Platforms for Advanced Wireless Research (PAWR), NSF will accelerate the lab-to-market translation of innovative research outcomes in academic and government labs to successful products and services for the benefit of society.

Goals

NSF's leadership in wireless research has three intertwined components:

1. *Fundamental Research on Advanced Wireless:* Support fundamental research enabling the conception, exploration, and development of advanced wireless technologies.
2. *Advanced Wireless Research Testing Platforms:* Establish advanced wireless research testing platforms, in collaboration with industry, to experiment with new technologies at scale and to generate data sets that can be used by the research community to validate proposed methods and techniques at earlier stages of development.
3. *Education and Workforce Development:* Catalyze academic, industry, and community leaders to work together to nurture the next generation of the wireless and spectrum workforce, including researchers, engineers, technicians, and practitioners, as well as to increase public awareness of advanced wireless.

FY 2023 Investments

Fundamental Advanced Wireless Research

- Through foundational research programs in CISE and ENG, outcomes from NSF investments in advanced wireless over the last decade have enabled 5G deployments capable of delivering multi-gigabit-per-second (Gbps) bandwidth to individual wireless users. Continued investments in advancing these frontiers are focused on developing advanced technologies to support ultra-low latencies of the order of sub-milliseconds while simultaneously connecting hundreds of millions of devices. NSF foundational research programs are also investing in technologies beyond 5G systems, developing more efficient uses of spectrum bands, higher-order spectrum, spectrum sharing, sensing using wireless communications, and novel codes for highly-efficient device-to-device communications as well as improving resilience and security of wireless networks. These investments will continue to support the foundations of U.S. leadership in advanced wireless R&D.
- In FY 2023, in partnership with the Department of Defense (DOD) Undersecretary of Defense for Research and Engineering (OUSD (R&E)), the National Institute of Standards and Technology (NIST), and nine industry partners, NSF will continue to support the RINGS program; laying the groundwork for next-generation wireless connections that will enable faster service; resiliency to natural disasters, malicious attacks, and service interruptions; and broader access to wireless connectivity for people across the U.S.
- In FY 2023, NSF will continue to support the Spectrum and Wireless Innovation enabled by Future Technologies (SWIFT) program with emphasis on miniaturized efficient low-cost hardware, innovations on radio-frequency (RF)/analog and hardware security, distributed machine learning, spectrum sharing, wireless-enabled smart manufacturing, and beyond-5G wireless components and systems.
- In FY 2023, NSF will support, in collaboration with DOD OUSD (R&E), use-inspired research on 5G security through a track of the Convergence Accelerator, Securely Operating Through 5G Infrastructure. The goal of this track is to enhance end devices and/or augment 5G infrastructure to enable military, government, and critical infrastructure operators to have the capability to operate through public 5G networks, while meeting security and resilience requirements.
- In FY 2023, NSF will support research on advanced sensing and communication technologies under water. Research will focus on new technologies addressing the challenges of communications and sensing to support underwater and under-ice science missions, which see increasing needs of advanced technologies given the importance of the ocean and polar regions and their roles in climate change and economic development.
- In FY 2023 NSF will continue its support for the NSF AI Institute for Edge Computing Leveraging Next-generation Networks (Athena) and the NSF AI Institute for Future Edge Networks and Distributed Intelligence (AI-Edge). Athena will focus on developing edge computing with groundbreaking AI functionality while keeping complexity and costs under control. AI-Edge will leverage the synergies between networking and AI to design future generations of wireless edge networks that are highly efficient, reliable, robust, and secure.
- NSF investments in fundamental advanced wireless research will be in synergy with the National Center for Wireless Spectrum Research (SII-Center) program under the Spectrum Innovation Initiative (SII) which also invests in the National Radio Dynamic Zones (SII-NRDZ) program. SII-NRDZ is an interdisciplinary program that seeks to foster collaborations among stakeholders to advance the use of dynamic spectrum sharing.

Advanced Wireless Research Testing Platforms

- NSF is pursuing a convergent approach to validate advanced wireless research through its PAWR program, a $100.0 million public-private partnership comprising $50.0 million of NSF investment paired with $50.0 million in cash and in-kind contributions from a wireless consortium of 35 companies. With oversight from the NSF-funded PAWR Project Office hosted at US Ignite, Inc., and Northeastern University, PAWR platforms in Salt Lake City, UT; West Harlem, NY; Research Triangle, NC, and Ames, IA, are helping to build core wireless capabilities through creative university partnerships, attracting government and corporate research funding as well as local wireless jobs, and using advanced wireless capabilities to enhance community services and economic development. FY 2023 will be the second year when all four PAWR testbeds are expected to be operational and generally available simultaneously to the research community, unleashing the full potential of translational opportunities for advanced wireless R&D.
- The PAWR testbeds will continue to benefit from NSF investments in the NSF National Radio Dynamic Zone program under the SII. In FY 2023, the PAWR testbeds will support proofs of concept for dynamic spectrum sharing across diverse geographic and spectrum use cases.

Education and Workforce Development

In FY 2023, NSF will continue emphasizing the need to develop a workforce trained in advanced wireless technologies, which is critical to maintaining U.S. leadership in advanced wireless. Through ongoing investments in programs such as Research Experiences for Undergraduates, Research Experiences for Teachers in Engineering and Computer Science, Computer Science for All: Researcher Practitioner Partnerships, Improving Undergraduate STEM Education: Computing in Undergraduate Education, NRT, and GRFP as well as the SII-Center, NSF will continue to train future generations of scientists, engineers, and practitioners to pursue careers in this domain.

ADVANCED MANUFACTURING

Advanced Manufacturing Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request
BIO	$7.16	-	$17.16
CISE	44.40	-	42.22
EDU[1]	22.19	-	5.00
ENG	123.65	-	174.37
MPS	193.42	-	123.13
SBE	0.50	-	3.50
TIP[2]	44.30	-	54.63
OISE	0.26	-	0.50
IA	16.24	-	1.00
Total	**$452.11**	**-**	**$421.51**

[1] Formerly known as Directorate for Education and Human Resources (EHR).

[2] FY 2021 funding for TIP is shown for comparability across fiscal years.

Overview

Manufacturing is essential to almost every sector of the U.S. economy, spurring 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 advances in manufacturing materials, technologies and systems through fundamental, multidisciplinary research that transforms manufacturing capabilities, methods, and practices.

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 sensing. NSF investments in advanced manufacturing have increased and will continue to increase U.S. prosperity, as well as the Nation's competitiveness, security, and quality of life (as measured through a growing advanced manufacturing workforce and translation of discovery to useful products).

Today, NSF continues to invest in fundamental research to create new and sustainable capabilities for chemical and materials synthesis and processing; fabrication and manufacturing of advanced semiconductors, quantum devices, and optical devices; discovery and manufacture of alternative materials with lower climate and environmental impacts; distributed and smart manufacturing systems; safe, productive, and collaborative worker-technology interactions; the ethical, social, economic, and legal consequences of advanced manufacturing; and general advanced manufacturing discovery. NSF invests in communities and experiential programs to grow and nurture a STEM-enabled manufacturing workforce and 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 in biotechnology, synthetic biology, sustainability, artificial intelligence, robotics, sensing technologies, the Internet of Things, data science, and computational modeling. Similarly, NSF's investments in Clean Energy, Climate Change and Emerging Technologies are bolstered by advanced manufacturing research.

Goals

1. *Advanced Manufacturing Research*: Support groundbreaking discoveries for advanced manufacturing that lead to products and processes with higher performance, new capabilities, and using fewer and more-sustainable resources.
2. *Future Manufacturing Research*: Increase knowledge in emerging areas to enable a new generation of manufacturing industries that do not exist today, that are compatible with human needs, that make U.S. manufacturing competitive far into the future, and that build in resilience to global disruptions for the Nation's manufacturing infrastructure.
3. *Workforce Development*: Attract, educate, train and reskill/upskill diverse workers, from K-12 to college and industry, across the Nation, for the manufacturing workforce of the future.
4. *Translation to Practice*: Leverage partnerships with other sectors to enable the translation of research results to the market and society.

FY 2023 Investments

<u>Advanced Manufacturing Research</u>
Continued investments in advanced manufacturing include the discovery of new methods, processes, analyses, tools, or equipment for new or existing manufacturing products, supply-chain components, or chemicals and materials, including replacements for environmentally harmful mainstay materials such as plastics. NSF also supports research in next-generation manufacturing infrastructure as part of a broader effort to design and renew national infrastructure.

<u>Future Manufacturing Research</u>
Initiated in FY 2020, the Future Manufacturing investment advances 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. Investments focus on cyber-, eco- and bio-manufacturing research advances.

<u>Workforce Development</u>
To prepare a diverse advanced manufacturing workforce, NSF invests in the Advanced Technological Education, Faculty Early Career Development, Engineering Research Initiation, Grant Opportunities for Academic Liaison with Industry, Sites and Supplements for both Research Experiences for Undergraduates and Research Experiences for Teachers programs, as well as in manufacturing engineering education in research projects. NSF support for Non-Academic Research Internships for Graduate Students (INTERN) provides individuals with experiences in other sectors, including industry and government.

<u>Translation to Practice</u>
NSF speeds translation of fundamental discoveries in advanced manufacturing into products and processes through its Engineering Research Centers, Industry-University Cooperative Research Centers, as well as the NSF Lab-to-Market Platform and other activities in TIP. In addition, NSF coordinates with other agencies and participates in the Manufacturing USA Institutes, particularly by connecting them to universities and community colleges.

ARTIFICIAL INTELLIGENCE (AI)

Artificial Intelligence Funding[1]
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request
BIO	$20.00	-	$20.00
CISE	344.00	-	369.80
EDU[2]	29.04	-	50.00
ENG	85.86	-	95.80
GEO	1.00	-	5.00
MPS	110.63	-	71.67
SBE	15.06	-	19.59
TIP[3]	86.79	-	101.55
OISE	0.33	-	-
IA	9.07	-	1.00
Total	**$701.78**	**-**	**$734.41**

[1] Funding displayed may have overlap with other topics and programs.
[2] Formerly known as Directorate for Education and Human Resources (EHR).
[3] FY 2021 funding for TIP is shown for comparability across fiscal years.

Overview

AI is advancing rapidly and holds the potential to vastly transform our lives. NSF has a long and rich history of supporting AI research, setting the stage for today's widespread use of AI technologies in a range of sectors, from commerce to healthcare to transportation. NSF-funded research is now laying the seeds for advances in AI that will transform not just these areas, but essentially every area of human endeavor, including science, education, energy, manufacturing, and agriculture. NSF's AI portfolio spans AI algorithms, robotics, human-AI interaction, and advanced hardware and systems for AI, as well as use-inspired research in neuroscience, biology, chemistry, physics, intelligent transportation, and many other disciplines across the full breadth of science and engineering in which NSF invests.

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 uniquely positions the agency to lead the Nation in expanding the frontiers of AI. In FY 2023, NSF will continue support for foundational research in AI, including machine learning (ML) and deep learning, natural language technologies, knowledge representation and reasoning, robotics, and computer vision, along with the fairness, ethics, accountability, transparency, explainability, safety, security, and robustness across all areas of AI. 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, biotechnology, 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 (OSTP), 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 addition, NSF co-chairs the NSTC Machine Learning and AI (MLAI), NSTC Networking and Information Technology R&D (NITRD), and NSTC Future Advanced Computing Ecosystem (FACE) Subcommittees, all of which serve to coordinate federal R&D investments in AI as well as other related information technology areas, including the underlying advanced computing ecosystem that is critical for advancing AI. NSF also co-chairs the National AI Research Resource Task Force (NAIRRTF), which is a Congressionally chartered Federal Advisory Committee charged with developing a roadmap and implementation plan for a shared computing and data infrastructure that would provide the Nation's AI researchers and students with access to a holistic ecosystem of resources to fuel AI discovery and innovation. A key goal of the NAIRRTF is to democratize access to these advanced resources, thereby engaging a broad and diverse population in cutting-edge AI research and innovation.

Goals

1. *Fundamental AI Research:* Sustain long-term investments 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.
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 as well as deep, high-quality, and accurate training datasets in order to advance AI research and education.

FY 2023 Investments

<u>Fundamental AI Research</u>

- In FY 2023, NSF will continue support for the National AI Research Institutes program that was initiated in FY 2019 to create national hubs for universities, federal and local agencies, industry, and nonprofits to advance AI research and workforce development in key areas addressing grand challenges. In FY 2020 and FY 2021, NSF funded 14 institutes in themes that included foundations of ML; trustworthy AI; AI-augmented learning; AI for accelerating molecular synthesis and manufacturing; human-AI interaction and collaboration; AI and advanced cyberinfrastructure and AI for discovery in physics. Each AI Institute is expected to receive up to $20.0 million over five years. NSF also partnered with the U.S. Department of Agriculture National Institute of Food and Agriculture (USDA NIFA) to establish two additional institutes in each of FY 2020 and FY 2021, advancing AI-driven innovation in agriculture and food systems; these four AI Institutes are being fully supported by USDA NIFA. NSF issued the latest solicitation in Fall 2021 and expects to make seven awards in FY 2023. This solicitation continues the ongoing collaboration with USDA NIFA as well as new partnerships with the Department of Defense Office of the Undersecretary of Defense for Research and Engineering, National Institute of Standards and Technology, Department of Education Institute for Education Sciences, and IBM Corporation.
- In FY 2023, the HDR Big Idea will continue support for Institutes for Data-Intensive Research in Science and Engineering (I-DIRSE) that will foster innovation by harnessing diverse data sources

and developing and applying new methodologies, technologies, and infrastructure for data management and analysis, notably advances in machine learning.

- Through the FW-HTF Big Idea, in FY 2023, 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 provide economic and educational benefits across a range of work settings—including manufacturing floors, hospitals, offices, construction settings, and schools.
- In FY 2020, NSF, in collaboration with the Simons Foundation, funded two five-year collaborative projects on the Mathematical and Scientific Foundations of Deep Learning. Interdisciplinary teams of computer scientists, engineers, mathematicians, and statisticians will advance theoretical and foundational investigations into deep learning, with a view to laying the groundwork for a rigorous science of deep learning. In FY 2023, NSF will continue support for these centers. In addition, beginning in FY 2021 and continuing for three years, NSF is supporting more than a dozen smaller-scale projects seeking to advance the mathematical and scientific foundations of deep learning.
- In FY 2023, through the Foundational Research in Robotics (Robotics) program, CISE and ENG will continue to support robotics research that combines advances in engineering with innovations in computer science. The Robotics program invests in robotics and autonomous systems that exhibit significant levels of 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>Education and Workforce Development</u>

- As noted above, in FY 2020, NSF established a five-year National AI Research Institute for AI-augmented learning to radically improve human learning and education writ large in formal (e.g., preK-12, undergraduate, graduate, vocational education) and informal settings. In FY 2021, NSF established two additional five-year National AI Research Institutes in AI and Education. The primary focus of these institutes is to support AI-driven innovation to improve human learning and education. One AI Institute will pursue research to support highly adaptable, personalized, and distributed AI systems to expand STEM learning across diverse learners and settings in the context of preK-12 education. The other Institute will advance AI-driven research and innovations for learners with or at risk for disabilities. Both AI Institutes will address achievement and opportunity gaps, particularly for learners from disadvantaged or underserved communities and pursue outcomes with direct educational impact.
- NSF will address a critical shortage of cybersecurity educators and researchers in priority areas including the cybersecurity aspects of AI as well as AI for cybersecurity, through the Education track in the SaTC program as well as the CyberCorps®: Scholarship for Service (SFS) program.
- In FY 2023, GRFP will continue to encourage applications from students who place a premium on 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 U.S. institutions.
- The 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 2023, NRT will continue to include a special focus on traineeships in AI and other emerging industries that align with the Administration’s priorities.
- In FY 2023, NSF’s Computer Science for All (CSforAll) and Innovative Technology Experiences for

Students and Teachers (ITEST) programs will continue to support projects that investigate promising educational approaches at the K-12 level to motivate and prepare a diverse cadre of learners for computationally intensive new industries, including those that that rely on AI.[1]

- In FY 2023, NSF will continue to support the Data Science Corps. This program enables education and workforce development by focusing on building capacity at the local, state, and national levels to unleash the power of data in service to society. In particular, Data Science Corps provides practical experiences, teaches new skills, and offers learning opportunities in a range of settings.

<u>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, Frontera, the largest and most powerful supercomputer NSF has ever supported, will enable access to advanced computing resources for AI research.
- 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 helps the academic 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 is specifically enabling new research in AI by broadening the access and impact of cloud computing across many fields of research and education.
- In FY 2020, the NSF Convergence Accelerator (CA) emphasized AI through themes relating to HDR and FW-HTF; this focus is continuing in FY 2023. In FY 2021, the NSF CA added another AI-related theme on AI-Driven Innovation via Data and Model Sharing, ultimately selecting 18 projects for Phase I funding. In FY 2023, the NSF CA will emphasize AI through themes on the development of innovative assistive or rehabilitative technologies to help improve equity, inclusion, and accessibility for persons with disabilities; informatics for sustainable materials; and modeling and prediction to address food and nutrition security.
- For FY 2023, NSF will continue to collaborate with other federal agencies to enable researcher access to deep, high-quality, and accurate federal training datasets for AI systems. For example, NSF is building upon a FY 2021 workshop that explored how researchers might collaborate with federal data stewards to bring the latest security- and privacy-enhancing techniques to bear on unlocking access to federal data sets, while adhering to applicable federal statutes, rules, and regulations.

[1] www.nsf.gov/pubs/2020/nsf20101/nsf20101.jsp

BIOTECHNOLOGY

Biotechnology Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request
BIO	$110.00	-	$130.00
CISE	6.92	-	6.00
EDU[1]	14.41	-	9.00
ENG	86.77	-	101.50
GEO	10.00	-	10.00
MPS	91.88	-	52.20
SBE	2.04	-	1.50
OPP	1.60	-	2.00
IA	1.00	-	1.00
TIP[2]	11.84	-	69.06
Total	**$336.47**	**-**	**$382.26**

[1] Formerly known as Directorate for Education and Human Resources (EHR).
[2] FY 2021 funding for TIP is shown for comparability across fiscal years.

Overview

Since the first genetic engineering experiments over 50 years ago, the U.S. has become a world leader in biotechnology with resulting products of biotechnology contributing over $900 billion in economic activity, approximately 5 percent of the U.S. GDP, in recent years[1]. Biotechnology comprises the data, tools, research infrastructure, workforce capacity, and innovation that enable the discovery, utilization, and reprogramming of living organisms, their constituent components, and their biologically related processes. Advances in biotechnology areas include genome sequencing, editing, and synthesis; synthetic and engineered biology; chemical biology and chemical genetics; imaging and biosensing; and computational methods including artificial intelligence and biomolecule structure prediction. This also include bio-related approaches from engineering, mathematics, physical sciences, and computational sciences, which are spurring rapid development of capabilities in biotechnology that drive innovation for the U.S. bioeconomy. These capabilities also provide solutions to societal challenges such as climate change and infectious disease and provide the foundational and use-inspired research that will lead to the creation of goods and services that contribute to the agriculture, health, security, manufacturing, energy, and environmental sectors of the United States.

NSF has long supported the breadth of fundamental research that catalyzes the development of biotechnology. Current investments—from programs in almost every directorate—include research and infrastructure encompassing studies across scales; from the molecular, to the organism and ecosystem, and from basic and fundamental to use-inspired, carried out by individual investigators, teams, and multi-institutional centers. NSF also invests in educational programs to prepare and enable a workforce to support U.S. needs in biotechnology, and NSF funds research on the ethical, social, legal, economic, and environmental consequences of synthetic biology and other biotechnologies that contribute to public understanding and socially responsible use. These

[1] Public and Private Funding Opportunities to Advance a Circular US Bioeconomy and Maintain U.S. Biotechnology Competitiveness, Interim Report of Schmidt Futures Bioeconomy Task Force, 2021.

investments enable biotechnology innovations that not only address societal problems, such as climate change, food security, and clean energy, but also promote development of a robust supply chain of biologically derived materials needed to ensure U.S. resilience to global interruptions. Biotechnology promises to enable new modes of computation, including for information storage, retrieval, and processing; foods and feedstocks that will provide raw materials for new bioindustries; new organs and organisms engineered for multiple purposes, technologies capable of sensing emerging infectious agents; self-healing materials for sustainable infrastructure; and other heretofore unimagined products, processes and technologies inspired by, or developed with, living systems. Biotechnology advances will enable novel predictive tools and platform technologies to empower the U.S. to react rapidly to new and emerging biological threats, to address economic and societal challenges, and to respond with solutions for unanticipated challenges.

NSF has responded to reports from the Office of Science and Technology Policy (OSTP)[2], the National Academies[3], and the Government Accountability Office[4] to lead and coordinate interagency activities to promote synthetic biology and to develop next-generation tools to advance biotechnology. New NSF investments in FY 2022 aimed at biotechnology innovation include programs for: Accelerating Innovations in Biomanufacturing Approaches through Collaboration between NSF and the DOE Bioenergy Technologies Office-funded Agile BioFoundry; Semiconductor Synthetic Biology Circuits for Communication and Information Storage; EFRI: Engineering Living Systems; EFRI: Brain-inspired Dynamics for Engineering Energy-Efficient Circuits and Artificial Intelligence; and new tracks on Sustainable Materials for Global Challenges and Food and Nutrition Security in the FY 2022 Convergence Accelerator solicitation. These programs build on programs initiated in FY 2021, e.g., Designing Synthetic Cells Beyond the Bounds of Evolution; Sentinel Cells for Surveillance and Response to Emergent Infectious Diseases; and Molecular Foundations for Biotechnology, and prior-year investments, e.g., Enabling Discovery Through Genomics; Future Manufacturing; Materials Innovation Platforms; Plant Synthetic Biology; and Reproducible Cells and Organoids via Directed-Differentiation Encoding. They also build on FY 2021 investments at the intersection of biotechnology and artificial intelligence and quantum sciences through the National Artificial Intelligence Research Institutes and Quantum Leap Challenge Institutes programs. Together, these new investments complement core programs in research, infrastructure, workforce development and translation that advance U.S. competitiveness and leadership in biotechnology and the bioeconomy.

Goals

1. *Fundamental Research:* Support foundational and use-inspired research in science and engineering that will fuel innovations in biotechnology.
2. *Computing and Physical Infrastructure:* Develop the computing and physical infrastructure necessary to generate fundamental knowledge and advance accompanying biotechnology.
3. *Proof-of-Concept Advances:* Deliver proof-of-concept processes, devices, bio-based robots (biobots), applications, tools, and systems that integrate fundamental engineering and translational research to exploit emerging biotechnological advances for scientific and societal

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[2] https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/national_bioeconomy_blueprint_april_2012.pdf

[3] www.nationalacademies.org/our-work/safeguarding-the-bioeconomy-finding-strategies-for-understanding-evaluating-and-protecting-the-bioeconomy-while-sustaining-innovation-and-growth

[4] www.gao.gov/products/gao-18-656

benefit.

4. *Education and Workforce Development:* Empower the full spectrum of U.S. talent to build the capacity to achieve the above goals and to generate the biotechnology-literate workers who will implement the results of these breakthroughs.

FY 2023 Investments

Fundamental Research

NSF will continue its support in the discovery of fundamental biological principles and the development of biotechnologies and other tools that permit measurement and use-inspired manipulation and design of living systems and their components. New interdisciplinary partnerships across the agency will motivate bio-inspired design and stimulate use-inspired solutions, including through the NSF Big Idea, Understanding the Rules of Life.

Computing and Physical Infrastructure

NSF will continue to invest in bioinformatics, computational biology, and artificial intelligence to support biotechnology. A new synthesis center in molecular and cellular biosciences will enable data synthesis and reuse for biological understanding and biotechnology design, and NSF will leverage distributed networks of biofoundries and regional mid-scale facilities–to support growth of U.S. biotechnology innovation.

Proof-of-Concept Development

Sustained support for synthetic and engineering biology as a pillar of biotechnology will accelerate the design-build-test-learn cycle and leverage bio-inspired design to develop bio-machines, biobots, and biomanufacturing technologies to address many of today's challenges. New investments in regional innovation will expand participation within the bioeconomy and accelerate the translation of biotechnology to solve societal problems.

Education and Workforce Development

To prepare a diverse biotechnological workforce, NSF will invest through programs such as the Advanced Technological Education program at two-year institutions, sites and supplements for Research Experiences for Undergraduates and Research Experiences for Teachers, and the NSF Research Traineeship Program that prepares graduate students to conduct research in convergent areas and acquire skills that allow them to succeed in diverse employment settings. NSF will also support training at the postdoctoral and early-career level through fellowships and participation in the NSF Innovation Corps (I-Corps™) program, to enable scientists and engineers to further the societal benefits of their work.

MICROELECTRONICS AND SEMICONDUCTORS

Microelectronics and Semiconductors Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request
CISE	$17.95	-	$23.46
ENG	43.07	-	46.00
MPS	57.31	-	26.00
TIP[1]	12.78	-	50.23
Total	**$131.11**	**-**	**$145.69**

[1] FY 2021 funding for TIP is shown for comparability across fiscal years.

Overview

Without semiconductors, the world would be a very different place; we would not have cellphones, personal computers, electronically controlled cars, appliances, or many other technologies we rely upon every day. They are omnipresent in transportation, communications, healthcare, manufacturing, and information technology, among other industries. Yet, U.S.-led innovations in semiconductors and microelectronics have slowed in recent decades, and the Nation is now facing historically unprecedented global competition.

Transistors, the building blocks of today's microelectronics, are approaching fundamental down-scaling limits in both size and energy efficiency. Additionally, current transistor technologies require a significant investment of scarce natural resources to produce and are energy inefficient when used. Microelectronics and semiconductors warrant strategic investment to ensure continued U.S. leadership in this foundational technology, which will also facilitate leadership in many other technology areas that underlie major sectors of the economy and critical aspects of national security. Investments in sustainable microelectronics—including holistic manufacturing processes that use environmentally-benign materials, encompass the entire manufacturing lifecycle, and account for energy efficiency, health and environmental impact, and cost effectiveness—are critical to the existential challenge of our generation: climate change.

The overarching objective of NSF's investment in Microelectronics and Semiconductors is to develop new paradigms in semiconductor capabilities. Ongoing activities and new, complementary opportunities will leverage and create advances in materials, devices, circuits, architectures, and related software and applications. Advances in microelectronics and semiconductors in recent years continue to be made through longstanding NSF programs, including Electronics, Photonics and Magnetic Devices; Communications, Circuits, and Sensing-Systems; Semiconductor Synthetic Biology; Foundations of Emerging Technologies; Software and Hardware Foundations; Advanced Manufacturing; and Materials Research programs; as well as Science and Technology Centers; Engineering Research Centers; and Industry-University Cooperative Research Centers. NSF programs for innovation and translation, including the NSF Partnerships for Innovation, NSF Innovation Corps (I-Corps™), and the Small Business Innovation Research and Small Business Technology Transfer programs, have enabled new knowledge and designs to make their way into the market and society.

NSF's investments aim to demonstrate sustainable new semiconductors and microelectronic devices capable of overcoming the looming natural limits of current technologies and architectures. These investments will also enable the training of a critically-needed U.S. workforce capable of adapting and advancing these technologies for a broad range of societal needs. This approach to NSF's investment in Microelectronics and Semiconductors will help overcome scientific barriers in essential technologies such as: advanced computing; artificial intelligence; distributed mobile processing platforms; internet of things; quantum communication, computing, and sensing; advanced communications; advanced manufacturing; and biological-semiconductor interfaces.

Goals

- *Support research and development of new, secure, high-performance devices* supported by novel and sustainable materials that offer improved security and energy-efficient functionality.
- *Investigate and implement methods and techniques to integrate new classes of devices into microelectronic circuits for diverse platforms.* Microelectronic devices are fabricated by integrating transistors with numerous other components that work with different physical principles. The need to bring various components—electrical, optical, magnetic, and quantum—into a microelectronic circuit necessitates the investigation of new co-design, packaging, and testing methodologies.
- *Create a semiconductor and microelectronics R&D ecosystem.* This ecosystem will enable researchers and trainees to fabricate novel transistors and devices and to integrate component technologies into systems using heterogeneous integration techniques. The ecosystem will connect user facilities to fabricate devices in the laboratory, advanced methods for semiconductor manufacturing, and collaboration with industries to translate laboratory-generated ideas into foundry-fabricated prototypes.
- *Grow a diverse workforce* across the U.S. to support the ecosystem, from researchers to technicians, theorists to experimentalists, and entrepreneurs to practitioners.

FY 2023 Investments

Research in Foundational Principles

Ongoing and new opportunities in foundational research, from individual-investigator projects to efforts comprising large multidisciplinary teams, will create new classes of novel, secure, sustainable, high-performance semiconductors for microelectronic devices.

Methods for Integrating Devices into Diverse Platforms

NSF will invest in existing and new opportunities, including research infrastructure and use-inspired research, to investigate and implement new methods for device integration.

Microelectronics Ecosystem

NSF will continue to invest in advanced manufacturing research, partnerships, and research infrastructure, such as the NSF Quantum Foundries and NNCI, to translate benchtop microelectronics and semiconductors research to fabrication and manufacturing.

Workforce Development

To prepare a diverse microelectronics and semiconductors workforce across the U.S., NSF invests in the Faculty Early Career Development, Research Experiences for Undergraduates, Research

Experiences for Teachers, as well as semiconductor and microelectronics education in research projects. NSF support for Non-Academic Research Internships for Graduate Students and I-Corps™ provides students with industrial and entrepreneurship experience.

An example of an activity funded in FY 2023 includes the Future of Semiconductors (FuSe), which will invest in new materials, materials processing and characterization, fabrication, devices and systems, and computing, sensing, and communication systems answering both near-term supply chain concerns and longer-term Post-Moore's Law challenges. FuSE will invest in research opportunities in semiconductor-related areas including new materials, fabrication and manufacturing, electronics, and computer systems. FuSE will also consider research infrastructure needs in this domain, particularly improving semiconductor fabrication foundry access for NSF-funded researchers, and how potential partnerships with industry may facilitate such access. Educational needs and opportunities, particularly those coupled to foundries as experiential learning, are also of interest.

QUANTUM INFORMATION SCIENCE (QIS)

Quantum Information Science Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request
BIO	$3.28	-	$3.28
CISE	20.70	-	24.28
EDU[1]	10.52	-	5.0
ENG	21.31	-	32.89
MPS	154.03	-	156.13
TIP[2]	20.53	-	38.42
OISE	0.09	-	1.00
IA	24.60	-	-
Total	**$255.06**	**-**	**$261.00**

[1] Formerly known as Directorate for Education and Human Resources (EHR).
[2] FY 2021 funding for TIP is shown for comparability across fiscal years.

Overview

QIS research 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 three 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 National Quantum Initiative (NQI) and address the Administration's focus on helping build emerging industries.

NSF's QIS investments build upon the agency's long-standing and continuing foundational investments in QIS as well as more recent, interdisciplinary investments in centers and small teams and targeted workforce development efforts. Investments will target all major areas of quantum computing, communications, sensing, networking, and simulation. 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. Collaboration with fields beyond the core of QIS will identify end users of new quantum technologies 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 advancing the U.S. economy.

Consistent with and crucial to its mission, NSF will form partnerships with other federal agencies, industry, private foundations, national laboratories, and existing centers to leverage NSF's investments in QIS research and education. 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. NSF will continue to provide funding opportunities for QIS researchers to enable researchers' access to industry-built quantum-computing platforms and to support international collaboration efforts. In FY 2023 NSF will continue the Expand QISE thrust begun in FY 2022, which focused on enhancing the participation of academic institutions not currently participating in the national QISE initiative and promoting the inclusion of members of groups currently underrepresented in the field.

Goals

- Answer key science and engineering questions to facilitate the fundamental understanding of quantum phenomena and systems, as well as the translation of that fundamental knowledge into technological applications.
- 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.
- Empower the full spectrum of talent to which NSF has access to build needed capacity and generate the quantum-literate workforce that will implement the results of these breakthroughs, with a special focus on reaching out to MSI's and expanding the QIS workforce in ways that will enhance the diversity of that workforce through the inclusion of members of groups heretofore underrepresented in the endeavor

Investments by Program Component Area

QIS Funding by Program Component Area
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request
Foundational Quantum Information Science Advances	$71.64	-	$73.00
Quantum Computing	67.02	-	64.71
Quantum Networks and Communications	37.14	-	43.59
Quantum Sensing and Metrology	46.05	-	42.31
Future Applications	17.37	-	21.61
Risk Mitigation	9.54	-	11.08
Supporting Technology	6.30	-	4.70
Total	**$255.06**	**-**	**$261.00**

Foundational Quantum Information Science Advances
Notwithstanding the significant progress that has been made in QIS over the past five years, as a technology, the field is still in its infancy. Many questions that lie at the heart of the field remain to be addressed and answered. At the same time, new discoveries enable new directions that open new as-yet-unexplored opportunities. NSF will maintain significant investment in the underlying disciplinary programs and will consider supporting new collaborative center-level activities in all areas that have the potential to enable these scientific breakthroughs.

Quantum Computing
Much progress has been made in superconducting and ion-trap quantum computing architectures, and NSF continues to lead the way through investments in approaches to scale these by at least a factor of ten or more. However, there is 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 continue to support researcher access to quantum systems and platforms to experiment in specific domains.

Quantum Networks and Communications

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 cross-disciplinary teams of engineers, mathematicians, 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 Sensing and Metrology

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 community-building activities such as Research Coordination Networks and “Dear Colleague” letters emphasizing areas of mutual interest.

Future Applications

In FY 2021, NSF initiated an investment in a QIS Convergence Accelerator track designed to promote the more rapid translation of basic quantum knowledge into the private sector. This investment will continue in FY 2022, together with on-going programs that support connections and collaborations with industry.

Risk Mitigation

Concomitant with investments that promote the development of new quantum-based computational and communications tool, NSF will support efforts to counter the risks that emerge with these new technologies.

Supporting Technology

Building the QIS technology portfolio will require the simultaneous development of classical tools that are needed to perform research and develop prototypes. Working through existing disciplinary programs, NSF will support researchers who are developing tools and algorithms that are especially adapted to quantum applications.

RESEARCH INFRASTRUCTURE THEME

For definitions of common acronyms used throughout NSF's FY 2023 Budget Request, see the NOTES found at the beginning of the entire document on pages iii-iv.

RESEARCH INFRASTRUCTURE

Description and Rationale

Research infrastructure (RI), from the scale of individual laboratories up to major research facilities, is at the heart of the scientific endeavor. Definitions of RI have evolved significantly over the years as remote access and cyberinfrastructure have increasingly become critical parts of almost every tool in use by the research community. These attributes have become even more essential during the COVID-19 pandemic and are major components of efforts to expand access to RI for traditionally underserved groups and communities. Likewise, NSF investments in science and engineering have transformed discovery and innovation, giving rise to new and different forms of RI.

The National Science and Technology Council's recently published *National Strategic Overview for Research and Development Infrastructure* defines Research and Development Infrastructure (RDI) as "[f]acilities or systems used by scientific and technical communities to conduct research and development (R&D) or foster innovation." It goes on to note that "RDI elements include experimental and observational infrastructure, knowledge infrastructure, and research cyberinfrastructure—all of which are integrated resources relied upon by our Nation's R&D enterprise." NSF follows this broadly inclusive definition for RI.

RI is a fundamental enabler of science and engineering research and education. RI is needed for all forms of basic research—from curiosity-driven, exploratory research to use-inspired, solutions-oriented research. RI is essential across a wide variety of disciplines and for success across a broad range of time scales. RI can enable advances in areas as varied as measurement of the evolution of carbon in the atmosphere, assessment of the rate at which glaciers are losing ice, analysis of the changes in biomass in forests, , modeling of the epidemiology of infectious diseases, detection of gravitational waves, the search for dark matter and dark energy, investigation of the fundamental structure of particles that make up everything in the universe, studies of biological, chemical, and physical processes at femtosecond and attosecond timescales, and characterization of the contents of our solar system (including potentially hazardous asteroids). RI also advances advanced wireless communications, research on new nanomaterials and development of new biomaterials, improved atmospheric and meteorological modeling as well as space weather forecasting, development of artificial intelligence (AI) algorithms for a variety of societal uses, and the development of quantum computing and communication capabilities. RI activities also advance STEM education, research, and broadening participation by providing training and research opportunities to students and partnerships with minority-serving institutions, such as the Laser Interferometer Gravitational-wave Observatory (LIGO) Science Education Center Partnership between Southern University in Baton Rouge, LA, the LIGO Livingston site in Livingston, LA, through the Baton Rouge Area Foundation. Importantly, future RI will increasingly comprise instrumented and living laboratories and testbeds enabling advances in Emerging Industries (see the Emerging Industries chapter for more details) as well as collection of multi-sensor, human observation, and behavioral data.

Modern RI for fundamental research and innovation gathers and processes vast amounts of data, makes sense of those data using data analytics, computational modeling and simulation, and AI, and supplies both raw and processed data to researchers across the U.S. and around the world. Advanced cyberinfrastructure is increasingly a key element of all successful RI. Importantly, cutting-edge RI is also integral to attracting, developing, and training the next generation of STEM talent and inspiring those who will lead the next generation of advances in infrastructure. The skills required to design, operate, and maintain RI are critical for the future of the Nation's STEM enterprise. NSF RI both benefits from and contributes to the training of the skilled technical workforce. For example, the Marine Technology Mentoring and Internship Program on Oceanographic Research Vessels provides interns work onboard research vessels. These experiences provide them with the opportunity to develop their technical, scientific, seamanship and interpersonal skills.

In short, investments in research must be complemented by corresponding investments in RI.

Goal of Investment

- Sustain state-of-the-art RI to enable discoveries and innovation at the forefront of a wide range of science and engineering disciplines.
- Leverage new and existing RI to enhance our understanding of and address societal challenges, such as climate change, biosecurity, and socioeconomic and regional inequities. This includes enhancement of our understanding of the large-scale impacts of climate change on the atmosphere, oceans, land, and biology of the Earth using the sensors and data made available through major and mid-scale research facilities.
- Enhance access to RI for all groups across the socioeconomic spectrum, with particular attention to communities and regions that have historically been underrepresented in science and engineering. Without access to the resources needed for research, other equity and broadening participation efforts cannot reach their full potential.

Potential for Impact, Urgency, and Readiness

RI is often the key ingredient that makes cutting-edge science and innovation possible. Consequently, demand is high. NSF's mid-scale RI programs are many-fold oversubscribed and research communities across many STEM fields have proposed ambitious infrastructure plans to support their science goals. The pace of climate change is accelerating, and investments are needed to provide robust estimates of the effects of climate change as well as to inform actions needed to mitigate the worst impacts. Exciting and robust RI is essential to attracting groups underrepresented in STEM to careers in science and engineering. Programs associated with RI that engage and attract groups underrepresented in STEM will be a growing part of NSF's investment in RI, and likewise, investments in expanding the accessibility of RI may often be the key ingredients that help a broader cross-section of Americans engage in STEM research.

Budget Justification

At the FY 2023 Request level, NSF will support activities such as those listed below. For ease of reading, these are divided into separate categories of fundamental research and workforce and equity, but there is considerable overlap between these categories, and many investments would benefit both of these focus areas.

Activities with a focus on fundamental research:

- Increasing investment in the commissioning and early science investigations of the Daniel K. Inouye Solar Telescope and the Vera C. Rubin Observatory will help the science community achieve full benefit from the telescopes sooner, since their commissioning and early science periods were shortened by COVID-19-induced delays in construction; this will enable earlier fulfillment of the scientific promise that led to the approval to build these facilities in the last decade, and will enhance provision of data access to students nationwide.

- More robust investment in Antarctic infrastructure and logistics to enable researchers to access remote areas of the Antarctic continent (both in person and remotely).
- More rapid development of the next-generation Antarctic Research Vessel, which will enable access to hitherto unreachable parts of the Southern Ocean, bringing that vessel closer to construction readiness.
- Development and design investments in the highest priority RI projects recommended by the 2022 National Academies of Science, Engineering and Medicine decadal survey *Pathways to Discovery in Astronomy and Astrophysics for the 2020s*.[1]
- Increased investment in the physical infrastructure of NSF's major facilities, targeting those that study the Earth's biosphere, atmosphere, and oceans, contributing to the U.S. Global Change Research Program (USGCRP), as well as in those in which aging of the physical infrastructure now threatens the ability to deliver forefront science.
- Development and design investments in the highest priority RI projects to be recommended by the work of the National AI Research Resource Task Force, a Federal Advisory Committee chartered by Congress to consider how to democratize access to data, computation, and other resources necessary for advancing AI and science and engineering more broadly.
- Investment enabling an agile, integrated, robust, trustworthy and sustainable CI ecosystem that drives new thinking and transformative discoveries in all areas of science and engineering, as articulated by the Federal strategy, *Pioneering the Future Advanced Computing Ecosystem: Strategic Plan*,[2] and NSF's vision and blueprint for cyberinfrastructure.
- Development of instrumented and living laboratories that drive innovation in emerging industries. For example, enhanced investment in the RI needed for advanced wireless technologies, including Platforms for Advanced Wireless Research (PAWR) and the National Radio Dynamic Zones within the Spectrum Innovation Initiative; and development of a broadly-accessible national quantum virtual laboratory, including quantum computing platforms and other resources that can be used to develop and test capabilities with a wide range of applications for technological innovation.
- Enhancement of core survey, data collection, and analytic activities, including nationally representative surveys of U.S. investment in R&D across all sectors of the economy, innovation, the education of scientists and engineers, and the science and engineering workforce.
- Conduct of large-scale, data-intensive surveys that study societal change and provide state-of-the-art, broadly accessible, and easily usable databases; shared research platforms; and educational tools to U.S. researchers, policymakers, students, and the public.
- Data are increasingly fundamental RI as well, just as essential to research progress and broad access as the instruments that generate those data. NSF will prioritize gathering, curating, indexing, and facilitating broad access to data repositories across the STEM fields and aligning these data resources with other NSF computational and experimental facilities for broad and efficient use.

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[1] www.nationalacademies.org/our-work/decadal-survey-on-astronomy-and-astrophysics-2020-astro2020
[2] https://catalog.data.gov/dataset/artificial-intelligence-and-wireless-spectrum-opportunities-and-challenges

Activities that specifically enable broader access to RI:

- Increased investment in cybersecurity and cyberinfrastructure at selected major facilities and in campus cyberinfrastructure and other key points of connection, to improve and secure virtual access to broader communities.
- Investment in mid-scale RI, with an emphasis on projects that enhance the engagement of a diverse workforce in the design, implementation, and ultimate use of RI.[3]
- Continued investment in major research instrumentation (MRI), with a sustained commitment to invest in predominantly undergraduate institutions, historically under-resourced institutions, and geographic diversity.
- Initiation of a program of research equipment grants for new faculty at under-resourced institutions, including primarily undergraduate and minority serving institutions, to support them in attracting talented early-career individuals and enhancing the research capacity of these institutions.
- Enhancement of programs at major facilities that provide opportunities for engaging the skilled technical workforce, such as internships focused on electronics, equipment operation and repair, etc., and partnerships with technical and community colleges.

For additional details, see the *NSF Research Infrastructure Summary* and *NSF Research Infrastructure Funding by Account* tables in the Summary Tables chapter.

[3] For example, in the first round of the NSF-wide Mid-scale Research Infrastructure solicitations, NSF funded a network of advanced Nuclear Magnetic Resonance (NMR) spectrometers that will specifically enable research at smaller universities and Minority Serving Institutions that have not previously had access to such infrastructure.

MAJOR RESEARCH EQUIPMENT AND FACILITIES CONSTRUCTION (MREFC) $187,230,000

Major Research Equipment and Facilities Construction Funding
(Dollars in Millions)

FY 2021 Actual	FY 2021 ARP Actual	FY 2022 Request	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
$161.27	$8.95	$249.00	$187.23	$25.96	16.1%

Overview

The Major Research Equipment and Facilities Construction 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. 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 2021 Actual	FY 2021 ARP Actual	FY 2022[1] Request	FY 2023 Request	FY 2024 Estimate	FY 2025 Estimate	FY 2026 Estimate	FY 2027 Estimate	FY 2028 Estimate
Antarctic Infrastructure Recapitalization	$3.86	-	$90.00	$60.00	$60.00	$60.00	$60.00	$60.00	$60.00
DKIST	9.38	8.95	-	-	-	-	-	-	-
HL-LHC Upgrade	28.74	-	36.00	33.00	38.00	-	-	-	-
Mid-scale Research Infrastructure[2]	74.04	-	76.25	76.25	76.25	76.25	76.25	76.25	76.25
RCRV[3]	10.98	-	5.00	1.98	-	-	-	-	-
Vera C. Rubin Observatory	34.09	-	40.75	15.00	7.61	-	-	-	-
Dedicated Construction Oversight	0.17	-	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Total	**$161.27**	**$8.95**	**$249.00**	**$187.23**	**$182.86**	**$137.25**	**$137.25**	**$137.25**	**$137.25**

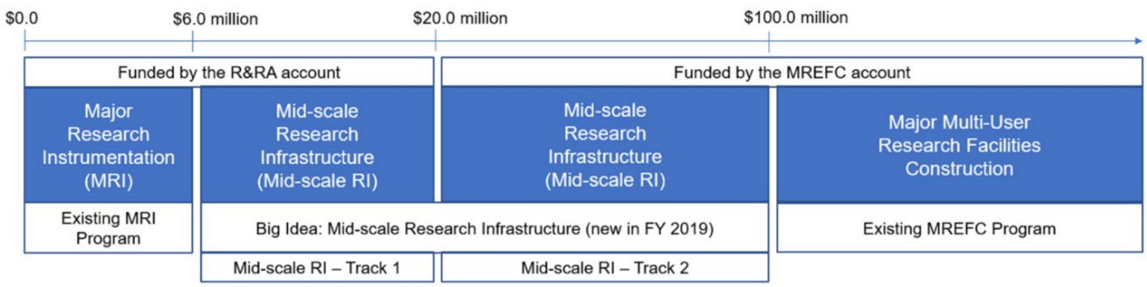
[1] A total of $260.21 million was carried forward from FY 2021 into FY 2022 including $51.05 million in ARP funding: $73.68 million for Mid-scale RI including $6.45 million in ARP funding, $115.84 million for AIMS, $14.05 million in ARP funding for RCRV, $46.74 million for the Rubin Observatory including $30.0 million in ARP funding, $553,350 in ARP funding for DKIST, $4.26 million for LHC, and $830,000 for Dedicated Construction Oversight.

[2] Outyear amounts are for planning purposes only. NSF will evaluate Mid-Scale Research Infrastructure in the context of agency priorities for future budgets

[3] FY 2022 Request excludes $25.0 million in one-time funding for necessary expenses related to RCRV construction impacted by Hurricane Ida as provided in P.L. 117-43, the "Extending Government Funding and Delivering Emergency Assistance Act."

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. Over time, these tools are becoming larger and more technically 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 (major 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 a distinct section below.

NSF Portfolio of Central Instrumentation and Infrastructure Implementation Programs



The graphic above summarizes NSF's centralized instrumentation and infrastructure programs. Information presented in this chapter focuses on the items funded at levels above $20.0 million, through the MREFC account. All Mid-scale Research Infrastructure (RI) – Track 2 (Mid-scale RI-2) investments are managed as a single portfolio, with individual projects selected from submissions to a dedicated program solicitation and evaluated using 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 earlier presentations to provide for greater consistency with definitions in the 2017 American Innovation and Competitiveness Act (AICA), as amended by the National Defense Authorization Act (NDAA) for FY 2021. Information on the Mid-scale RI program (Tracks 1 and 2) can be found in the Mid-scale section of the Big Ideas narrative within the NSF-wide Investments chapter. Information on the Major Research Instrumentation (MRI) program can be found in the Integrative Activities narrative in the R&RA chapter.

In FY 2023, NSF requests a total of $187.23 million to support mid-scale research infrastructure and continued construction on four ongoing major facility projects; Antarctic Infrastructure Recapitalization (AIR),[1] the High Luminosity-Large Hadron Collider (HL-LHC) Upgrade, the Vera C. Rubin Observatory, and Regional Class Research Vessels (RCRV). For more information on each major facility project, see the individual narratives later in this chapter.

Major Facilities

Since FY 2009, major 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 Research Infrastructure Guide (RIG) 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 impacts resulting from unforeseen

[1] "Antarctic Infrastructure Recapitalization (AIR)" replaces the item called Antarctic Infrastructure Modernization for Science (AIMS) in previous budget requests. Appropriated funds from FY 2021 and a fraction of the funds requested from FY 2022 will be used to complete a re-baselined AIMS project. The nature of Antarctic infrastructure investments has been revised in light of the impacts of COVID-19.

events that are beyond the recipient's control. The ongoing COVID-19 pandemic constituted such an unforeseen event for all major facility construction projects, and mitigation of that risk continues to fall outside the "no cost overrun policy" and the use of contingency. NSF policy allows for both authorization of management reserve and re-baselining, with a subsequent increase in total project cost, to address the consequences of unforeseen events. The overall NSF response to COVID-19 for its major facilities is described at the end of this section.

Mid-scale Research Infrastructure

AICA required the agency to develop a strategy for supporting research infrastructure with a total project cost above the upper limit for the 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 assessed community demand that resulted in the submission of approximately $10.0 billion in ideas for projects in the NSF cost range of $20.0–$100.0 million. After evaluating that community input, existing mechanisms, and implementation options, NSF included a dedicated funding line within the MREFC account beginning in FY 2020 for research infrastructure projects in the $20.0–$70.0 million range. The upper limit has been increased to $100.0 million in the second Mid-scale RI-2 solicitation to align with the lower threshold defining a major facility project as given in the FY 2021 NDAA, which amended the original AICA definition. This funding line supports upgrades to major facilities as well as stand-alone projects. Projects with total project costs between $6.0 million and $20.0 million are addressed by individual directorates and through an NSF-wide program (Mid-scale RI-1) that draws its heritage from the NSF-wide MRI program.

Dedicated Construction Oversight

All major facility projects funded through the MREFC account undergo periodic cost, schedule, and risk reviews as required by the RIG and the terms and conditions of the cooperative agreements or contracts governing the projects. 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.

Enhanced oversight of the construction stage includes mandatory incurred cost audits, Earned Value Management System surveillance, and re-baseline 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.

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 are required to provide a detailed Project Execution Plan for review. The RIG, Section 5, notes that the detailed oversight requirements, and application of major facility oversight practices, depend on characteristics such as the technical scope, type and mix of work performed, and assessment of the technical and programmatic risks.

Continued COVID-19 Impacts on MREFC Projects

Beginning in FY 2020 and continuing into FY 2022, NSF has increased investments in programs that aid institutions and groups of people most strongly impacted by COVID-19, with an emphasis on supporting individuals at vulnerable career transition points. The COVID-19 pandemic constitutes an unforeseen event that was not within the control of the recipients managing the ongoing major facility construction projects. NSF expects most or all of these projects to cost more than their originally authorized total project costs, which only included sufficient contingency to cover the known risks that were within the recipient's control. NSF had policies for responding to unforeseen events that were established in advance of the COVID-19 pandemic, which subsequently have been further refined to support the current situation.

Funding for FY 2022, the FY 2023 Request, and out-year forecasts for all projects have been adjusted from previous estimates based on NSF's current assessment of COVID-19 impacts. As appropriate, re-baselining of several projects will continue to take place, as cost and schedule impacts become better known. Impacts due to COVID-19 that can now be forecast (e.g., higher personnel costs and slower progress due to known social-distancing and quarantining requirements) are included in the re-baseline as known risks. Potential impacts that cannot be forecast (e.g., deteriorating circumstances because of the impact of a new COVID-19 variant) are held as agency-level risks that would be covered by application of management reserve, in accordance with existing policy described in the RIG. Further details for each project can be found in the individual narratives later in this chapter.

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, $~~249,000,000~~187,230,000, to remain available until expended.

Major Research Equipment and Facilities Construction
FY 2023 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 2021 Appropriation	$301.00	$129.35	-$260.21	$0.08	-	$170.22
FY 2022 Annualized CR	241.00	260.21				501.21
FY 2022 CR (Emergancy funding H.R 5305)[1]	25.00					25.00
FY 2023 Request	187.23					187.23
$ Change from FY 2022 Annualized CR						-$313.98
% Change from FY 2022 Annualized CR						-62.6%

[1]FY 2022 CR includes $25.0 million for necessary expenses related to Regional Class Research Vessel construction impacted by Hurricane Ida, to remain available until expended.

Explanation of Carryover

Within the MREFC account, $260.21 million (including $51.05 million in American Rescue Plan Funding) was carried over into FY 2022.

Mid-scale Research Infrastructure Track 2 (Mid-scale RI-2)
- Amount: $73.68 million (including $6.45 million in American Rescue Plan funding)
- Purpose: Funding for continuing Mid-scale Track 2 awards, awards pending independent cost estimates required by Congress in the American Innovation and Competitiveness Act (AICA), and to complete the NSF cost analysis on the new projects prior to award.
- Obligation: FY 2022 Quarter 1–2 and remaining amounts to be obligated in Quarter 3.

Antarctic Infrastructure Recapitalization (AIR)
- Amount: $115.84 million
- Purpose: Baseline and budget contingency funding not obligated in FY 2021.
- Obligation: FY 2022 Quarter 3.

Regional Class Research Vessel (RCRV)
- Amount: $14.05 million in American Rescue Plan funding
- Purpose: Management reserve funding not obligated in FY 2021.
- Obligation: FY 2022 Quarter 1-2.

Vera C. Rubin Observatory
- Amount: $46.74 million (including $30.0 million in American Rescue Plan funding)
- Purpose: Management reserve funding not obligated in FY 2021.
- Obligation: FY 2022 Quarter 1–2 and remaining amounts to be obligated in Quarter 3.

Daniel K. Inouye Solar Telescope (DKIST)
- Amount: $553,350 in American Rescue Plan funding
- Purpose: Management reserve funding not obligated in FY 2021.
- Obligation: FY 2022 Quarter 3.

High-Luminosity Large Hadron Collider (HL-LHC)
- Amount: $4.26 million
- Purpose: Management reserve funding not obligated in FY 2021.
- Obligation: FY 2022 Quarter 3.

Dedicated Construction Oversight
- Amount: $830,000
- Purpose: Support for major facility construction oversight required under AICA and NSF policy, National Ecological Observatory Network construction close-out.
- Obligation: FY 2022 Quarter 1–2 and remaining amounts to be obligated in Quarter 3.

ANTARCTIC INFRASTRUCTURE RECAPITALIZATION (AIR) $60,000,000

Appropriated and Requested MREFC Funds
for the Antarctic Infrastructure Modernization for Science (AIMS) Project and the
Antarctic Infrastructure Recapitalization (AIR) Program
(Dollars in Millions)

	FY 2019	FY 2020	FY 2021	FY 2022 Request[1]	FY 2023 Request	FY 2024 Estimate	FY 2025 Estimate	Total Project Cost
Authorized AIMS Total Project Cost	$103.70	$97.89	$90.00	$90.00	$28.81	-	-	$410.40
COVD-19 Adjustment	-	-19.40	-	-	-	-	-	-19.40
Unfunded AIMS scope transferred to AIR	-	-	-	TBD	-28.81	-	-	TBD
Revised Estimated AIMS Total Project Cost	$103.70	$78.49	$90.00	TBD	-	-	-	TBD
AIR Request	-	-	-	TBD	60.00	60.00	60.00	TBD
AIMS+AIR TOTAL	**$103.70**	**$78.49**	**$90.00**	**$90.00**	**$60.00**	**$60.00**	**$60.00**	**$542.19**

[1] The final division of the FY 2022 Request between AIMS and AIR will depend on a re-baseline currently in progress.

Brief Description

The AIR program is a portfolio of investments in facilities and infrastructure across U.S. Antarctic Program (USAP) stations and gateways that will assure safety, enhance efficiency, increase resilience, and support USAP's continued leadership on the continent. As discussed below, FY 2022 support for the Antarctic Infrastructure Modernization for Science project (AIMS) will be used to complete funding of the re-baselined AIMS scope and initiate activities within a broader recapitalization portfolio of NSF's Antarctic infrastructure under the AIR program. Near-term AIR investments have been developed and prioritized in close coordination with internal and external stakeholders, and AIR work planned for FY 2022 and FY 2023 can proceed despite any continued COVID restrictions that may be in place. AIMS construction will continue with a focus on meeting near-term needs, and unfunded parts of AIMS will be considered for inclusion into the longer-term AIR program.

AIMS was initiated in FY 2019 with an investment of $103.70 million, followed by $78.49 million in FY 2020, $90.0 million in FY 2021, and a final investment in FY 2022, which will be determined once the revised baseline is complete. The National Science Board (NSB) authorized a Total Project Cost (TPC) of $410.40 million for AIMS, and the ongoing baseline revision will be completed in FY 2022 to inform a revised cost, scope, and schedule, including provisions to account for uncertainties presented by lingering COVID-19 impacts. The project was in the early stages of implementation when COVID-19 restrictions required on-ice construction to be placed on hold. That extended on-ice work stoppage, as well as substantial disruptions to workforce and supply chains, has significantly delayed completion of the project, requiring a re-baselining of AIMS.

Significant AIMS schedule delays also meant that other USAP investments in facilities and infrastructure emerged as priorities that could not be deferred until after completion of AIMS. As a result, the re-baselined scope of AIMS is anticipated to include only the Vehicle Equipment and Operations Center (VEOC) and the Lodging Building (and associated utilities), both of which continue to be important near-term needs. Unfunded AIMS scope will be considered within the broader AIR program. The FY 2022 Request of $90.0 million will be used to complete funding of the re-baselined AIMS scope and to initiate activities within the AIR program. The enduring AIR program will ensure continued U.S. leadership and influence in this strategic region.

Scientific Purpose

NSF manages an Antarctic infrastructure portfolio that consists of a wide range of facilities, utilities, equipment, and fleet that enables the United States' world-leading science across three permanent stations, seasonal field camps, and two research vessels that are supported by three gateway/port locations. This infrastructure portfolio is unmatched by that of any other nation and underpins the entire USAP. From the facilities that house scientists and the generators that power the stations to traverse vehicles that enable drilling of climate-revealing ice cores and operation of field camps where scientists study the role of glaciers in future sea level rise, robust and healthy infrastructure is the foundation of Antarctic science.

Most of this infrastructure operates year-round in one of the harshest environments on Earth. In 2012, a Blue Ribbon Panel (BRP) of experts noted the importance of ongoing infrastructure renewal by observing: "The lack of a capital budget and supporting plan to replace out-of-date facilities, together with the lack of a funded plan to address major maintenance needs, has led to a deteriorating and inefficient infrastructure, particularly at McMurdo Station." The AIR program fulfills that recommendation for renewal by improving physical infrastructure to assure safety, enhance efficiency and sustainability, increase resilience, and ensure the Nation's continued leadership on the continent.

Key objectives of the AIR program are to support current infrastructure and to take advantage of opportunities where advances in infrastructure can enable new science capabilities. For example, improved data connectivity can facilitate discovery at greater speed and scale and broaden participation in Antarctic science. Likewise, expanded traverse capabilities can dramatically reduce risk and cost for science teams accessing deep field locations. The AIR program will include technical support for needs assessments, cost-benefit analyses, and preliminary designs to define transformative solutions to Antarctica's unique challenges as an integral part of infrastructure renewal.

Baseline History

In 2011, the Office of Science and Technology Policy and NSF convened a BRP to evaluate the 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 could support the scientific opportunities articulated by an earlier 2011 National Research Council (NRC) report, *Future Science Opportunities in Antarctica and the Southern Ocean.*[1] The BRP report, *More and Better Science in Antarctica Through Increased Logistical Effectiveness,*[2] made numerous recommendations regarding maintaining and enhancing the United States' world-class science program in Antarctica.

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 was a pivotal component of the McMurdo Station Master Plan with a specific focus on the primary core functions of this critical logistics hub. The AIR program will continue to refine and carry forward those long-term plans.

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[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

AIMS sought to enhance operational support for science by improving operations efficiency, containing operating costs, and enhancing safety. The following major scope elements were 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 comprises primarily single-occupancy rooms recommended by the BRP to promote safety and health. Single rooms mitigate rest issues that can arise from unique work shifts and travel schedules of the station workforce and scientists; they also help control the spread of contagious illnesses.
- Upgrade of utilities distribution networks for fire protection water, domestic water, heating, power, communications, and sanitary sewer.

The AIMS Final Design Review was held in October 2018 and the NSB authorized NSF to award a contract for AIMS in February 2019. The AIMS award was made under the Antarctic Support Contract to Leidos. The NSB-approved not-to-exceed TPC for AIMS was $410.40 million.

Project Status

To manage the potentially severe risks of COVID-19, on-site AIMS work at McMurdo was paused in March 2020 and construction personnel were not deployed to McMurdo for the FY 2021 or FY 2022 construction seasons. While plans are in place to resume construction as soon as it is safe to do so, this pause in construction activities, as well as disruption to the supply chain on which the project relies, resulted in multi-year delays to the AIMS construction schedule. AIMS is being re-baselined to include important near-term needs while unfunded AIMS scope will be considered within the broader AIR program. On-ice construction on AIMS is set to resume in October 2022.

Work was initiated in FY 2021 on the two highest priority AIR activities – acquisition of the planning and design support necessary to define efficient and effective technical solutions and minimize disruption to the science program, and the start of design work for a permanent McMurdo Cargo Offload solution that will dramatically reduce programmatic risk. Both projects are described more fully below.

Meeting Intellectual Community Needs

- NSF has collected and continues to seek feedback from members of the research community on the quality of the support they receive from the USAP in Antarctica.
- The research community participates in decisions regarding the necessary reach of the USAP's logistics system.

- Members of the research community participated in requirements development and refinement in the planning and design stages for AIMS, as well as in design reviews.
- The need for upgrades in many components of Antarctic infrastructure was informed by the 2011 NRC report and the 2012 BRP report. Additionally, the critical need to flexibly support a broad range of Antarctic research was further affirmed in a 2015 NRC report, *A Strategic Vision for NSF Investments in Antarctic and Southern Ocean Research.*[3]
- The AIR program will enable broad community engagement in the long-term vision for USAP infrastructure and logistics capabilities through the development of the South Pole Master Plan and routine updates to the plans already developed for each station.

Governance Structure and Partnerships

NSF Governance Structure

The AIR program is managed by GEO and implemented by the OPP Antarctic Infrastructure and Logistics (AIL) section. For oversight of AIR, NSF tailors the best practices outlined by NSF's Research Infrastructure Guide (formerly known as Major Facilities Guide), which includes the use of independent cost estimates where appropriate, routine status reports at the program and activity level, and periodic reviews of the portfolio by internal and external experts. The AIR program is overseen by the Chief Officer for Research Facilities and by a Capital Investment Review Board that includes NSF representatives from AIL and Antarctic Sciences Sections, Polar Safety and Occupational Health, Large Facilities Office, and Division of Acquisition and Cooperative Support.

Partnerships and Other Funding Sources

The National Oceanic and Atmospheric Administration is partnering with NSF to support upgrading satellite weather/communications data down/uplink facilities. That project is separate from AIR but will complement AIR in modernizing McMurdo Station and facilitating future communication improvements. As part of the transition to an enduring AIR program, the Capital Investment Review Board that oversees the portfolio of investments will be expanded to include inter-agency partners, providing a robust mechanism to develop future partnerships towards common objectives.

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

Cost and Schedule

Total Funding Requirements for AIMS and AIR

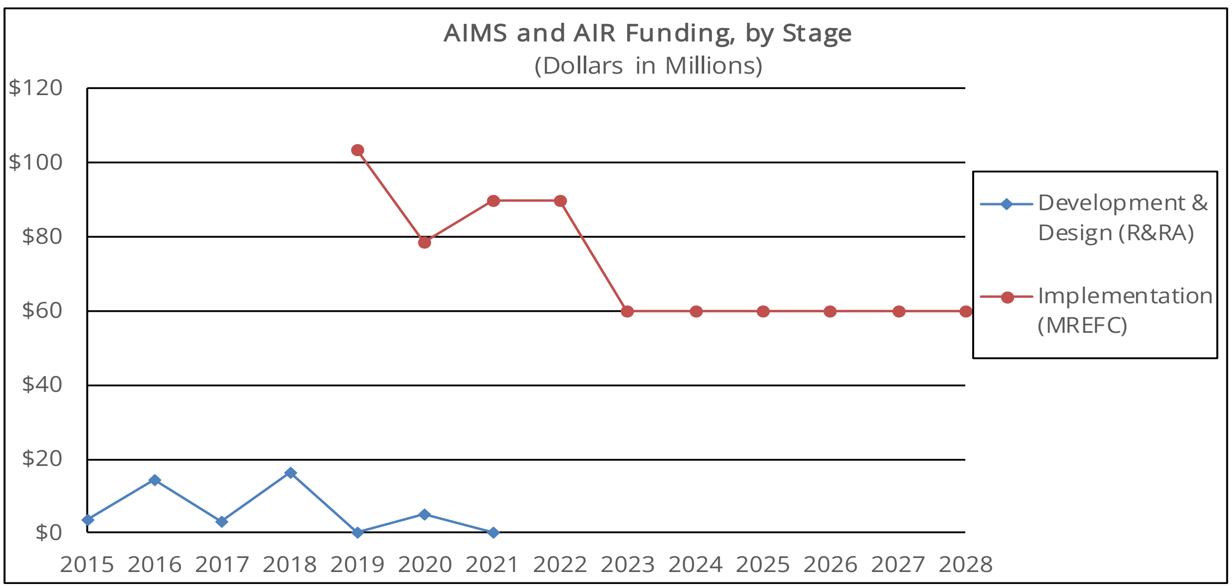
(Dollars in Millions)

	Prior Years	FY 2021 Actual	FY 2022 Request[2]	FY 2023 Request	ESTIMATES[3]				
					FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
R&RA:									
Development & Design	$42.24	$0.22	-	-	-	-	-		
Subtotal, R&RA	$42.24	$0.22	-	-	-	-	-	-	-
MREFC:									
AIMS Implementation[1]	182.19	90.00	TBD	-	-	-	-	-	-
AIR Implementation	-	-	TBD	60.00	60.00	60.00	60.00	60.00	60.00
Subtotal, MREFC	$182.19	$90.00	$90.00	$60.00	$60.00	$60.00	$60.00	$60.00	$60.00
TOTAL REQUIREMENTS	**$224.43**	**$90.22**	**$90.00**	**$60.00**	**$60.00**	**$60.00**	**$60.00**	**$60.00**	**$60.00**

[1] Includes $115.84 million carried forward into FY 2022.

[2] The final division of the FY 2022 Request between AIMS and AIR will depend on a re-baseline currently in progress.

[3] Outyear estimates are for planning purposes only.



Note: The AIR program will include future development and design activities within MREFC appropriations.

Construction of the VEOC and Lodging facility are anticipated to resume in October 2022 under a newly revised AIMS baseline schedule. The AIR program is being managed as a portfolio of investments guided by Station Master Plans that have been developed with robust engagement from across the science community and with inter-agency partners. Activities are prioritized by a Capital Investment Review Board as conditions and requirements change, which allows the program to be responsive to the research community, proactive in mitigating risks, and well-positioned to take advantage of opportunities as they arise. The table below shows active and near-term planned investments.[4] Scheduling of these investments will be dynamic, depending on a combination of Capital Investment Review Board prioritization and complex logistical considerations. Despite ongoing COVID-19 restrictions, these activities can all make progress without an immediate on-ice presence.

McMurdo Cargo Offload Infrastructure	Status: Acquisition
Mission Need: McMurdo, South Pole Station, and field camps are all reliant on resupply vessels that bring food, fuel, equipment, and materials each January. Vessels have historically offloaded at McMurdo via an ice pier in Winter Quarters Bay where materials are then trucked, traversed, or flown to their destination. The ice pier has failed three times in the past 12 years, requiring the last-minute deployment of temporary offload solutions that are costly and inefficient.	
Project Scope: This project will construct and deploy a barge-type structure that will be moored off McMurdo and can be used reliably and efficiently year after year, significantly reducing program risk.	
Antarctic Recapitalization Planning and Design Support	Status: Acquisition
Mission Need: Robust and independent planning, analysis, and early-stage design support is essential for ensuring that the AIR program delivers maximum benefit to the science community through innovative solutions. Once work is underway, integrated planning will minimize unnecessary disruption for science teams and ensure work is well-integrated with operations and science support.	
Project Scope: This acquisition will provide technical support for needs assessments, cost-benefit analyses, and preliminary designs to define transformative solutions to Antarctica's unique challenges as an integral part of infrastructure renewal. It will also provide an integrated planning and scheduling capability to minimize science disruptions.	
McMurdo Power Plant Switchgear Controls Upgrade	Status: Acquisition
Mission Need: Control systems manage eight generators and three wind turbines that provide power for McMurdo Station as well as New Zealand's Scott Base. The system has no redundancy, is unreliable, and has frequent outages.	
Project Scope: New software will eliminate outages related to control errors and support future generator replacements. The upgrade will enable an increase in monitoring, remote diagnostics, and will resolve information technology security vulnerabilities.	
Future USAP Data Center	Status: Planning
Mission Need: The USAP Data Center is currently housed in its own facility, which limits NSF's ability to take advantage of the efficiency and security available in the cloud environment.	

[4] Total project cost information is included when no longer procurement sensitive, which is typically when the activity has been awarded for construction.

Project Scope: This project will identify a cost-effective cloud provider and migrate the USAP data center to the new service.	
South Pole Blue Building Lifting System and ARO Raise	Status: Planning
Mission Need: South Pole Station's Blue Buildings (e.g., the IceCube Lab, the Dark Sector Lab that houses the South Pole telescope, Martin A. Pomerantz observatory (MAPO) with its attached BICEP array, and the Atmospheric Research Observatory (ARO)) are being buried in snow and without action, will become unusable.	
Project Scope: This project will lift the ARO and provide a "proof of principle" for the remaining structures. Lifting the buildings will extend their useful lifespan by 20 years and drastically reduce annual snow management workload.	
SPoT2 Module Refresh	Status: Planning
Mission Need: The South Pole Traverse (SPoT)-2 delivers approximately 100,000 gallons of fuel to the South Pole Station each year at a fraction of the cost of airlifting the fuel. SPoT-2 modules, such as the mobile kitchen and crew quarters, were acquired in 2003, have traveled over 60,000 miles, and are failing structurally and electrically.	
Project Scope: This project replaces the generator module, living module, and kitchen module.	
Fleet and Equipment Refresh	Status: Planning
Mission Need: More than two-thirds of the USAP fleet, which includes cargo and passenger transport vehicles, snowmobiles, loaders, light tracked utility vehicles, and light trucks, is beyond end-of-life, in some cases by decades. Air Traffic Control and mobile communications equipment is also aging and at increasing risk of failure.	
Project Scope: This investment returns the fleet to a safe, sustainable state, allowing USAP to transition to more fuel efficient and environmentally friendly vehicles, and refreshes aging communications equipment.	
Environmental Satellite Ground System	Status: Planning
Mission Need: Environmental satellite ground systems are crucial for weather forecasting and flight planning. They are also essential for safe aviation, station operations, and science support. The current McMurdo and Palmer Station systems, Tera Scan, are at or beyond end-of-life.	
Project Status: This project will replace the McMurdo and Palmer systems, providing modern weather forecasting tools that ensure compatibility with new and future weather satellites.	
McMurdo Power Plant Generator Replacement	Status: Planning
Mission Need: McMurdo Station has five primary generators that power the stations. The existing generators are aging and have experienced two catastrophic failures since 2018.	

Project Scope: This project replaces McMurdo generators with modern, efficient equipment.	
Doppler Weather Radar	Status: Planning
Mission Need: Successful and safe flight operations rely on accurate and timely weather information. McMurdo does not have any Doppler weather radar capabilities.	
Project Scope: This project will deploy Doppler weather radar to McMurdo, greatly enhancing weather forecasting capabilities which in turn improves the level of science support possible with USAP flight operations.	
Tactical Air Navigation Upgrade	Status: Planning
Mission Need: Tactical Air Navigation (TACAN) systems are critical for providing bearing and distance guidance and non-precision landing approach capability at McMurdo. The current TACAN is beyond end-of-life, and the Department of Defense will no longer support its use in coming years.	
Project Scope: This project will replace the McMurdo TACAN with a new, modern system.	
Undersea Fiber Optic Cable – Feasibility Study	Status: Planning
Mission Need: McMurdo Station's bandwidth is equivalent to that of a single 4G LTE cell phone. Providing the ability to dramatically increase the rate of data transfer to the station could be transformational and open the door to broader participation in Antarctic science.	
Project Scope: This project will conduct a feasibility study, including a hydrographic route survey, physical survey of McMurdo Station, environmental assessments in New Zealand and McMurdo, and risk mitigation methods.	

Reviews

Conceptual Design and Preliminary Design Reviews (PDR) for AIMS 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 AIMS 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, despite 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 and weekly communications with Leidos' AIMS project management, NSF conducts a formal monthly project management review. This review covers progress described in the monthly project management report produced by Leidos. Also planned are annual Construction Reviews by OPP, the Large Facilities Office, and an external panel, with the first one having occurred in November 2020. Given the severe impacts of COVID-19 on the AIMS project, as discussed above, a re-baselining of the remaining components of AIMS will be completed in FY 2022 to inform a revised cost, scope, and schedule.

The last Capital Investment Review Board meeting to prioritize activities in the Antarctic Infrastructure Recapitalization program was held in January 2022. In FY 2022, readiness reviews for AIR activities will be conducted based on the scale and complexity of individual projects.

Risks

If the infrastructure that enables Antarctic science is not kept robust and efficient, USAP is at risk of losing science capabilities year over year as facilities, utilities, equipment, and vehicle fleet degrade.

As described above, ongoing and planned near-term activities in the AIR program will mitigate critical risks facing USAP, including some that represent single points of failure to the mission. In executing the projects, NSF has implemented a rigorous risk management approach that includes the identification of risks and mitigation strategies. Robust risk management will also be required of contractors and awardees. In all cases, NSF holds the risk of cost and schedule increases that are beyond the control of the contractor, including events such as pandemics, unpredictably severe weather, icebreaker and supply vessel availability, and macroeconomic changes.

COVID-19 impacts on the construction market, labor force, supply chains, travel restrictions, and safety protocols present the greatest near-term risk to AIMS and AIR(?) due to its size and complexity.

HIGH LUMINOSITY-LARGE HADRON COLLIDER UPGRADE (HL-LHC) $33,000,000

Appropriated and Requested MREFC Funds for the
High Luminosity-Large Hadron Collider Upgrade
(Dollars in Millions)

	FY 2020	FY 2021	FY 2022 Request	FY 2023 Request	FY 2024 Estimate	Total
Previous Authorized Total Project Cost	$33.00	$33.00	$36.00	$33.00	$18.00	$153.00
Preliminary Est. of Future COVID-19 Impact[1]	-	-	-	-	20.00	20.00
Estimate prior to Rebaseline	$33.00	$33.00	$36.00	$33.00	$38.00	$173.00

[1] COVID-19 impact estimates are preliminary and not yet fully substantiated. Ongoing schedule and cost impacts will lead to revisions of the current funding plan through a re-baseline process.

Brief Description

The Large Hadron Collider 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 is designed to accelerate and collide counter-propagating bunches of protons at a total energy of up to 14 TeV (one TeV=10^{12} electron volts). Physicists study the debris from these collisions to learn about the elementary particles and fundamental forces that shape the universe. U.S. involvement in the LHC is jointly supported and overseen by NSF and the Department of Energy (DOE) and is primarily focused on supporting operations, research, upgrades, and O&M at two general purpose detectors: "A Toroidal LHC ApparatuS" (ATLAS) and "Compact Muon Solenoid" (CMS). HL-LHC is an enhancement to the accelerator that will increase the proton collision rate by a factor of about 5-7. The detector upgrades are modifications to the ATLAS and CMS detectors that will enable them to operate at the higher rate and with greater measurement precision.

NSF's FY 2023 Request for HL-LHC is $33.0 million to continue support for ongoing component upgrades of the ATLAS and CMS detectors. The FY 2023 Request amount supports the current NSB-authorized Total Project Cost (TPC) of $153.0 million. NSF's HL-LHC upgrade program represents about seven percent of the global high luminosity upgrade effort at the LHC, which is being supported by 45 funding agencies internationally.[1]

As discussed below, assessment of the COVID-19 impacts is under way using a range of assumptions. For planning purposes, a preliminary estimate of about $20.0 million in additional COVID-related funding need is incorporated into the FY 2024 funding estimate (which would raise the TPC to about $173 million). This estimate and future planning will be refined through a re-baselining of the HL-LHC detector upgrade program once there is a stable and quantifiable understanding of the pandemic's consequences. See the Baseline History section below for more details on the approval timeline and refer to the Project Status section for a summary of the current understanding of COVID-19 impacts.

[1]U.S. DOE is among the other agencies supporting the overall HL upgrade effort, including the upgrade to the accelerator, while NSF supports only the upgrades to the ATLAS and CMS detectors. The scope of DOE-supported activities is independent of the NSF-supported scope, though some links exist at the level of university-based efforts. NSF and DOE coordinated development and design efforts in preparation for construction of the HL upgrades and will continue joint oversight of the U.S. components of the ATLAS and CMS O&M programs through the HL upgrades and subsequent operations; see the Governance Structure and Partnerships section below for details.

Scientific Purpose

The LHC probes the fundamental structure of matter to elucidate the basic forces that have shaped our Universe since the beginning of time and that will determine its fate. Studies are carried out by colliding protons and heavy ions at the highest energies ever produced in a laboratory and recording, reconstructing, and analyzing the by-products of these collisions that take place within the ATLAS and CMS detectors.

The discovery of the Higgs boson in 2012 was one of the original goals of the LHC. It is one of the most important particle physics discoveries of the last 50 years, confirming the existence of the final element of the Standard Model of Particle Physics. Despite the predictive power of the Standard Model, there is strong evidence that it is incomplete. For example, it does not account for the existence of dark matter, nor does it explain why the mass of the Higgs particle is so low. Now, with the HL-LHC, the scientific focus has shifted to understanding the detailed properties of the Higgs boson and its coupling to other known processes to discover possible deviations from expectations—deviations that might indicate new physical phenomena beyond those described by the Standard Model. In addition, the HL-LHC research program will continue to search more broadly for new particles and interactions.

Baseline History

Following an agreement among NSF, DOE, and CERN ("Experiments Protocol I"), signed in December 1997, NSF began support for construction of ATLAS and CMS detector elements and software development in 1998. NSF has subsequently supported ongoing O&M,[2] as well as a previous smaller-scale upgrade to each detector. Since 2011, U.S. funding for ATLAS and CMS O&M has included investments in advanced R&D for investigations into detector modifications that enable the detectors to function at much higher collision rates in conjunction with an upgrade to the LHC to increase its luminosity. The ATLAS and CMS groups, consisting of researchers from all participating countries, each developed scoping documents describing their scientific goals and the technical paths 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 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 major facility level to enable meaningful participation by NSF-supported scientists in the HL-LHC research program. An estimated $150.0 million funding target was defined by NSF in consultation with the MPS AC.

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.

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[2] Oversight of the U.S. component of the ATLAS and CMS O&M programs is jointly conducted by NSF and DOE. See the Governance Structure and Partnerships section below.

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 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 targeted the estimated TPC at $150.0 million, or $75.0 million for each detector.

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. Funding to begin construction was provided in the FY 2020 MREFC appropriation, and the NSF Director obtained the NSB's authorization, in February 2020, to begin construction in FY 2020 with separate construction awards to Columbia and Cornell Universities (for ATLAS and CMS, respectively) totaling $153.0 million (adjusted upward by $3.0 million in the Final Design Review process).

Project Status

The ATLAS and CMS Final Design Reviews (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 2019 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 they offered suggestions to NSF on areas to follow closely during construction. NSF and the NSB conducted additional assessments that assured each project was ready to start construction in April 2020. NSF's Large Facilities Office (LFO) led an independent cost estimate of each project as part of the overall cost analysis process carried out by BFA. These were completed and satisfactorily reconciled prior to awarding construction funds in FY 2020.

Each project is currently (as of February 2022) more than 21 percent complete, but well behind schedule due to the COVID-19 pandemic. Preparatory work by CERN-led international consortia to develop custom silicon sensors and custom integrated circuits utilized by both detectors is nearly one year behind schedule, which has delayed the start of some NSF-supported construction activities.

<u>Summary of COVID-19 Impacts</u>

The pandemic is causing schedule and cost impacts to the NSF-funded scope for the LHC detector upgrades. Cost impacts realized since MREFC-funded construction began April 1, 2020, are relatively small in comparison to the pre-pandemic estimate of the total project cost to NSF. This is because initial construction activities are mostly focused on detailed production design work, procurement, and software development activities that are being accomplished through remote telework. However, fabrication activities have progressed more slowly than anticipated because of labor inefficiencies resulting from pandemic restrictions on activities in university labs and workshops, and these delays are growing as the pandemic continues. Delays in the availability of custom prototype silicon sensors and chips, which are part of each upgrade, are due to the closure during 2020 of radiation test facilities needed to validate the radiation hardness of the components.

Impacts stemming from the pandemic continue to emerge. Substantial uncertainties remain regarding the pandemic's effects on industrial suppliers and vendors, with whom procurement negotiations may be delayed due to the inability to conduct site visits and who may have diminished capacities to meet pre-pandemic delivery forecasts. For example, the global shortage in the availability of custom integrated circuits and surging demand for semiconductor fabrication are likely to hamper fabrication plans. The pandemic is delaying the schedules of international partners in each detector upgrade, disrupting linkages to NSF-funded activities. Foreign partners, in development activities led by CERN, are responsible for the development of several custom Application-Specific Integrated Circuits that have been designed into many subsystems in the ATLAS and CMS detectors. These are widely used across each detector in the upgrade scope undertaken by many countries and are not specific to NSF-supported scope. Some examples are the low-power gigabit transceiver, the silicon pixel readout chip, the DC-DC converter for the silicon sensor power, and silicon pixel sensors themselves. CERN's governing body is closely monitoring these and other impacts of the pandemic on HL-LHC plans at the international level. In January 2022, CERN announced a one-year delay to the start of installation of the HL-LHC accelerator and detector components, from January 2025 until January 2026, and an extension in the installation period to three full years (rather than the two and one-half years that had been previously planned) to allow these activities to be completed. The new schedule was developed in reaction to the impacts arising from the pandemic and was recommended by CERN's relevant scientific and technical advisory committees.

NSF will initiate a process to assess and validate a revised Total Project Cost once the cumulative impacts of the pandemic are understood. Quantifiable forecasting of schedule delays and cost increases is not yet available, although the ATLAS and CMS management teams are periodically modeling future scenarios to bracket the expected longer-term impacts of the pandemic on the upgrade program. This modeling quantitatively forecasts the pandemic impacts on tasks needed to deliver each of the upgraded detector subsystems based on assumptions as to how the pandemic will evolve and the societal responses that will be employed in response. From these assumptions, ATLAS and CMS teams estimate factors such as labor efficiency, costs to establish and maintain safe working environments, escalation costs arising from schedule delays, and contingency costs arising from re-estimation of future risks due to COVID-19. Estimates are periodically updated as understanding of COVID-19 continues to evolve. For preliminary planning purposes, NSF has incorporated a rough estimate of $20.0 million in additional COVID-related funding needs in the FY 2024 funding estimate presented in this Request.

Meeting Intellectual Community Needs

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. 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 is upgrading the accelerator, which will be renamed the High Luminosity-LHC, to deliver the high intensity proton beams required. The HL-LHC is planned to commence ten years of operation in 2028. During that time, it is expected to produce more than 10 times the data collected by LHC operation through 2025 (a hundred-fold increase relative to the data set confirming the 2012 Higgs discovery).

In parallel with the accelerator upgrade, NSF is funding 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. NSF contributions primarily fund radiation-hard electronics that increase the spatial granularity of calorimeter and muon detectors, expansion of the charged-particle tracking close to the beam direction in the CMS detector, and major improvements to the fast-decision-making electronics that trigger each detector to select and record interesting, rare events. The accelerator enhancements and the detector upgrades are currently planned to be installed and commissioned from 2026 through 2028.

Currently, more than 1,200 U.S. researchers participate in the ATLAS and CMS collaborations, including more than 100 post-doctoral fellows and more than 400 students, of whom about half are undergraduates. The U.S. researchers comprise about 20 percent of the total membership of the ATLAS and CMS collaborations. NSF supports about 20 percent of the U.S. ATLAS and CMS contingents.

Governance Structure and Partnerships

<u>NSF Governance Structure</u>

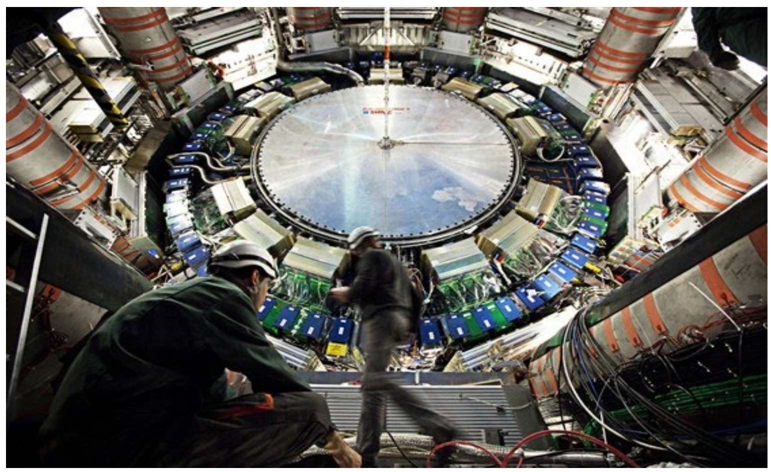
NSF oversight is handled by a program officer in the Division of Physics (PHY). Cross-foundation coordination is provided by an Integrated Project Team that includes staff from MPS, BFA, EDU, OISE, the Office of the Director, the Office of the General Counsel, and the Office of Legislative and Public Affairs. Within BFA, the Large Facilities Office (LFO) 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 provide 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 at least 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 more than two decades. It is based on an interagency Memorandum of Understanding (MOU) that was initially implemented in December 1999 and that was replaced by a new MOU in March 2018 to encompass HL-LHC activities.

<u>External Governance Structure</u>

NSF-funded principal investigators at Columbia University and Cornell University are responsible for managing and 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-funded construction scope for ATLAS and CMS was selected, at the outset of conceptual design, to be minimally coupled with 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 receives monthly reports from the ATLAS and CMS teams that describe the technical and financial status of NSF-funded construction activities and that update assessments of project risks. The monthly reports also document all revisions to the scope, budget, and schedule baselines, which are implemented through NSF-approved change-control processes. In those cases where revisions exceed thresholds defined in the cooperative agreements for construction, the ATLAS and CMS teams separately submit them to NSF for approval prior to making baseline adjustments.

Partnerships and Other Funding Sources

More than 45 funding agencies worldwide are contributing various components of the upgraded detectors. NSF investments in the upgrades enable university-based U.S. scientists and students to participate in the HL-LHC experimental program, which currently has about 7,000 participants worldwide. NSF is working closely with DOE to coordinate construction activities and to jointly oversee each detector's operation.



View of the ATLAS detector. *Credit: 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 established 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 detector upgrade program are 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 oversee and approve all LHC upgrade plans and major decisions at the international level.

Cost and Schedule

Commencement of NSF-funded construction in April 2020 was considered critical to enable recipient U.S. universities to undertake timely fabrication and delivery to CERN to meet the international integration schedule. A significant delay could have resulted in the transfer of NSF-funded scope to other international partners for accomplishment, resulting in lost leadership opportunities for U.S. scientists.

The major facility construction project will be completed when the NSF-funded components for both detectors are delivered and verified at CERN to be in good working order. NSF will support the subsequent installation, integration, and system testing of the NSF-funded components at CERN through awards to U.S. ATLAS and U.S. CMS collaborations for detector O&M. These activities will be coordinated by CERN. This work is currently planned to occur during CY 2026-2028. NSF's share of installation and commissioning costs was estimated before the pandemic outbreak at about $5.0 million per detector and reconfirmed in reviews NSF held in July 2021. The annual O&M cost is forecast to remain constant during and following the HL-LHC Detector Upgrade installation.

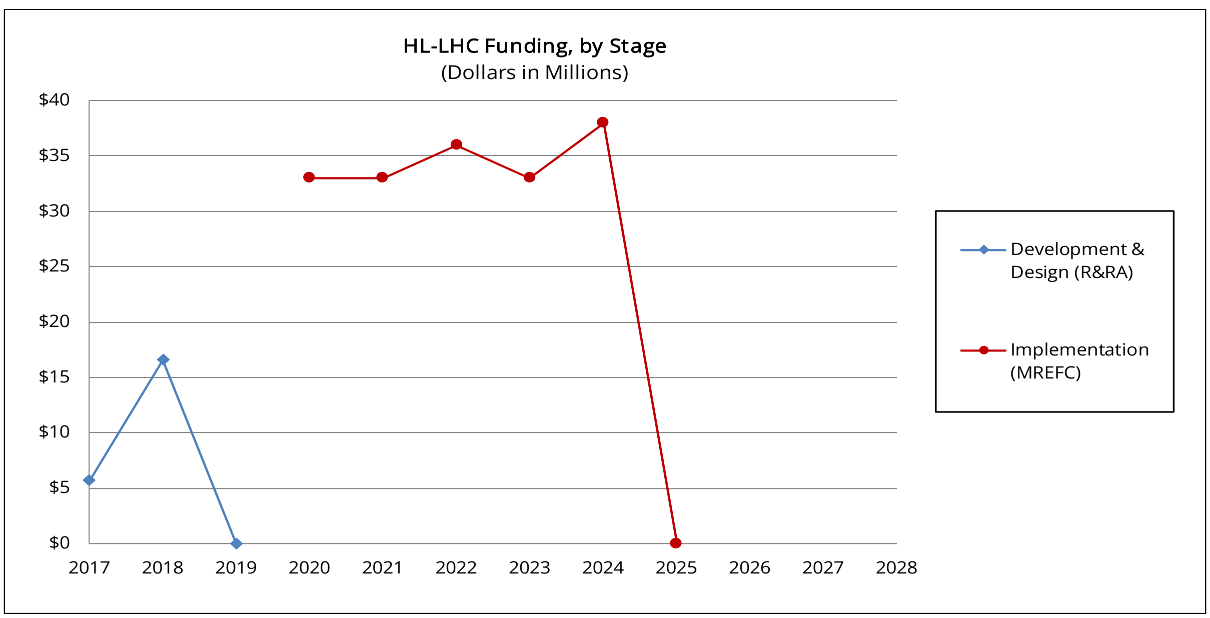
Total Funding Requirements for HL-LHC Upgrade
(Dollars in Millions)

	Cumulative Prior Years	FY 2021 Actual	FY 2022 Request	FY 2023 Request	ESTIMATES[1]				
					FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
R&RA:									
Development & Design	$24.31	-	-	-	-	-	-	-	-
Operations & Maintenance[2]		-	-	-	-	TBD	TBD	TBD	TBD
Subtotal, R&RA	$24.31	-	-	-	-	-	-	-	-
MREFC: Implementation[3]	33.00	33.00	36.00	33.00	38.00	-	-	-	-
Subtotal, MREFC	$33.00	$33.00	$36.00	$33.00	$38.00	-	-	-	-
TOTAL REQUIREMENTS	**$57.31**	**$33.00**	**$36.00**	**$33.00**	**$38.00**	**-**	**-**	**-**	**-**

[1] Outyear estimates are for planning purposes only. The current cooperative agreements end in December 2026 (CMS) and January 2027 (ATLAS) - see LHC request in the Major Facilities section.

[2] FY 2025 and beyond are TBD because COVID-19-related delays are increasingly likely to move the operations phase of HL-LHC past this reporting window.

[3] COVID-19 impacts are prelimary. An estimate of an additional $20.0 million in COVID-related funding need is incorporated in the FY 2024 estimate for planning purposes. Schedule and cost impacts will lead to revisions of the funding plan.



Future Operations Costs

An additional agreement among NSF, DOE, and CERN ("Experiments Protocol II"), signed in December 2015, follows on from the more general cooperation agreement signed in May 2015; it documents the responsibilities of U.S. participants to provide normal O&M 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 operations 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 projections are reasonable and are based on realistic assumptions. These projections are regularly revisited during the period of construction to incorporate evolving understanding of the pandemic impacts on future operation.

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 in areas of mutual interest. The coordination framework extends across the U.S. ATLAS and U.S. CMS collaborations, the U.S. funding agencies, other national funding agencies, and CERN. In July 2021, NSF conducted reviews of the software and computing R&D efforts that are underway to develop tools and methods that will satisfy future computing needs during HL-LHC operation. The reviewers expressed confidence that the multiple software research programs now underway to address these challenges are likely to provide affordable solutions within the flat computing budgets that are planned (by NSF, DOE, and funding agencies in other countries). Many of the R&D tasks now underway are promising, and only a subset needs to be successful to meet the needs of the HL operating program.

Reviews

- Conceptual Design Reviews (2016), Preliminary Design Reviews (2017-2018) and Final Design Reviews (2019) with external review panels were carried out in accordance with the requirements of NSF's Major Facilities Guide, with panel reports favorable to the continuation of the program as designs matured.
- 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) were held in July 2016.
- 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 that reported to the LHCC (July 2017-April 2018).
- Full Life-cycle Cost Reviews: NSF held reviews of the cost impacts of the HL upgrades on the LHC operations program in October 2019.
- NSF held external reviews of ATLAS and CMS installation plans and software and computing R&D projects in July 2021 to assess the stability of the planned scope, the forecast budget needs and schedule requirements, and the risk projections for these activities. The reviews indicated that these activities are well-planned and appropriately budgeted. Impacts from possible future revisions by CERN to the LHC run schedule are estimated to have minimal budget impact.

- Reviews of ATLAS and CMS HL upgrade activities took place in August 2021 to examine the current technical, financial, schedule, and risk status of each project and their current assessments of total pandemic impacts.

Risks

Technical Risk

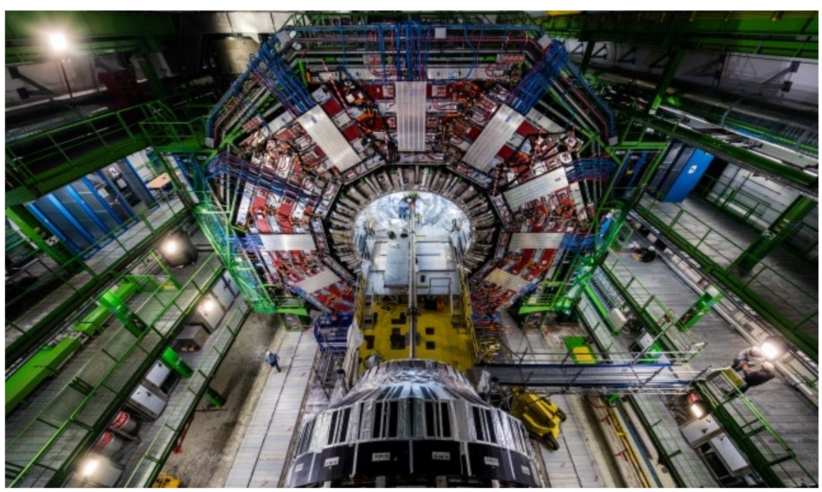
Technical designs were sufficiently mature at the start of construction to credibly support estimates of the costs to complete construction. Cost and schedule impacts due to technical risks are credibly bounded. There are multiple alternatives for dealing with the known production uncertainties, although the unanticipated impacts of the pandemic have introduced uncertainties in supply chain issues and substantially delayed access to radiation testing facilities needed to verify design performance.

Deployment Risk

The MREFC-supported construction projects conclude with delivery and verification of subcomponent operability at CERN. CERN has overall responsibility for coordinating the assembly, integration, and commissioning of the upgraded detectors, integrating the contributions from more than 40 different countries to each detector. While a slip in the CERN schedule for installation will delay scientific research, the total project cost of the NSF-funded construction projects is not anticipated to increase due to the expanded time interval between delivery of the NSF-funded elements to CERN and CERN's recently revised start of their installation (which NSF supports through its funding of ATLAS and CMS O&M programs). If pandemic impacts are prolonged, this could result in additional changes to installation and commissioning requirements and methods, but external reviews confirmed that overall cost impacts due to potential schedule delays are minor. If there is another significant delay in the start of installation, or a prolonged installation period, NSF will trade off installation support against O&M support to remain within the flat overall annual O&M budget profile planned.

Management Risk

The FDRs established that the management risk was low; the ATLAS and CMS management teams are well-qualified and well-prepared to undertake 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 (pre-pandemic) 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 could be accomplished within its estimated TPC, after adjusting the CMS estimate upward by $3.0 million to cover possible increased costs related to



View of the CMS detector. *Credit: CERN.*

critical components. The ATLAS and CMS Project Execution Plans included detailed (pre-COVID) risk management considerations and mitigation strategies. Each project maintains a risk register that is regularly updated (and which includes risks resulting from the pandemic).

Partnership Risk

The NSF scope for the detector upgrades relies on the successful and timely completion of testing by international partners of some key components, such as radiation-tolerant custom electronic circuits that are used throughout both detectors in many HL upgrade applications. COVID-19 impacts on international partners, as well as impacts on foreign suppliers of components for the NSF-funded scope, have added new schedule and cost risks to those considered when construction budgets were developed.

A further partnership risk arises from possible disruption of the detector fabrication activities that rely, in part, on DOE and NSF research grants to universities. Faculty, post-docs, and graduate students 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 could be confidently addressed. These pre-COVID assessments did not consider the possibility that the pandemic would close some university laboratories and shop facilities and restrict the level of student and post-doctoral fellow participation in hands-on activities associated with testing and characterizing detector components. As most of the fabrication of production quantities of various detector components occurs later in the construction schedule, only minor impacts from this risk have been realized so far. Most university laboratories and shop facilities in the U.S. are now opening, but the future availability of materials from vendors may pose a similar threat to the production schedule. This has not been a significant problem so far.

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 collaboration estimated these costs at approximately $1-2 million (not escalated).

REGIONAL CLASS RESEARCH VESSELS (RCRV) $1,980,000

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	FY 2022 Reqeust	FY 2023 Request	Total Project Cost
Previous Authorized Total Project Cost	$121.88	$105.00	$127.09	-	-	-	-	$353.97
Preliminary Estimate of COVID-19 Impact	-	-	-	-	-	5.00	1.98	6.98
Hurricane Ida Construction Impacts[1]	-	-	-	-	-	25.00	-	25.00
American Rescue Plan[2]	-	-	-	-	14.05	-	-	14.05
Estimate prior to Rebaseline	**$121.88**	**$105.00**	**$127.09**	**-**	**$14.05**	**$30.00**	**$1.98**	**$400.00**

[1] P.L 117-43, the "Extending Government Funding and Delivering Emergency Assistance Act", included $25.0 million in one-time funding for necessary expenses related to RCRV construction impacted by Hurricane Ida.
[2] Includes $14.05 million carried forward into FY 2022.

Brief Description

The Regional Class Research Vessel project is the NSF contribution to right-sizing and modernizing the U.S. Academic Research Fleet (ARF). It is expected that an ARF that includes three RCRVs will have sufficient usage to support efficient operation, while meeting regional demands. The first RCRV, R/V *Taani,* will be operated on the West Coast by Oregon State University (OSU). The second RCRV, R/V *Narragansett Dawn*, will be operated on the East Coast by the East Coast Oceanographic Consortium led by the University of Rhode Island. The third RCRV, R/V *Gilbert R. Mason,* will be operated in the Gulf of Mexico and nearby waters by the Gulf-Caribbean Oceanographic Consortium. The FY 2023 Request for the RCRV project is $1.98 million.

Scientific Purpose

The 2015 National Research Council report, *Sea Change: 2015-2025 Decadal Survey of Ocean Sciences*,[1] (hereafter simply *Sea Change* report) described eight high-priority science questions that will be supported by the RCRVs 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?

[1] www.nap.edu/read/21655/chapter/1

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?

The RCRVs were designed to support research to address each of the science questions and to meet the needs of researchers for work in coastal zones in support of biological, chemical, physical, and geological oceanography. The vessels will be capable of precise station-keeping for water column and sediment sampling, as well as supporting the use of remotely operated and autonomous vehicles. They will also enable virtual participation of shore-based scientists using telepresence-data presence technology, greatly expanding the potential user base. Each RCRV is expected to operate approximately 200-250 days per year, which is consistent with the optimal utilization for comparable ships in the ARF. Coordination of ARF scheduling is supported by the University-National Oceanographic Laboratory System (UNOLS).

Baseline History

The RCRV project is a major component in the plan for modernizing the ARF.[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. OSU was selected to manage the project and received the award in 2013. Input from external review panels, UNOLS, and the *Sea Change* report was received during the period 2013 to 2015 and informed the final decision to pursue construction. The *Sea Change* report recommended constructing only two of the three RCRV vessels originally planned, but Congress ultimately appropriated funding to build all three.

In 2015, the NSB 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 subsequently awarded a contract for construction to Gulf Island Shipyards (now Bollinger Houma Shipyards; see below) based in Houma, LA for the first vessel with options for two more. NSF plans to fund the operations of the RCRVs within the overall projected budget for the ARF, partially leveraging savings from fleet right-sizing through the retirement of older and less capable vessels.

Prior to the COVID-19 pandemic, the RCRV project had been planned within an NSB-authorized Total Project Cost (TPC) of $365.0 million. In FY 2017, $121.88 million was appropriated to facilitate the construction of three vessels, followed by $105.0 million in FY 2018 and $127.09 million in FY 2019. To date, the measurable impacts of COVID-19 on the RCRV project have been modest, but future impacts are likely. In December 2020, the NSF Director increased the authorized TPC from the NSB-authorized

[2] National Ocean Council. Federal Oceanographic Fleet Status Report, 2013.
https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/NSTC/federal_fleet_status_report_final.pdf

value of $365.0 million to $375.0 million to account for COVID-19 impacts that reduced the efficiency of the construction effort and increased the time to completion. In FY 2021, NSF approved the use of $14.05 million in American Rescue Plan funds to address COVID-19 impacts on the RCRV project. The FY 2022 Request of $5.0 million, in conjunction with the FY 2023 Request of $1.98 million, to address continuing pandemic impacts, would increase the total appropriated RCRV funds to $375.0 million. In FY 2022, $25.0 million was appropriated to cover necessary expenses related to impacts of Hurricane Ida, which heavily damaged the area around the shipyard. The full extent of damages is still being evaluated.

Project Status

OSU is managing the construction of the RCRVs 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 - **Complete**
Phase II: Shipyard Selection - **Complete**
Phase III: Construction – **In progress**
Phase IV: Transition to Operations – **Estimated Spring 2023**

The project completed Phase II in CY 2017, during which bids for construction of RCRV were solicited from U.S. shipyards and evaluated. The project is now in Phase III, construction. Keel-laying for the first RCRV, named R/V *Taani*, was completed in November 2018; for the second RCRV, named R/V *Narragansett Dawn*, in May 2019; and for the third RCRV, named R/V *Gilbert R. Mason*, in March 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 conduct science operations safely and efficiently before entry into the ARF. 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 Spring 2023 and will likely begin operations in Spring 2024. The project is planning a six-month stagger between vessel deliveries, with the projection that R/V *Narragansett Dawn* will enter the ARF in late 2024 and R/V *Gilbert R. Mason* will enter in early 2025.

In April 2021, Gulf Island Shipyards, the shipyard under contract with OSU for RCRV construction, was acquired by Bollinger Houma Shipyards (BHS). The contract was novated under the existing terms and conditions and assigned to BHS. Construction progress was improving as a result of the additional resources available under a larger shipyard, and BHS and OSU were concurrently replanning the project's schedule to account for more efficient processes as well as COVID-19 impacts. However, on August 29, 2021, Hurricane Ida made a direct hit on the city of Houma and on the shipyard. The shipyard survived relatively intact, with the main construction facility housing RCRV hulls one and two experiencing little damage. Two temporary warehouses erected to store RCRV components were destroyed by the storm; however, the materials stored in these areas are of a nature that they can withstand exposure to the elements for a limited time. The full extent of damages is still being evaluated, so the impact of Hurricane Ida on the RCRV project will likely not be known for several more months. Additional schedule delay is anticipated due to hurricane impacts. In FY 2022, $25.0 million was appropriated for necessary expenses related to RCRV construction impacted by Hurricane Ida. Any additional funding required to address Hurricane Ida impacts will be specified in the FY 2024 Request.

Summary of COVID-19 Impacts

The realized impacts to the project cost, scope, and duration resulting from COVID-19 during 2020 include a delay in delivery of the first vessel, R/V *Taani*, and slightly lesser delays for the other two vessels. In October 2020, OSU estimated likely COVID-19-specific impacts through 2021 for the entire three-ship build of $14.05 million and nine months. Depending on the additional realized impacts in FY 2022 and beyond, and the impact of Hurricane Ida, NSF will further adjust the TPC, as necessary.

Governance Structure and Partnerships

NSF Governance 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 Large Facilities Office, Cooperative Support Branch, 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 Governance Structure

The RCRV project is funded through a series of 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 for the award. The PM manages the RCRV project 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 federal stakeholders (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.

Partnerships and Other Funding Sources

NSF is the sole sponsor of RCRV construction to provide three ships for inclusion in the ARF. ARF vessels support the needs of all federal stakeholders who conduct oceanographic research, particularly NSF, the National Oceanic and Atmospheric Administration and the Office of Naval Research. Other users are granted access to ARF ships for research purposes, and all users pay the same daily rates. NSF is expected to support approximately 70 percent of RCRV utilization. NSF intends to make separate awards to each RCRV-operating institution.

Cost and Schedule

Total Funding Requirements for RCRV
(Dollars in Millions)

	Prior Years	FY 2021 Actual	FY 2021 ARP	FY 2022[2]	FY 2023 Request	ESTIMATES[3] FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
R&RA:										
Development & Design	$10.47	-	-	-	-	-	-	-	-	-
Operations & Maintenance		-	-	-	-	4.90	12.93	15.10	15.60	16.10
Subtotal, R&RA	$10.47	-	-	-	-	$4.90	$12.93	$15.10	$15.60	$16.10
MREFC:				-						
Implementation[1]	353.97	-	14.05	30.00	1.98	-	-	-	-	-
Subtotal, MREFC	$353.97	-	$14.05	$30.00	$1.98	-	-	-	-	-
TOTAL REQUIREMENTS	**$364.44**	**-**	**$14.05**	**$30.00**	**$1.98**	**$4.90**	**$12.93**	**$15.10**	**$15.60**	**$16.10**

[1] Includes $14.05 million of ARP funding carried forward into FY 2022.

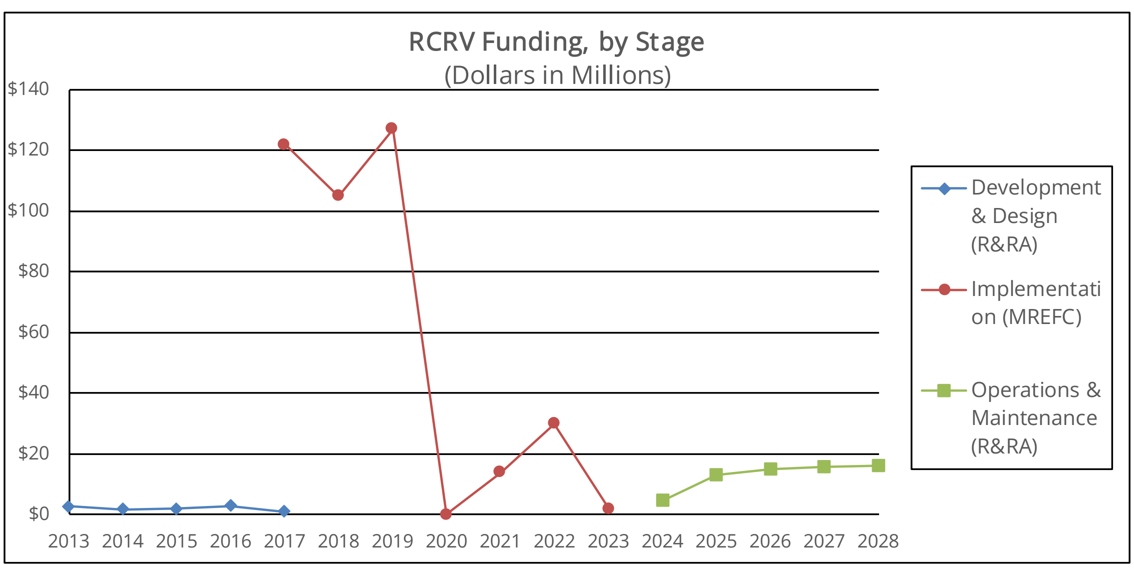
[2] The FY 2022 column includes $5.0 million from the FY 2022 Request and $25.0 million provided under H.R. 5305, the "Extending Government Funding and Delivering Emergency Assistance Act" for necessary expenses related to RCRV construction impacted by Hurricane Ida.

[3] Outyear estimates are for planning purposes only.

Total R&RA funding from FY 2017 to FY 2019 for RCRV design was $10.47 million. Total MREFC funding appropriated to support construction is currently $353.97 million. An additional $14.05 million in FY 2021 American Rescue Plan/MREFC funding was allocated to RCRV for COVID-19 impacts, which is planned for obligation in FY 2022.

An additional $5.0 million in FY 2022 MREFC funding was requested for NSF-held management reserve due to known construction delays from COVID-19, which is an unforeseen event that cannot be covered by budget contingency, per NSF policy. The FY 2023 Request of $1.98 million is the current estimated amount needed to address the remaining impacts due to COVID-19.

NSF received $25.0 million in one-time funding for necessary expenses related to RCRV construction impacts from Hurricane Ida. As the full extent of damages is still being evaluated, no additional funds are requested to address Hurricane Ida impacts in FY 2023.



Future Operations Costs

Annual ship operations costs are well understood after several decades of experience with vessels of all classes in the U.S. Academic Research Fleet. OSU developed an estimate for the first year of operations assuming 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 operating cost of current vessels after applying the appropriate multipliers for size and complexity. The ultimate annual cost for operating three RCRVs will be partially offset by cost savings from vessel retirements elsewhere in the ARF.

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 for operation of the first vessel.
- 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 review panel expressed confidence that the OSU Team was well qualified, had extensive relevant experience in ship acquisition, had established a positive, professional working relationship with Gulf Island Shipyards, and could deliver up to three RCRVs, within budget and on schedule, that would meet science mission requirements. Quarterly Management Reviews are conducted by OSU at the shipyard with NSF staff in attendance. The February 2020 Annual Construction Review was held at Gulf Island Shipyards, while the February 2021 review was held virtually due to the pandemic. The review panels expressed confidence that the OSU Project Team remains capable of delivering three RCRVs to the Academic Research Fleet despite the current challenges (See Risks below).

Risks

The following principal risks have been identified on OSU's project risk register. Planned mitigation strategies are included here with each identified risk.

- Hull Delivery Delay: BHS is replanning the construction schedule and indicated an anticipated nine-month delay to the delivery of the *R/V Taani* beyond the contractual date. This delay is expected to impact the deliveries of the *R/V Narragansett Dawn* and the R/V *Gilbert R. Mason*, although the overall delay to the project will likely be mitigated by refinements to the transition-to-operations strategy. The root cause of the delay is COVID-19 and the cost to the project will likely be mostly from additional project management expenses.
- Transition to Operations: Experience with commissioning new research vessels demonstrates the likelihood of unplanned events that could result in the need for additional port calls during sea trails and/or construction support if equipment fails. This risk will remain until the vessels are put to sea.
- Requirements Changes: All stakeholders, including the construction team, operating institutions,

Science Oversight Committee, and NSF can recommend requirements changes if improvements to operations or science support justify such changes. The ability to accommodate such recommendations is related to the availability of resources and an evaluation of the necessity for them.

- Inadequate Shipyard Performance: Shipyard's performance, including its subcontractors', will remain a risk throughout construction. Realization of this risk resulted in a pause in construction from January to August 2020, and the use of approximately $18 million in contingency, which also mitigated future likelihood of occurrence. Additionally, construction progress is improving under the new, larger shipyard owner, BHS. The February 2022 Annual Progress Review panel remarked that BHS adds resources not previously available to the project, such as fabrication of the RCRV aluminum superstructure at another BHS facility.
- Unanticipated Personnel Costs: Personnel costs or required support may be greater than anticipated for operating institutions during construction and commissioning. This risk includes higher than anticipated crew costs, including training for RCRV level of tonnage, or necessary additional personnel. This risk does not include additional time that could be required for transition to operations.

Approximately $34.0 million in contingency has been allocated to date as a result of realizing known risks. This amount decreased by $890,000 from that reported in the FY 2022 Request due to funds having been returned to contingency, which occurred because actual costs for completed tasks were below their estimates. A science-prioritized and time-phased scope management plan is in place to minimize impacts to science capabilities in case contingency funds are insufficient to cover realized risks. Scope reductions are not being considered to mitigate cost impacts from the pandemic. Although statistical estimates of downtime due to weather could be included in the risk model, a direct hit from a hurricane is not a risk that can be estimated probabilistically by the project team, and thus is a risk held by NSF.

VERA C. RUBIN OBSERVATORY (RUBIN OBSERVATORY) $15,000,000

Appropriated and Requested MREFC Funds for
Vera C. Rubin Observatory
(Dollars in Millions)

	Prior Years	FY 2019	FY 2020	FY 2021[1]	FY 2022 Request	FY 2023 Request[2]	FY 2024 Estimate[2]	Total Project Cost
Previous Authorized Total Project Cost	$331.72	$48.82	$46.35	$40.75	$5.36	-	-	$473.00
Current Authorized Total Project Cost (COVID-19)		-	10.00	-	-	-	-	10.00
Preliminary Estimate of Future COVID-19 Impact	-	-	-	-	35.39	15.00	7.61	58.00
ARP Estimate	-	-	-	30.00	-	-	-	$30.00
Estimate after Re-baseline	**$331.72**	**$48.82**	**$56.35**	**$70.75**	**$40.75**	**$15.00**	**$7.61**	**$571.00**

[1] In December 2021, based on the recent re-baseline of the Rubin construction project, NSB authorized a new Total Project Cost of $571.0 million.
[2] The FY 2023 Request, together with the FY 2024 Estimate, are based on the current best estimate of the total funding needed to address COVID-19 impacts. The COVID-19 situation continues to evolve, and ongoing schedule and cost impacts may lead to revisions of this funding plan.

Brief Description

Vera C. Rubin Observatory (formerly known as the Large Synoptic Survey Telescope) will comprise an 8.4-meter wide-field optical telescope located on Cerro Pachón in northern Chile, a 3.2-gigapixel camera supplied by the Department of Energy (DOE), and an advanced data management system. Taken together, these components are designed to carry out a deep survey of nearly half of the sky that will enable a broad range of fundamental astrophysical studies by the research community. Begun in August 2014, FY 2023 represents the tenth year of support for the construction project, originally planned to last 99 months. The original NSB-authorized Total Project Cost (TPC) was $473.0 million for NSF's contribution to Rubin Observatory, which is a joint project of NSF and DOE. The project is currently being re-baselined to account for the impacts of the COVID-19 pandemic. Delays due to the pandemic have now shifted the expected project completion to mid-FY 2024. The FY 2023 NSF request for Rubin Observatory is $15.0 million, to be followed by an estimated request for the final $7.6 million in FY 2024. This request is based on the re-baselined plan to complete construction given the anticipated approximately 22-month-delay and the revised Total Project Cost (TPC) $571.0 million[1] approved by the NSB in December 2021. The impacts of COVID-19 are described in more detail in the Project Status section.

Future operations of Rubin Observatory will be fully integrated into NSF's National Optical-Infrared Astronomy Research Laboratory (NOIRLab), which launched at the start of FY 2020 (Rubin Observatory construction is a stand-alone project outside NOIRLab). NOIRLab also includes the Mid-Scale Observatories, the Community Science & Data Center, and the Gemini Observatory.

Scientific Purpose

Rubin Observatory's initial 10-year survey has a cadence that will enable repeat observation of each

[1] NSF intends to draw upon multiple funding sources to cover the additional costs. NSF reprogrammed $10.0 million from FY 2020 funds within the MREFC account, originally intended for the Antarctic Infrastructure Modernization for Science project; that project did not need all its appropriated funds in FY 2020 because of the COVID-19 pandemic. In FY 2021, NSF allocated an additional $30.0 million from within the American Rescue Plan appropriation to cover pandemic-related costs. The remaining funds needed to complete the Rubin construction project are requested in FY 2022, FY 2023, and FY 2024 appropriations.

survey field approximately twice weekly. The requirements for 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, Rubin Observatory's initial Legacy Survey of Space and Time (LSST) will result in a comprehensive data set that will enable a broad range of astrophysical studies on these and other topics. Thus, 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

Rubin Observatory is a joint NSF and 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*.[2]

Prior to NSF's construction award, NSF, DOE, and private (non-federal) partners invested over $130.0 million in Rubin Observatory-related work, of which about 70 percent supported design and development. 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.

NSF and DOE conducted a series of reviews in 2011 and 2012, including the NSF Preliminary Design Review and a subsequent cost estimation review, to determine the project baseline. 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.

Project Status

NSF's construction award was issued in August 2014. 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 of Cerro Pachón. The secondary mirror (M2) has been successfully coated at the summit facility, and staff have moved into the completed base facility in La Serena, Chile. Following the onset of COVID-19, the project has been executing activities to minimize the impact of delays on the integrated project schedule. Installation of the telescope mount assembly (TMA) on the summit resumed after work restarted in January 2021. While a resurgence of COVID-19 in Chile caused significant additional delays later in FY 2021, the telescope mount's major structure is now complete. Dome installation is now progressing well, despite the earlier delays caused by weather and realization of other known risks. Commissioning activities for the Auxiliary Telescope, which will

[2] www.nap.edu/catalog/12951/new-worlds-new-horizons-in-astronomy-and-astrophysics

be used for calibration purposes, are proceeding well. NSF- and DOE-supported activities remain tightly coordinated, both at the project level and among agency program officers.

Summary of COVID-19 Impacts

- In March 2020, the project suspended all construction activity on the summit while most work on data management was able to continue through telework. Other remote activities have prioritized tasks that will help recover schedule as on-site work resumes.
- Summit construction activity began a slow ramp-up on September 28, 2020. Fortunately, no significant damage resulted from site exposure to the elements during Chilean winter storms, while summit construction was paused. Key contractors gradually returned to the summit over several months. The dome is now substantially closed. In January 2021, work on the TMA, which is on the critical path, resumed successfully, and March 2, 2021 marked the spectacular installation of the TMA's top-end assembly.
- In FY 2020, NSF authorized $10.0 million in NSF-held management reserve for any urgently required expenses necessitated by COVID-19, such as ramping down and ramping up activity on the summit, protecting exposed equipment from the elements, mitigating potential damage to sensitive equipment during the Chilean winter, and direct expenses for new procedures and protocols required for COVID-19.
- TMA work paused again for five months while some subcontractors awaited the cancellation of Chilean COVID-19 quarantines that prevented their return to the summit. The current schedule remains tentative and is subject to potential additional delays as the global pandemic continues.
- In FY 2021, the NSB authorized $12.0 million in NSF-held management reserve to sustain the project while the re-baseline review was conducted. The amount was based on an NSF analysis of anticipated construction costs related to COVID delays and availability of previously authorized management reserve.
- In December 2021, the NSB authorized a new TPC of $571.0 million, based on the re-baselined plan for the construction project, including an additional $98.0 million for realized and potential impacts caused by the COVID-19 pandemic and new data security requirements identified since project initiation, based on the estimated cost of a projected 22-month schedule delay and estimated remaining uncertainty in COVID-19-induced schedule delay. This would also move the anticipated final year of MREFC funding to FY 2024.

Meeting Intellectual Community Needs

The site on Cerro Pachón, Chile, was selected for 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 Rubin Observatory's 10-year survey. Rubin Observatory will collect about 20 terabytes of multi-color imaging data every night[3] 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 the sky accessible from Cerro Pachón will identify explosive events such as cataclysmic variable stars, supernovae, and the optical counterparts of X-ray flashes, as well as find new moving objects and better characterize those already known. Estimates of Rubin

[3] See Ivezić et al. (2019), *The Astrophysical Journal,* 873, 111.

Observatory's ability to locate NEOs[4] and Potentially Hazardous Asteroids (PHAs)[4] have been refined by the Rubin Observatory project members,[5] as well as by external studies, including an independent Jet Propulsion Laboratory study[6] supported by NASA's Planetary Defense Coordination Office. Assuming other existing NEO efforts continue, at the end of Rubin Observatory's 10-year initial survey, the catalogue for objects larger than about 140 meters across should be about 75 percent complete for NEOs (about 80 percent for PHAs). Without Rubin Observatory, the completeness would be about 60 percent for NEOs (about 65 percent for PHAs).

While the facility is under construction, there are currently no science users. However, the Rubin Observatory project expects to create a science-ready database of enormous utility throughout astronomy research and education. 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 public.

Governance Structure and Partnerships

NSF Governance Structure

NSF oversight is provided by a program officer in the MPS Division of Astronomical Sciences (AST) working cooperatively with other NSF staff through the Integrated Project Team having members from MPS, Office of International Science and Engineering, BFA, the Office of the 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 and commissioning of the camera.

External Governance Structure

The responsible awardee for Rubin Observatory construction is the Association of Universities for Research in Astronomy, Inc. (AURA), a non-profit science management corporation. The Rubin Observatory Project Office is an AURA-managed center for construction, and AURA established a separate management council that oversees this Project Office. The 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 Rubin Observatory pre-operations ramp-up activity that began in October 2018 and for coordinating construction activities and pre-operations activities that are executed side-by-side. Pre-operations activities are fully integrated into NOIRLab for which AURA has a separate NOIRLab Management Oversight Council. The NOIRLab management team works with

[4] 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 0.05 au (roughly 7,500,000 kilometers) of Earth and are larger than roughly 140 meters in diameter.

[5] www.doi.org/10.1016/j.icarus.2017.11.033

[6] www.arxiv.org/abs/1705.06209

the Rubin Observatory Operations Director to oversee NOIRLab integration activities as Rubin Observatory prepares for operations.

Partnerships and Other Funding Sources

The Rubin Observatory Project is a partnership between NSF and the DOE Office of High Energy Physics, with NSF as the lead agency. Private funding totaling approximately $39 million was critical for reducing risk and beginning the fabrication of the novel primary telescope mirror prior to the initiation of the NSF and DOE construction projects. DOE is providing the world-leading 3.2-gigapixel digital camera and is contributing to design, development, installation, commissioning, operations, and scientific research support. Interagency coordination is accomplished through weekly meetings of the NSF-DOE Joint Oversight Group (JOG) and was formalized through a Memorandum of Understanding signed in July 2012. The JOG coordinates all aspects of activities during all phases of the project. The DOE-funded effort is managed by the SLAC National Accelerator Laboratory.

Cost and Schedule

NSF obligations for design and development (D&D) are complete at $57.13 million; other contributions to D&D came from DOE ($26.0 million) and from private, non-federal support (approximately $13 million).

In 2013, the FDR panel considered the proposed TPC of $473.0 million to be reasonable and recommended that the project improve its planning of potential descoping options. NSF carried out further cost review prior to making the Construction Stage award. The Project Team performed a Monte Carlo analysis on its resource-loaded integrated master schedule and determined the probability of completing the project within the proposed budget and by the planned survey start date of October 1, 2022, to be over 90 percent. As described more fully above, it is expected that the COVID-19 pandemic will impose a delay of approximately 22 months in project completion with a cost increase that is currently estimated to be approximately $98 million above the original TPC of $473.0 million. DOE's baseline cost for the camera was fixed at $168.0 million.[7] The total construction cost also included approximately $39 million from non-federal sources, all of which have been expended.

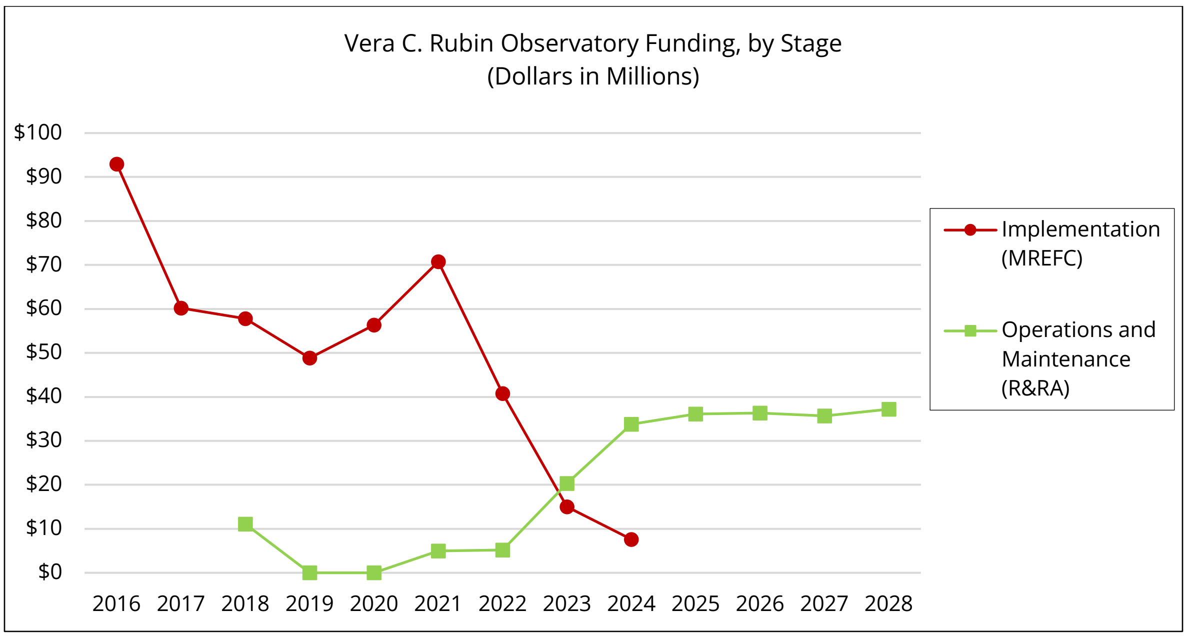
The FY 2023 NSF Request level for Rubin Observatory will enable the construction project to account for the impacts of COVID-19 and continue progress to completion in FY 2024. It is based on the re-baselined plan, incorporating the funding needed to address the delays due to COVID-19. The COVID-19 situation continues to evolve, and ongoing schedule and cost impacts may lead to revisions of this funding plan.

[7] Any COVID-related changes in the DOE camera costs are outside the scope of the NSF Request.

Total Funding Requirements for Vera C. Rubin Observatory
(Dollars in Millions)

	Prior Years	FY 2021 Actual	FY 2021 ARP Estimate	FY 2022 Request	FY 2023 Request	Estimates[1] FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
R&RA:	-	-	-	-	-	-	-	-	-	-
Development & Design	$57.13	-	-	-	-	-	-	-	-	-
Operations & Maintenance[1]		6.09	-	5.20	20.30	33.80	36.09	36.34	35.71	37.20
Subtotal, R&RA	$57.13	$6.09	-	$5.20	$20.30	$33.80	$36.09	$36.34	$35.71	$37.20
MREFC:										
Implementation	436.89	40.75	30.00	40.75	15.00	$7.61	-	-	-	-
Subtotal, MREFC	$436.89	$40.75	$30.00	$40.75	$15.00	$7.61	-	-	-	-
TOTAL REQUIREMENTS	**$494.02**	**$46.84**	**$30.00**	**$45.95**	**$35.30**	**$41.41**	**$36.09**	**$36.34**	**$35.71**	**$37.20**

[1] Outyear funding estimates are for planning purposes only. A new cooperative support agreement for O&M is anticipated in FY 2023. These values represent NSF support only and amount to about 50 percent of the total operations cost. DOE provides the balance of the funding required, while non-federal contributors will also provide some in-kind contributions.



Future Operations Costs

The total annual operations cost for Rubin Observatory is currently estimated to be about $70 million in the first full year of operations (FY 2025). NSF and DOE are partnering on observatory operations. The final full operations costs will be determined through a review, approval, and award process.

Initial, pre-operations funding began with NSF providing $11.10 million in FY 2018 for the period FY 2019–FY 2021, with an additional $6.09 million awarded in FY 2021 to cover the COVID-19 delays through FY 2022. The balance of Rubin Observatory pre-operations and full operations funding for the period FY 2023–FY 2027 is expected to be funded as part of the NOIRLab-wide operations plan.

In FY 2019, NSF and DOE jointly established a new model for in-kind contributions from international participants. The shift from cash contributions mitigates the risk of future funding for operations being inadequate, at the cost of a larger commitment from the federal agencies. 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 with international participants.

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 Rubin Observatory Project Office during Design and Construction.

Management, Cost, and Schedule Reviews

Cost, schedule, and risk are also scrutinized during the technical reviews. During construction, NSF and DOE hold regular joint progress reviews. The most recent reviews are summarized below.

- In April 2020, NSF and DOE held a joint review of the project's latest pre-operations progress and operations planning for the full ten-year survey, including the remaining years of pre-operations ramp-up activity and two years of post-survey activity. A panel of expert external reviewers concluded that "the operations team has a strong, appropriate plan for its current phase, and is well on the way to full development of the operations plan." NSF and DOE will continue funding pre-operations ramp-up activity, which began in FY 2019.
- The sixth joint agency progress review occurred in August 2020 with a positive outcome. A significant portion of the review focused on the cost and schedule status immediately prior to the COVID-19 pandemic shutdown of construction activity on the summit, and the review panel judged the project to be on track to finish on time and on budget prior to the shutdown. The balance of the review focused on COVID-19 safety; replanning of the remaining assembly, integration, and commissioning activities; risk management; and technical status.
- An Earned Value Management System (EVMS) surveillance review coincided with the 2020 annual progress review and was used to evaluate the project's alignment with GAO good practices on schedule. This review determined that the Rubin Observatory EVMS continues to meet NSF requirements for EVMS, and there were no required corrective actions.
- A joint agency-led review of the project re-baseline request was held June 15-17, 2021. The review looked at the Project's performance to date and the execution plan, including technical scope, cost, schedule, and the safety and risk management plans. The reviewers endorsed the re-baseline request and recommended revisions to document costs in greater detail and to update the request following a more certain restart of TMA work on the summit.
- An EVMS surveillance review of the re-baseline request coincided with the re-baseline review and focused on the impacts of the COVID-19 pandemic. The review team identified several items to revise in the re-baseline request to assure confidence in the revised TPC.
- The seventh joint agency progress review occurred in October 2021 with a positive outcome. The review was comprehensive but with particular focus on the work remaining, the readiness of the project team for the re-baselined activities, the on-going COVID-19 response, definition of construction completeness criteria, and the planned transition to operations.

Risks

Technical

Much of the technical risk was retired during development and design and, since full construction began, no new major technical risks have been identified. Realized risks have been mitigated by use of budget and schedule contingency or re-planning by the Rubin Observatory Project Office. The Data

Management (DM) effort was previously identified as a risk and subsequently re-planned following panel recommendations from a July 2017 DM review, including the use of contingencies. Careful planning to stage DM deliverables in coordination with commissioning sequencing will mitigate the remaining risks associated with DM. Commissioning plans overall have strategies to mitigate technical risks as the entire system is assembled and integrated over the next two years.

Site

The possible site risk due to local geological anomalies was realized during excavation and successfully handled. Site disruptions from geologic events and extreme weather remain as possible risks with appropriate mitigation plans.

Environmental Health and Safety

The 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. In FY 2020, AURA initiated appropriate policies, procedures, and protocols to adapt to working safely in the global COVID-19 pandemic. Such policies are reviewed and adjusted as conditions in various locations evolve. External reviews have given the project high marks for its safety culture. Risks due to currently anticipated COVID-19 conditions are included in the project re-baseline, whereas risks due to unpredictable evolution of COVID-19 conditions are held by the federal agencies.

Credit: Rubin Observatory/AURA/NSF.

Partnership Risk

Significant attention has been paid to partnership risk, and that risk has been mitigated by careful coordination and unified project governance and management structures. The 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 and associated work packages daily. Remaining project risks can impact the cost and schedule of each phase of the project. Such risks may affect one or both partner agencies, and the Project Manager carefully manages, coordinates, and mitigates such risks accordingly. 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 Rubin Observatory construction, and the agencies' Program Officers, Grants and Agreements Officer, and AST financial managers.

System Integration Risk

Final delivery of the integrated project will include delivery of the NSF construction scope (site, telescope, and data management system) and the DOE construction scope (the 3.2-gigapixel camera). Late delivery of any subsystem could delay project completion. The project management team continually monitors risk of late deliveries and plans mitigation strategies to reduce potential impacts on the overall project cost and schedule.

MID-SCALE RESEARCH INFRASTRUCTURE TRACK 2 (MID-SCALE RI-2) $76,250,000

Appropriated and Requested MREFC Funds for the
Mid-Scale Research Infrastructure Track 2 Program
(Dollars in Millions)[1]

FY 2021 Actual	FY 2022 Request	FY 2023 Request	FY 2024 Estimate	FY 2025 Estimate	FY 2026 Estimate	FY 2027 Estimate	FY 2028 Estimate
$74.04	$76.25	$76.25	$76.25	$76.25	$76.25	$76.25	$76.25

[1]Outyear estimates are for planning purposes only. NSF will evaluate mid-scale in the context of agency priorities for each future budget submission.

Scientific Purpose

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 Priorities chapter. Here, we describe Track 2 (Mid-scale RI-2), covering projects with individual implementation costs between $20.0 million and $100.0 million, with funding requested from the MREFC account.

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. The Mid-scale RI-2 track is intended to respond directly to that demand.

In the 2018 appropriation for NSF, report language from the House of Representatives encouraged the NSB "to consider further changes that would bridge the gap between the Major Research Instrumentation program and the MREFC account while also developing processes appropriate for mid-scale infrastructure, cyberinfrastructure, and instrument upgrades to be funded through the MREFC account." The NSB issued a report (NSB-2018-40)[1] that made several recommendations, including "a long-term *agency-level* commitment to mid-scale research infrastructure."

NSF responded to the NSB recommendations and the AICA mandate to develop a strategy with the detailed Mid-scale RI program. 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 beginning in FY 2020. NSF issued its first solicitation for Mid-scale RI-2 in December 2018, requesting proposals with total implementation costs in the range between $20.0 million and $70.0 million. A second solicitation[2] with a new upper limit of $100.0 million was issued in December 2020 and full proposals were received in

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[1] www.nsf.gov/nsb/publications/2018/NSB-2018-40-Midscale-Research-Infrastructure-Report-to-Congress-Oct2018.pdf
[2] www.nsf.gov/pubs/2021/nsf21537/nsf21537.pdf

September 2021. These proposals are undergoing a series of review, including scientific and technical panels, site visits, and reverse site visits focused on project management. Award decisions are anticipated in late 2022.

Since Mid-scale RI-2 is a portfolio of implementation awards that span all NSF research communities, it does not have a single set of *a priori* scientific goals. In the 2020 solicitation, NSF stated that "[t]he Mid-scale Research Infrastructure programs are aimed at transforming scientific and engineering research fields as well as science, technology, engineering, and mathematics education research by making available new capabilities, while simultaneously training early-career researchers in the development, design, and construction of cutting-edge infrastructure." The solicitation defines research infrastructure as "any combination of facilities, equipment, instrumentation, or computational hardware or software, and the necessary human capital in support 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, next-generation computer networking testbeds, and higher-sensitivity instrumentation at LIGO. Results from the first NSF-wide solicitation are discussed below.

Total Funding Requirements for Mid-scale RI-2[1]
(Dollars in Millions)

	FY 2021 Actual	FY 2022 Request	FY 2023 Request	ESTIMATES[2] FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
R&RA:								
Development & Design	-	-	-	-	-	-		
Subtotal, R&RA	-	-	-	-	-	-	-	-
MREFC:								
Implementation	$74.04	$76.25	$76.25	$76.25	$76.25	$76.25	$76.25	$76.25
Subtotal, MREFC	$74.04	$76.25	$76.25	$76.25	$76.25	$76.25	$76.25	$76.25
TOTAL REQUIREMENTS	**$74.04**	**$76.25**	**$76.25**	**$76.25**	**$76.25**	**$76.25**	**$76.25**	**$76.25**

[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.

[2] Outyear numbers are for planning purposes only. NSF will evaluate mid-scale in the context of agency priorities for each future budget submission.

Management and Oversight

Mid-scale RI-2 proposals have been solicited from all scientific disciplines covered by NSF, as noted above. In anticipation of the funding of such proposals, the NSF Major Facilities Guide (NSF 19-068)[3] was updated with an extensive discussion of management and oversight processes for Mid-scale RI, found in Section 5 of that Guide. That guidance has been further refined in the newest version of the Guide, now renamed the NSF Research Infrastructure Guide (NSF 21-107).[4] Because of the varied nature of potential Mid-scale RI-2 awards, the Research Infrastructure 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

[3] www.nsf.gov/pubs/2019/nsf19068/nsf19068.pdf
[4] www.nsf.gov/pubs/2021/nsf21107/nsf21107.pdf

> 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…"

Each mid-scale project is overseen by a program officer from a relevant research directorate as well as a grants and agreements officer from BFA. Additionally, within BFA, the Large Facilities Office has designated a liaison for the entire mid-scale portfolio, including the Mid-scale RI-2 program, to assure a consistent and effective approach to project management oversight for these awards. To enable appropriate oversight, all Mid-scale RI-2 proposals are required to submit a detailed Project Execution Plan. This plan helps NSF assess project risk and complexity to tailor the oversight for each project once awards are made.

Oversight requirements for individual awards are detailed in the grant or cooperative agreement terms and conditions. Portfolio-wide oversight, ensuring that the Mid-scale RI-2 program meets its overall objectives, is led by the Chief Officer for Research Facilities in the Office of the Director.

Mid-scale RI Track 2 Status

NSB authorization for the first awards was given in May 2020. The authorized awards underwent full cost analyses and final award negotiations, including Independent Cost Estimates required under AICA and assessment of any imminent impacts from COVID-19. The first three Mid-scale RI-2 awards from the MREFC account were made in October 2020. Those three awards are listed below and described further in an NSF special report[5]:

- "High Magnetic Field Beamline," Cornell University, $32.69 million
- "Global Ocean Biogeochemistry Array," Monterey Bay Aquarium Research Institute, $52.94 million
- "Grid-Connected Testing Infrastructure for Networked Control of Distributed Energy Resources," University of California at San Diego, $39.47 million.

NSB authorized additional awards for proposals from the first solicitation in February 2021. The fourth award was made in June 2021, and a fifth award was announced in February 2022:

- "Network for Advanced NMR [Nuclear Magnetic Resonance]," University of Connecticut, $39.70 million.[6]
- "Research Data Ecosystem: A National Resource for Reproducible, Robust, and Transparent Social Science Research in the 21st Century," University of Michigan, $38.36 million.[7]

As stated above, a solicitation for a second round of proposals for Mid-scale RI-2 was released in December 2020, and NSF anticipates making new awards from that competition in the first half of FY 2023.

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[5] www.nsf.gov/news/special_reports/announcements/102920.jsp
[6] www.nsf.gov/news/special_reports/announcements/061621.jsp
[7] www.nsf.gov/news/special_reports/announcements/020422.jsp

Future Operations Costs

The Mid-scale RI-2 solicitations 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 to reap the scientific benefits of an award. At a hypothetical level of $200 million in awards from the first solicitation and an estimated upper limit to the operations cost of 10 percent of the capital costs per project per year,[8] the total operations cost impact from the first round of Mid-scale RI-2 awards could potentially ramp up to a steady state of no more than $20 million per year by FY 2025. Given the variety of operational models for the funded infrastructure, this cost would only be partially borne by NSF.[9] Operations costs of projects funded from the second solicitation, released in FY 2021, and from subsequent solicitations, would not begin until well after FY 2025.

Reviews

The Mid-scale RI-2 proposals do not go through the Conceptual/Preliminary/Final Design phases and accompanying reviews typical of major facility projects, which enables a more agile process for these important, but smaller, projects. However, the Mid-scale RI-2 program only considers projects that have reached a high state of readiness for implementation through previous investments in development. The program has been designed to include a two-step, pre-proposal/full-proposal process to limit the burden on the research community of both preparing and reviewing full proposals. Lead NSF directorates are identified to review each pre-proposal and full proposal. Pre-proposals are externally reviewed according to the standard NSF merit review criteria and solicitation-specific review criteria, with a subset invited to submit full proposals. Those full proposals are also externally reviewed, with a subset selected for a Site Visit. Based on the results of the site visit, a further subset of proposals is invited to a Reverse Site Visit at NSF (or virtual) for detailed assessment of the Project Execution Plans. Some highly meritorious projects with weaknesses in their Project Execution Plans may be asked to submit revised Project Execution Plans, responding to reviewer recommendations and subsequent NSF guidance, before final funding recommendations are made.

Based on the extensive input from external merit review, the most meritorious proposals are identified by the lead directorates and submitted to the Mid-scale RI-2 Working Group. That working group prepares sample portfolios of those proposals at different levels of total funding and forwards them to the Office of the Director. A final recommended portfolio is constructed that also takes account of strategic agency considerations, technical and programmatic risk, projected funding availability, and overall portfolio balance. The Director recommends, and the NSB authorizes, the full portfolio of awards. During the recommendation process, NSF also conducts a rigorous cost analysis of each candidate project to ensure compliance with the Government Accountability Office good practices as required by the solicitation and the Research Infrastructure Guide. That analysis may inform modifications to the award portfolio if it reveals substantial deficiencies in the proposed cost

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[8] www.nsf.gov/nsb/publications/2018/NSB-2018-17-Operations-and-Maintenance-Report-to-Congress.pdf

[9] An annual operations cost of 10 percent of the total capital costs is a typical “high-end” estimate for a major infrastructure project. Since some of the Mid-scale RI-2 awards being made by NSF are additions to existing facilities or infrastructure, the predicted increments to the operations costs are less than that high-end estimate for several projects.

of a project.

Risks

Technical risks and risk management for the individual projects are included as part of the Project Execution Plans and evaluated rigorously by an external panel of project management experts. The construction of the final portfolio also relies significantly on an evaluation of agency risks. These include, for example, a constraint that not all the projects should have very high or very low technical risk,[10] potential cost risks identified during the review process, assessment of any partnership risks, the risk that events out of the control of an awardee might significantly impact an individual project, and/or the risk of overcommitting future budgets such that the next solicitation might be significantly delayed.

[10] NSF does not want all projects to have very high technical risk, because of the desire for a high probability of very successful projects coming out of the Mid-scale program. On the other hand, NSF does not want all projects to be “safe” projects with very low technical risk, because a portfolio consisting only of such projects might have less potential for dramatic increases in scientific knowledge.

MAJOR FACILITIES

Major Facilities Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2021 ARP Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total Research and Related Activities	**$975.63**	**-**	**-**	**$1,015.53**	**39.90**	**4.1%**
Operations and Maintenance of Existing Facilities	671.29	-	-	679.32	8.03	1.2%
Federally Funded Research and Development Centers	289.63	-	-	303.48	13.85	4.8%
Operations and Maintenance of Facilities under Construction	6.09	-	-	20.30	14.21	233.4%
R&RA Design Stage Activities	8.62		-	12.43	3.81	44.2%
Major Research Equipment and Facilities Construction	**$161.27**	**$8.95**	**-**	**$187.23**	**25.96**	**16.1%**
Total, Major Multi-User Research Facilities	**$1,136.90**	**$8.95**	**-**	**$1,202.76**	**65.86**	**5.8%**

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 use 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. Recommendations from the Review resulted in NSF establishing a new practice to have at least three months of funding obligated to the major facility awards to span potential periods of funding discontinuity and thus provide financial stability. The FY 2020 Strategic Review assessed options for improving NSF internal processes for the Development and Design Stages. Recommendations included collecting consistent information annually from all Divisions on projects in development to promote strategic awareness, expanding Mid-scale and Major Facility development and design funding opportunities, building capacity in project management expertise for NSF staff and the research community through training opportunities and engagement, and clarifying the Research Infrastructure Guide on expectations for entering the Design Stage at points beyond the Conceptual Design Phase. These recommendations are being implemented by the Office of the Director and the Large Facilities Office.

The Facility Operation Transition activity proposed in IA is the fourth year of a pilot program that reflects NSF's strategic commitment to successful O&M of new major facilities as well as balancing portfolio funding between facilities and individual 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] 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. In FY 2021, these funds supported facilities operations and maintenance costs in BIO ($7.50 million) and MPS ($2.50 million); in FY 2022, the allocation of these funds to specific organizations is pending submission and approval of NSF's FY 2022 Current Plan.

All NSF's major facilities continue to experience impacts from the COVID-19 pandemic. Typically, there have been periods of reduced or interrupted scientific operations, revisions of operational procedures to enable social distancing, and slowdowns in upgrade and maintenance projects because of inefficiencies introduced by COVID-19 precautions. NSF and its awardees made use of flexibilities provided by the Office of Management and Budget and the Uniform Guidance in maintaining facility operational readiness throughout the pandemic.

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 that are funded through NSF's MREFC account is provided in the MREFC narratives. The following pages contain information on the budget requests for NSF's major facilities in FY 2023.

[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.*FY 2021 Budget Request to Congress.*

MAJOR FACILITIES FUNDING, BY PROJECT
(Dollars in Millions)

	FY 2021 Actual	FY 2021 ARP Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Operations and Maintenance of Major Facilities	**$967.01**	**-**	**-**	**$1,003.10**	**$36.09**	**3.7%**
National Ecological Observatory Network (NEON)	65.00	-	-	70.00	5.00	7.7%
Biological Sciences	***$65.00***	**-**	**-**	***$70.00***	***$5.00***	***7.7%***
Academic Research Fleet[1]	99.54	-	-	119.11	19.57	19.7%
Geodetic Facility for the Advancement of GEoscience (GAGE)	14.56	-	-	14.55	-0.01	-0.1%
International Ocean Discovery Program (IODP)	48.00	-	-	50.40	2.40	5.0%
National Center for Atmospheric Research (NCAR) FFRDC	104.10	-	-	116.20	12.10	11.6%
Ocean Observatories Initiative (OOI)	45.30	-	-	51.00	5.70	12.6%
Seismological Facility for the Advancement of GEeoscience (SAGE)	22.30	-	-	23.37	1.07	4.8%
Geosciences	***$333.79***	**-**	**-**	***$374.63***	***$40.84***	***12.2%***
Arecibo Observatory[2]	48.23	-	-	6.00	-42.23	-87.6%
Green Bank Observatory (GBO) FFRDC[3]	8.90	-	-	10.83	1.93	21.7%
Large Hadron Collider (LHC) - ATLAS and CMS	20.00	-	-	20.50	0.50	2.5%
Laser Interferometer Gravitational Wave Observatory (LIGO)	45.00	-	-	45.00	-	-
National High Magnetic Field Laboratory (NHMFL)[4]	26.13	-	-	40.49	14.36	54.9%
National Radio Astronomy Observatory (NRAO) FFRDC[5]	98.21	-	-	98.11	-0.10	-0.1%
NRAO O&M	*49.53*	-	-	*44.45*	-5.08	-10.3%
Atacama Large Millimeter Array (ALMA) O&M	*48.68*	-	-	*53.66*	4.98	10.2%
National Solar Observatory (NSO) FFRDC	24.19	-	-	27.74	3.55	14.7%
NSO O&M[6]	*4.65*	-	-	*7.06*	2.41	51.9%
Daniel K. Inouye Solar Telescope (DKIST)[7]	*19.54*	-	-	*20.68*	1.14	5.8%
National Superconducting Cyclotron Laboratory (NSCL)[8]	15.50	-	-	-	-15.50	-100.0%
NSF's National Optical-Infrared Astronomy Research Laboratory FFRDC[9]	60.32	-	-	70.90	10.58	17.5%
NOIRLab O&M (Mid-Scale Observatories & Community Science and Data Center	*29.95*	-	-	*25.99*	-3.96	-13.2%
GEMINI Observatory O&M	*24.27*	-	-	*24.61*	0.34	1.4%
Vera C. Rubin Observatory O&M	*6.09*	-	-	*20.30*	14.21	233.4%
Mathematical and Physical Sciences	***$346.48***	**-**	**-**	***$319.57***	***-$26.91***	***-7.8%***
Antarctic Facilities and Operations (AFO)[10]	214.65	-	-	231.24	16.59	7.7%
IceCube Neutrino Observatory (ICNO)	7.08	-	-	7.66	0.58	8.1%
Office of Polar Programs	***$221.74***	**-**	**-**	***$238.90***	***$17.16***	***7.7%***
Major Research Facilities Construction Investments	**$169.89**	**$8.95**	**-**	**$199.66**	**$29.77**	**17.5%**
R&RA Design Stage Activities[11]	**$8.62**	**-**	**-**	**$12.43**	**$3.81**	**44.2%**
Major Research Equipment and Facilities Construction (MREFC)	**$161.27**	**$8.95**	**-**	**$187.23**	**$25.96**	**16.1%**
Total, Major Facilities	**$1,136.90**	**$8.95**	**-**	**$1,202.76**	**$65.86**	**5.8%**

FFRDC is an acronym for Federally-Funded Research and Development Center.

[1] ARF: Includes ship operations and upgrade support. Regional Class Research Vessels (RCRV) began construction in FY 2017 and the final year of MREFC funding was FY 2019, with additional COVID-19 contingency funds for FY 2023 included in the MREFC line below. Operations and mainenance of RCRV is not anticipated to begin until FY 2024.

[2] Arecibo: FY 2021 Actual includes $41.31 million for emergency cleanup of the Arecibo site, and excludes $0.97 million in operations funding obligated in FY 2020.

[3] GBO: FY 2023 Request includes $1.71 million in special projects funding.

[4] NHFML: FY 2021 Actual excludes $12.0 million obligated in FY 2020 for FY 2021 operations. FY 2023 Request includes $2.21 million in special projects

[5] NRAO: FY 2021 Actual includes $10.08 million for ngVLA development. FY 2023 Request includes $6.95 million in special projects funding.

[6] NSO O&M: FY 2023 Request includes $1.18 million in funding for transition activities at Sacramento Peak Observatory.

[7] DKIST: FY 2021 Actual includes $2.0 million to another awardee for cultural mitigation activities as agreed to during the compliance process. FY 2023 Request includes $1.1 million to optimize community access.

[8] NSCL: 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

[9] NOIRLab: FY 2021 Actual and FY 2023 Request include $9.44 million and $4.86 million, respectively, for special projects funding.

[10] Funding for Antarctic Facilities and Operations excludes support for the Antarctic Infrastructure Modernization for Science (AIMS) project of the Antarctic Infrastructure Recapitalization (AIR) program in FY 2020 ($4.93 million), and $1.80 million in FY 2021 and $8.0 million in FY 2022 for the Antarctic Research Vessel (ARV), which is captured under Design Stage Activities below.

[11] Design Stage Activities include support for potential next generation multi-user facilities. This line reflects FY 2021 funding of $7.0 million for the Leadership Class Computing Facility and $1.62 million and $12.43 million in FY 2021 and FY 2023 for the Antarctic Research Vessel (ARV).

U.S. ACADEMIC RESEARCH FLEET (ARF)

$119,110,000
+$19,570,000 / 19.7%

Academic Research Fleet Funding
(Dollars in Millions)

FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
$99.54	-	$119.11	$19.57	19.7%

Brief Description

The U.S. Academic Research Fleet currently consists of 18 oceanographic vessels and various submersibles/autonomous vehicles owned by NSF, the Office of Naval Research (ONR), and U.S. universities and laboratories. All of the ARF ships and vehicles are operated by research universities and laboratories. The ARF is a subset of the U.S. Federal Oceanographic Fleet, with collaboration under the Interagency Working Group on Facilities and Infrastructure (IWG-FI). Coordination to access the ARF vessels and vehicles is accomplished through collaboration with the University-National Oceanographic Laboratory System (UNOLS) organization. Universities and laboratories that operate ARF vessels are designated as UNOLS operators, and as such adhere to the UNOLS Research Vessel Safety Standards, as well as other applicable U.S. Coast Guard Code of Federal Regulations and International Maritime regulations. All ARF vessels are U.S.-flagged vessels and are tracked by the U.S. Department of Transportation Maritime Administration.

Scientific Purpose

The ARF consists of technologically advanced ships and submersibles/autonomous vehicles that enable scientists to conduct research on the complex ocean, seafloor, and sub-seafloor environment, the Great Lakes, and in the remote polar regions. ARF vessels collect observational data on Earth systems that provides a foundation for understanding how these systems interact and for improved modeling. Through at-sea sampling and observing, researchers have begun to understand, model, and predict the responses of marine populations to both long-term and episodic changes in ocean conditions.

Status of the Facility

Much of the ARF has continued successful operations despite being under strict COVID-19 risk mitigation protocols. In 2020, ARF experienced an initial stand-down, from March 17-June 30, during which the ships returned to port and crews conducted work that could be accomplished either remotely or under social distancing requirements. UNOLS, working with its medical advisory team, developed a risk-based decision-making process for returning the Fleet to service. A strict protocol, including extensive testing and isolation requirements for the crews and science parties, was adopted and has been updated as pandemic conditions change.

Summary of COVID-19 Impacts

Although many planned cruises were deferred in 2020 and 2021 because of COVID-19 travel restrictions, ARF was able to safely accomplish approximately 95 percent of normal operations in 2021. In addition, crucial activities such as the mid-life refit of R/V *Atlantis* and bi-annual shipyard and dry-docking work were completed. The overhaul of the submersible DSV *Alvin*, including an upgrade to 6,500-meter depth capability, was also conducted under strict COVID-19 protocols.

R/V Sikuliaq. *Credit: Mark Teckenbrock, crewmember on R/V Sikuliaq.*

Meeting Intellectual Community Needs

The National Research Council's Committee Report, *Sea Change: 2015-2025 Decadal Survey of Ocean Sciences*, documented that ships provide invaluable access to the sea and are an essential component of the ocean research infrastructure. The Committee found that the ARF was a critical asset in addressing each of the eight decadal science priorities of highest importance to the Nation in the decade of 2015-2025.

Users of ARF vessels collect data during a cruise both at sea and onshore, via tele-presence/data-presence. Users are involved in pre-cruise development of instrumentation, the maintenance of vessels, post-cruise use of the data collected, and data management. The number of "onshore users" is not quantifiable, but is substantial based on published papers, the number of personnel involved in shore support of the vessels, and the number of university laboratories involved with instrument development.

Governance Structure and Partnerships

NSF Governance Structure

NSF oversees the ARF through awards to each ship-operating institution and separately to the UNOLS Office. NSF also oversees the Fleet through site visits, ship inspections, Business Systems Reviews (BSRs) and participation at UNOLS Council/Committee meetings. NSF is the Cognizant Federal Agency that negotiates annual ship and technician rates. Several program directors within the Division of Ocean Sciences (OCE) at NSF, the National Oceanic and Atmospheric Administration (NOAA), and ONR are involved in the ARF activities and overall oversight. Additional oversight is provided by the ARF Integrated Project Team consisting of program directors and staff from GEO, BFA's Large Facility Office, the Cooperative Services Branch in the Division of Acquisition and Contract Support, as well as representatives from the Office of Legislative and Public Affairs and the Office of General Council.

Annual reports submitted to NSF include a description of the work performed in the prior year, the final costs, and the proposed work for the following year, along with the provisional costs. These costs divided by the number of operational days determine the ship's day rate, which is charged to all users. The annual reports address crew training and ship safety, as well as the detailed Major Overhaul Stabilization Account plan, which serves to spread the high cost of shipyard overhaul and drydocking activities over several budget years.

External Governance Structure

There is no formal external governance structure for the ARF. As stated above, the Fleet is overseen through a variety of activities conducted by the Federal agencies and by the coordination of the activities of the ARF stakeholders through the UNOLS Council and Committees. For example, the UNOLS Ship Scheduling Committee is the mechanism used by stakeholders to develop the annual operating schedule for the ARF to maximize the efficient support for the funded science work. Through the UNOLS Fleet Improvement Committee, the stakeholders update documents identifying the capabilities needed by each class of ship to support the science missions, which then helps determine funding needs to keep the vessels up-to-date. Additionally, the material condition of the vessels, which is determined through the NSF Ship Inspection Program, helps inform future Fleet modernization needs. This process resulted in the development of the Regional Class Research Vessel (RCRV) Project (see MREFC chapter on RCRV). The three vessels that the RCRVs will replace are planned for retirement from the Fleet as the new vessels are integrated into the ARF.

Partnerships and Other Funding Sources

The ARF is supported through an interagency partnership, principally with ONR and NOAA. The Fleet's operating costs are divided proportionally among the vessel users based on usage. NSF supports approximately 70 percent of the total, which includes the Ocean Observatories Initiative's (OOI) use of the ARF for servicing of OOI sensors and equipment.

Funding

Total Obligations for ARF

(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	ESTIMATES[1] FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Operations & Maintenance	$99.54	-	$119.11	$119.11	$119.11	$119.11	$119.11	$119.11

[1] Outyear estimates will include O&M costs for new RCRVs as they become operational.

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 OCE. The increase in FY 2023 reflects lingering impacts on ship demand and scheduling of work deferred due to the COVID-19 pandemic as well as increased operations in support of research on climate change. In addition, there is an expected increase in the cost of ship operations due to the rising cost of fuel.

NSF funds approximately 70 percent of the total cost of the ARF. NSF-specific missions represent roughly 60 percent of the ARF cruises in any given year and the remainder funds the facilities such as the Winch & Wire Pool and the Van Pool which support all the cruises requiring these services.

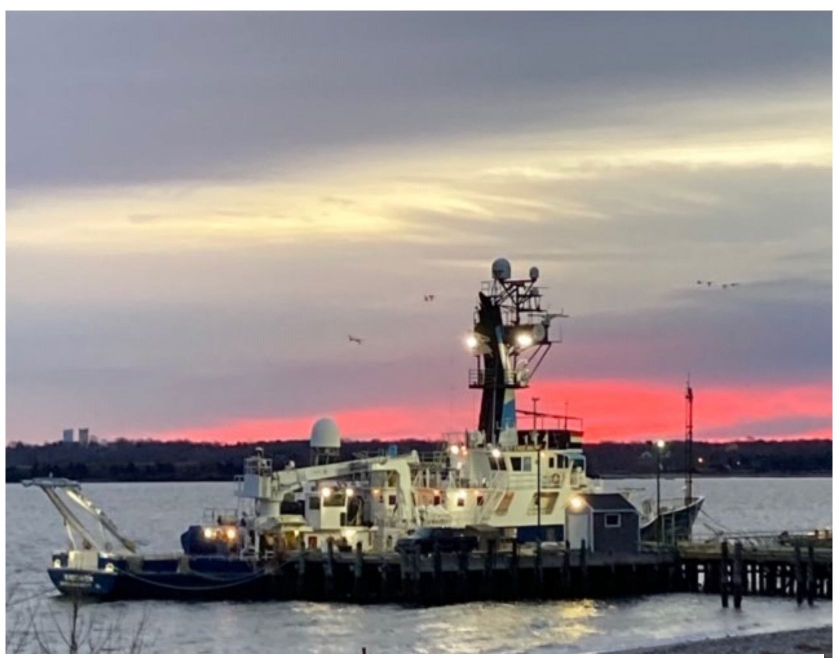
Reviews

Each NSF cooperative agreement with a ship-operating institution is reviewed by an external panel every five years. The current cycle of cooperative agreements ends in FY 2022. A BSR of the University of Washington, operator of R/V *Thomas G. Thompson* and R/V *Rachel Carson*, is underway. In FY 2020, a BSR of the Bermuda Institute for Ocean Sciences, operator of R/V *Atlantic Explorer*, was conducted. In FY 2021, a BSR was started with the University of Minnesota, Duluth, for operations of R/V *Blue Heron*. The scope of this review was tailored given the small award size and the ship's status as a non-NSF-owned asset.

Renewal/Recompetition/Termination

NSF owns three vessels in the ARF, but relies on all ships to support NSF-funded research at sea, requiring an operations award with each of the ship-operating institutions. All operating institutions received new five-year awards in 2018. NSF funded year four of the five-year awards for all of the ships in FY 2021. For the ships not owned by NSF, the operating awards will be renewed in FY 2022. A decision was made to request a 5-year renewal proposal from the University of Alaska Fairbanks for continued operations of the NSF-owned ship, R/V *Sikuliaq*. The proposal will undergo external panel review for a possible award in 2023. Of the remaining two NSF-owned ships, R/V *Oceanus* is anticipated to be retired in FY 2022 and replaced by the new RCRV R/V *Taani* in late FY 2024 and R/V *Endeavor* is anticipated to be retired in FY 2023 and replaced by R/V *Narragansett Dawn* in early FY 2025. The third new RCRV, R/V *Gilbert R. Mason,* will replace R/V *Pelican* (owned by LUMCON) in late FY 2025 after retirement of R/V *Pelican* in FY 2024. Operators for the vessels were chosen through a competitive process.

In FY 2018, NSF announced the decision to begin a process to divest NSF ownership and retire the seismic research vessel R/V *Marcus G. Langseth*. The process included opportunities for an interested academic institution to assume ownership and continue operating the ship as part of the ARF to support seismic research. In FY 2020 NSF accepted a proposal from Columbia University-Lamont Doherty Earth Observatory to purchase R/V *Langseth* and continue operating the ship through 2024.



ANTARCTIC FACILITIES AND OPERATIONS (AFO) $243,670,000

+$27,400,000 / 12.7%

Antarctic Facilities and Operations Funding
(Dollars in Millions)

FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
$216.27	-	$243.67	$27.40	12.7%

Brief Description

Antarctic Facilities and Operations supports the infrastructure, logistics, and science operations underlying the United States Antarctic Program (USAP). In direct support of the Nation's goals under the Antarctic Treaty System, the program strives to maintain an active and influential presence in the region through fostering the conduct of world-class science and mutually beneficial international cooperation when and where appropriate. At the same time, the program strives to optimize funding efficiency while ensuring safe, environmentally sound, and effective operations.

Scientific Purpose

By Presidential directive, NSF is the single-point manager of all U.S. activities in Antarctica and is required to, among other things, occupy the geographic South Pole and operate two coastal stations, McMurdo Station on Ross Island and Palmer Station on Anvers Island near the Antarctic peninsula. Presently the Antarctic Infrastructure and Logistics Section (AIL) within OPP, through its contractor Leidos, supports about 150 NSF-funded science projects each season as well as long-term observing facilities. Examples of these facilities include the Long-Term Ecological Research sites in the Dry Valleys and in the Antarctic Peninsula marine environment; the IceCube neutrino detector; the South Pole Telescope for sub-millimeter and microwave signal detection of the universe; and the Center for OLDest Ice Exploration (COLDEX), a Science and Technology Center funded in FY 2021. NSF also supports several projects funded by other agencies including the National Aeronautics and Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA). For example, the NASA Long Duration Balloon program launches major observing payloads into the upper atmosphere from a dedicated facility on the Ross Ice Shelf.

Helicopters provide support to field science on Ross Island's Mt. Erebus and to other remote camps in Antarctica. *Credit: Air Center Helicopters Incorporated.*

Status of the Facility

The U.S. presence in Antarctica is maintained in accordance with U.S. policy and supports Antarctic Treaty administration under Department of State leadership. AFO comprises the infrastructure and logistics needed to conduct U.S. research in Antarctica, including research funded by other U.S. agencies. Research activities occur on two research ships, at a variety of remote field camps, and year-round at the U.S. stations. All support for these activities is provided, including transportation, facilities, communications, utilities (water and power), health and safety infrastructure, and environmental stewardship.

Summary of COVID-19 Impacts

The COVID-19 pandemic had a major impact on AFO. The inherently close quarters of remote facilities and the limited medical capacities of Antarctic stations made it essential for all national Antarctic Programs to avoid the introduction of COVID-19 to Antarctica. NSF greatly reduced the presence of personnel on the continent during the 2020-21 austral summer season and again in the ongoing 2021-22 season. NSF did not support new science investigations in order to manage COVID-19 risks and to work within the constraint of international travel restrictions that persist into FY 2022. The minimal number of logistical support staff required to undertake critical maintenance and support functions was deployed. Construction work on-ice was halted mid-season in FY 2020, throughout FY 2021, and will remain deferred through FY 2022. In FY 2022, environmental conditions enabled fabrication of an ice pier at McMurdo Station. Resupply of McMurdo Station will be conducted by cargo vessel, tanker, and aircraft; South Pole Station will be resupplied by tractor traverse and aircraft; and Palmer Station via vessel.

Meeting Intellectual Community Needs

The research community participates actively in decisions regarding scientific platform and logistics requirements through the annual science planning process managed jointly by AIL and the Antarctic Sciences Section (ANT) of OPP.

The Antarctic Infrastructure Recapitalization (AIR) program is initiated in FY 2022 in response to a 2012 Blue Ribbon Panel (BRP) report, which recommended that NSF create a capital plan to renew the USAP's aging physical plant. Unfunded parts of the Antarctic Infrastructure Modernization for Science (AIMS) project, currently in the construction phase,[1] will be considered as part of the ongoing refresh of the McMurdo Station master plan and may be accomplished as part of the broader AIR program. The AIMS project will provide a reduction in the annual cost to maintain and operate McMurdo Station. The longer-term recapitalization of McMurdo Station and other Antarctic infrastructure under the AIR program is expected to produce further efficiencies.

Governance Structure and Partnerships

NSF Governance Structure

In addition to the OPP Advisory committee's biannual meetings, its sponsored Committee of Visitors (COV) reviews whether AIL's provision of infrastructure, logistics and science support is appropriately

[1]AIMS is currently undergoing a re-baselining in light of a pause in on-ice construction due to COVID-19, and significant disruptions to workforce and supply chains.

integrated with science needs every four years. The last COV review was in the fall of 2020.

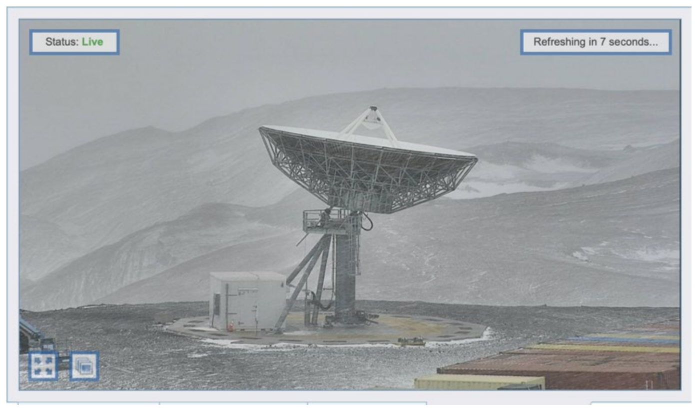
OPP also receives contract oversight and management support from NSF's Division of Acquisition and Cooperative Support (DACS) as well as assisted acquisition services from the Department of Interior's Interior Business Center.

External Governance Structure

The USAP undergoes higher level review at approximately 10 to 15-year intervals. The most recent review culminated in the 2012 BRP Report which is discussed further below. The USAP is also subject to the Antarctic Conservation Act as well as provisions within the Antarctic Treaty, under Department of State leadership. USAP stations in Antarctica are subject to inspection by Treaty member nations on short term notification.

Partnerships and Other Funding Sources

NSF has arrangements for cooperative sharing of logistics and science capabilities with international treaty partners operating in the general vicinity of USAP stations and remote field sites. These arrangements depend on in-kind contributions and generally do not involve transfers of cash. NSF supports field work sponsored by other agencies from which it recovers certain incremental costs.



Ross Island Earth Station under construction. *Credit*: McMurdo Station webcam.

NSF entered into an agreement with NOAA to co-fund the design and construction of an expanded weather and communications satellite downlink/transmission station on Ross Island (Ross Island Earth Station) to replace aging facilities currently located across McMurdo Sound on Black Island. The facility is under construction and is expected to be completed in 2022.

Funding

Total Obligations for AFO

(Dollars in Millions)

	FY 2021	FY 2022	FY 2023	ESTIMATES[1]				
	Actual	(TBD)	Request	FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Operations & Maintenance	$216.27	-	$243.67	$243.67	$243.67	$243.67	$243.67	$243.67

[1] Outyear estimates are for planning purposes only. The current contract ends in March 2025.

In FY 2023, AFO funding is increased by $27.40 million to $243.67 million from the FY 2021 level. This increase will cover higher deployment costs and accommodate continued operation of the stations, as well as support for priority science activities including the International Thwaites Glacier Collaboration. COVID-19, and the resulting need for pre-deployment quarantine in New Zealand, has led to significantly higher per-person costs for grantees and contract personnel deploying to Antarctica. Higher deployment costs could persist into the FY 2023 season, increasing the overall operating cost even though the deployment tempo will still be lower than prior to the COVID-19 pandemic. Once pre-deployment quarantine periods are no longer required, the lower per-person cost will be offset by a higher deployment tempo, which will be needed to clear the backlog of field science projects that were deferred during the pandemic.

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 comprising knowledgeable NSF staff in OPP and BFA. In addition, OPP programs are reviewed externally by Committees of Visitors and the OPP Advisory Committee. The USAP BRP released a report on its review of the program in July 2012. The initial NSF response to the USAP BRP report was released in March 2013 and progress to address recommendations is ongoing.[2] The AIR program is a significant step towards addressing the report recommendations and is covered in detail in the MREFC chapter.

Renewal/Recompetition/Termination

- Lockheed Martin Corporation was awarded a 13.5-year Antarctic support contract in December 2011. The award consists of a five-year base period and four option periods exercised based on performance and totaling an additional 8.5 years. In FY 2017, Lockheed Martin Corporation novated the Antarctic support contract (ASC) to Leidos Corporation. Transition from Lockheed Martin management to Leidos management of the ASC was successfully completed in August 2017. The third two-year option with Leidos was exercised in September 2020.
- In anticipation of the need to recompete the ASC prime contract, NSF conducted a Virtual Industry Day for Operations and Science Support to the United States Antarctic Program on February 16, 2021.
- A contract for helicopter support was awarded to Air Center Helicopters in April 2019. It is a one-year contract that, in FY 2023, will be in the third of four option years.
- A fixed-wing small aircraft support contract was awarded in August 2018 to the incumbent, Kenn Borek Air. It is a one-year contract that, in FY 2022, will be in the final option year. OPP anticipates a follow-on support contract in 2023.
- NSF divested its four LC-130H aircraft to the U.S. Air Force in FY 2021 to improve the efficiency of their operational support. The aircraft will continue to be operated by the New York Air National Guard under the existing Memorandum of Agreement with the DOD without any loss of continuity.
- Currently there are no plans for divestment of this facility.

[2] www.nsf.gov/geo/opp/usap_special_review/usap_brp/rpt/nsf_brp_response.pdf

ARECIBO OBSERVATORY (AO)

$6,000,000
-$42,230,000 / 87.6%

Arecibo Observatory Funding
(Dollars in Millions)

FY 2021 Actual[1]	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
$48.23	-	$6.00	-$42.23	-87.6%

[1] FY 2021 Actual includes $41.31 million for emergency cleanup following the collapse of the platform above the 305-meter telescope in December 2020.

Brief Description

AO is a center for multidisciplinary research and education. AO's principal facility was 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 NSF-owned land. AO is currently operated and managed by the University of Central Florida (UCF) and subrecipients, Yang Enterprises, Inc. (YEI) and Universidad Ana G. Méndez (UAGM, formerly Universidad Metropolitana), under a cooperative agreement with NSF that began on April 1, 2018. The 305-meter telescope suffered an uncontrolled collapse of its suspended receiver platform on December 1, 2020, after the failure of several supporting cables. Emergency cleanup activities began immediately and comprise the bulk of the increase in funding since FY 2020. NSF has provided funding for cleanup efforts under the current award to UCF, with the primary efforts led through a sub-award to the engineering firm Thornton Tomasetti. In addition to the work being performed by subcontractors under the direction of Thornton Tomasetti, specialists from Jacobs Engineering have provided oversight of environmental and historical preservation work on NSF's behalf.

Scientific Purpose

Despite the collapse of the 305-meter telescope platform, science continues at AO with archival data and other facilities. The Light Detection and Ranging (LIDAR) facilities on site conduct observations of metal ions and atoms in the upper atmosphere, at altitudes around 100 kilometers, which are critical for our understanding of atmospheric composition and chemistry. The optical facilities at AO and in Culebra are being used to measure optical emissions from the upper atmosphere at multiple wavelengths and to study neutral dynamics and structure of the upper atmosphere. Repairs to other AO scientific assets damaged by the 2017 hurricanes, such as the 12-meter radio telescope, are under way, and are expected to contribute to the scientific program in FY 2022. Potential future extensions of the science that has been supported by the 305-meter reflecting dish in the past are being explored with community input, and an extended workshop to discuss future options with the scientific and educational communities took place in June 2021.

Status of the Facility

In 2020, AO continued repairs from damage caused by Hurricane Maria in Fall 2017 with $2.0 million awarded by NSF in Summer 2018 and $12.30 million awarded in Summer 2019.[1] The work under the initial award was completed in Spring 2020 with repairs for the most critical activities post-Hurricane. The remaining repair tasks were to be accomplished over a four-year period. However, several unexpected events impacted AO before many of these repairs were implemented. In December 2019 multiple earthquakes occurred near the southern coast of Puerto Rico (Arecibo is closer to the northern coast), including 11 greater than magnitude 5. These caused some minor damage on the AO site, which led to facility closure for a short period of time. COVID-19 led to island-wide closures and curfews. AO quickly re-established scientific observations with new protocols in place, but the Visitor's Center was closed for a longer period. A cable/socket failure on the 305-meter telescope occurred in August 2020 and another cable failed in November 2020, leading to a prolonged closure for stabilization efforts and repairs. After the November cable failure, NSF announced plans to begin decommissioning the telescope as there was no longer a safe pathway to stabilize the facility. Prior to implementing the decommissioning, the suspended platform experienced an uncontrolled collapse on December 1, 2020. Since then, efforts have shifted to safe and environmentally sound cleanup and debris removal, historical preservation, and evaluation of possibilities for the future.[2]

As mentioned above, AO continues to support scientific research. Current scientific activities have been focused on restoring immediate scientific productivity, including prioritizing those technologies that are already operational and those funded for restoration using normal operations and maintenance funds. Repairs to some facilities (such as the 12-meter telescope and LIDAR facility) were originally budgeted in the Hurricane Maria repair funds; those repairs are also proceeding. Ongoing scientific and related activities include use of the LIDAR facility to study the composition and motion of the ionosphere along with maintenance of the roof of the facility and modernization of the laser equipment. In addition, scientific staff continue to work on analysis of data in the historical archives, operations of the remote Culebra optical facility, and restoration and use of the 12-meter radio telescope.

Meeting Intellectual Community Needs

AO continues to support an array of optical instruments, including the LIDAR systems and interferometers, to make measurements of the ionosphere and thermosphere. These instruments are operated as often as possible when sky conditions are optimal, and staffing is available. In addition, once repaired, the 12-meter radio telescope will be available at both 2.4 and 8 GHz for scientific use via competitive observing proposals. Access to archival data from the decades of Arecibo observations (approximately 3 petabytes) will be facilitated by a new agreement amongst the Texas Advanced Computing Center (TACC),[3] UCF, AO, and several NSF-supported cyberinfrastructure projects including the Engagement and Performance Operations Center, the Cyberinfrastructure Center of Excellence Pilot, and Globus at the University of Chicago. This consortium is establishing a backup of all AO 305-meter telescope data to TACC's Ranch, a long-term data mass storage system,

[1] Funds provided by the Further Additional Supplemental Appropriations for Disaster Relief Requirements Act of 2018 (P.L. 115-123).
[2] See www.nsf.gov/news/special_reports/arecibo/ for more details.
[3] www.tacc.utexas.edu/

and plans to provide a cloud-based user interface to facilitate use of the data for new and ongoing research. The ability to review archival data has proven invaluable in several scientific studies, the most notable being the discovery and characterization of fast radio bursts (FRBs).

One area in which AO continues to excel is educational and public outreach programming at all levels. Once the site is restored to a safe condition, both in terms of emergency clean-up and COVID-19 considerations, programs that are currently taking place remotely will be able to resume in-person STEM learning curricula. These include the long-running NSF-funded Research Experience for Undergraduates and the NASA-funded STAR Academy programs. In addition, the Visitor's Center—which normally hosts nearly 100,000 visitors a year, many of them local K-12 school groups—will reopen following minor repairs.

NSF convened members of the scientific and STEM education community in June 2021 for a workshop exploring novel ideas for future activities at AO following the collapse of the 305-meter telescope platform. The workshop focused on finding actionable and innovative ways to support, broaden, and strengthen the radio science community across Puerto Rico and to create or enhance the opportunities for scientific, educational, and cultural activities and public outreach at AO. The workshop generated several innovative design ideas for AO for the short (1–3 years), medium (3–10 years), or long term (10+ years). NSF has encouraged the community to develop these ideas into proposals that could be submitted for consideration to NSF or other funding agencies.

Governance Structure and Partnerships

NSF Governance Structure

The lead NSF program officer in the MPS Division of Astronomical Sciences (AST), in close cooperation with a program officer in the GEO Division of Atmospheric and Geospace Sciences (AGS), provides ongoing oversight. The NSF 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. Program officers 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 within 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.

NSF oversight increased during the Fall of 2020 with efforts to stabilize and repair the structure. Post-collapse, NSF program officers, AO staff, contracted experts, and the engineer of record from Thornton Tomasetti have weekly meetings to discuss the status of the emergency cleanup work. In addition to the work being performed by subcontractors under the direction of Thornton Tomasetti, specialists from Jacobs Engineering have provided oversight of environmental work on NSF's behalf. NSF and UCF have also recognized the need to address concerns about historical and cultural preservation. NSF has remained in contact with the Puerto Rico State Historic Preservation Office and the Advisory Council on Historic Preservation since the day of the collapse to consult on the protection and preservation of historically important elements of the site. These meetings, along with periodic site visits, provide critical information to ensure compliance with all federal and local environmental and historic preservation laws.[4]

<u>External Governance Structure</u>

Funding is via a cooperative agreement with UCF and its sub-awardees, UAGM and YEI. The awardees provide management and oversight through their own advisory and visiting committees, a Scientific User Advisory Committee, and a Scientific Management Advisory Committee. The award Principal Investigator is a senior employee of UCF. The AO Director, based at the telescope site, oversees daily operations of the facility, while the engineer of record from Thornton Tomasetti oversees the cleanup efforts and coordinates subcontracted work on the site. Since the collapse, NSF's Office of General Counsel and Jacobs Engineering (with the support of Thornton Tomasetti, its subcontractors, and UCF) have reached out to federal agencies, including the Environmental Protection Agency, the Council on Environmental Quality, and the U.S. Fish and Wildlife Service, to assure full compliance with the National Environmental Policy Act and the National Historic Preservation Act in the cleanup of the site. NSF and AO staff have also provided notifications to the Puerto Rico Department of Environment and Natural Resources.

<u>Partnerships and Other Funding Sources</u>

Since FY 2010, the NASA Near Earth Object Observation Program has committed funds annually to AO for the planetary radar program; their contribution in FY 2021 was approximately $4.65 million. This funding was reduced at the start of FY 2022, as observations cannot continue without the 305-meter telescope. Additional support in FY 2021 included funds from UAGM, private foundations, pay-to-observe, grants from NASA focusing on education and public outreach, and modest income from the Visitor's Center and cafeteria.

Funding

The FY 2023 request for AO operations and maintenance is $6.0 million. AO O&M is jointly supported by AST and AGS. Additional funding was provided in FY 2021 and FY 2022 for cleanup activities following the collapse of the 305-meter telescope platform, including debris removal, environmental mitigation, and historical and cultural preservation. Cleanup and recovery activities continued in FY 2022 as efforts to restore AO's scientific, cultural, and educational programs ramped up, consistent with recommendations from the June 2021 workshop and other input from the astronomical community and advisory groups as well as the local Puerto Rican communities.

Total Obligations for AO

(Dollars in Millions)

	FY 2021	FY 2022	FY 2023	ESTIMATES[1]				
	Actual	(TBD)	Request	FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Operations & Maintenance (MPS)	$3.26	-	$3.00	$3.00	$3.00	$3.00	$3.00	$3.00
Operations & Maintenance (GEO)	3.66	-	3.00	3.00	3.00	3.00	3.00	3.00
Cleanup[2]	41.31	-	-	-	-	-	-	-
Total	**$48.23**	**-**	**$6.00**	**$6.00**	**$6.00**	**$6.00**	**$6.00**	**$6.00**

[1] Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in March 2023.

[2] Supplemental funding for emergency cleanup of the Arecibo site includes $34.92 million in MPS and $6.38 million in GEO in FY 2021.

[4] See www.nsf.gov/mps/ast/env_impact_reviews/arecibo/eis/305-meter_collapse.jsp for more details.

Reviews

In January 2017, NSF issued a solicitation requesting proposals to provide continued operations and management of AO for five years, but at reduced funding.[5] Proposals received in response to this solicitation were afforded extensive NSF internal review together with formal review by a panel of external experts in AO management and operations, leading to the current award to UCF. Additionally, AST and AGS jointly conduct annual external reviews of AO program plans. The next formal annual external review of UCF's management, particularly as it pertains to the cleanup and recovery following the collapse, is scheduled to take place in early 2022.

Renewal/Recompetition/Termination

The current cooperative agreement with UCF for the management of AO was awarded on April 1, 2018, when UCF succeeded the previous managing organization, SRI International. This followed a competitive process for a new five-year cooperative agreement, consistent with NSF policy. The first annual external review of UCF's management took place in April 2020. The review in 2019 focused on the plans for the hurricane repairs. NSF's current cooperative agreement with UCF for operations and management of AO ends in March 2023. The timeline for potential recompetition is uncertain, pending further definition of the scope of future AO operations.

[5] The reduced funding profile was in alignment with NSF's 2017 Record of Decision regarding AO, which documented NSF's decision to pursue collaboration with interested parties for continued science-focused operations with reduced funding from NSF.

GEODETIC FACILITY FOR THE ADVANCEMENT OF GEOSCIENCE (GAGE)

$14,550,000
-$10,000 / -0.1%

Geodetic Facility for the Advancement of GEoscience Funding
(Dollars in Millions)

FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Percent
$14.56	-	$14.55	-$0.01	-0.1%

Brief Description

The Geodetic Facility for the Advancement of GEoscience (GAGE) is a distributed, multi-user facility that enables a diverse principal investigator (PI) community to make advances in understanding Earth processes that would otherwise not be possible, through broad access to geodetic instrumentation, field training and support, and data services. GAGE operates networks of Global Positioning System (GPS) and Global Navigational Satellite Systems (GNSS) instruments; provides geodetic and related geophysical instrumentation for field experiments; supports data archiving, quality control, and distribution; and provides education and outreach activities that serve a wide range of audiences.

Scientific Purpose

GAGE serves a broad spectrum of geosciences disciplines that use geodetic instrumentation and data, including Earth, atmospheric, and polar sciences. GAGE data support transformative advances in current understanding of the Earth system, including crustal deformation, plate boundary processes, landscape evolution, the earthquake cycle, volcano, tsunami, and hurricane hazards, continental groundwater storage and soil moisture dynamics. Data from GAGE real-time, high-rate GPS/GNSS observations also support the commercial surveying and engineering industries, particularly in the western U.S.

Status of the Facility

GAGE is currently operating in year four of a five-year NSF award to UNAVCO, and the capabilities provided by the facility have evolved based on input from a series of community engagement activities held in 2015, including an NSF-sponsored workshop entitled "Future Seismic and Geodetic Facility Needs in the Geosciences".[1] The Division of Earth Sciences (EAR) in GEO continues to evaluate NSF's geophysical facilities to best enable emerging research directions. In 2018, EAR commissioned a National Academies of Science, Engineering, and Medicine-led decadal survey that identified the top research priorities for the Earth sciences for the next decade. Released in July 2020, *A Vision for NSF Earth Sciences 2020-2030: Earth in Time*[2] reaffirmed the importance of NSF's seismic and geodetic facilities in advancing Earth science research over the next decade.

As part of the decadal survey process, a workshop entitled *Management Models for Future Seismological and Geodetic Facilities and Capabilities* was held to review the strengths and weaknesses of different

[1] www.iris.edu/hq/files/workshops/2015/05/fusg/reports/futures_report_high.pdf
[2] www.nap.edu/catalog/25761/a-vision-for-nsf-earth-sciences-2020-2030-earth-in

management models for NSF geophysical facilities.[3] Following the release of the workshop report, EAR announced that, at the time of the next competition for their management and operations, the current Seismological Facility for the Advancement of GEoscience (SAGE) and GAGE facilities would be consolidated into a single facility with a single operator.[4]

In FY 2020, after announcement of the consolidated facility, GEO commissioned a portfolio review from a subcommittee of its Advisory Committee to inform planning for a consolidated geophysical facility. The group reviewed possible geophysical instrumentation and sensor networks that a new facility might support to address the science priorities highlighted in the decadal survey. Additionally, the portfolio review report emphasizes the importance of developing partnerships in support of elements of SAGE and GAGE that are mission critical for other Federal agencies. EAR is working to define the best path forward for a future facility and undertaking efforts to expand existing federal partnerships.

In FY 2019, NSF issued a Dear Colleague Letter (NSF 19-072) to let the community know of the intent to divest 10 percent of the GPS/GNSS stations that comprise the Network of the Americas (NOTA) as part of GAGE. EAR received requests to adopt 95 of the 128 stations for continued operations, and all station adoptions were completed in July 2021. The remaining stations are expected to be removed from the ground by end of FY 2022.

<u>Summary of COVID-19 Impacts</u>
The impact of COVID-19 on GAGE has been relatively minor. While there is a backlog of maintenance issues at some NOTA sensor network stations, network uptime currently exceeds target performance levels. In 2021, UNAVCO shifted to a permanent hybrid work model, enabling most employees to work from home, except when individuals are required to work in the warehouse or when visiting field sites for maintenance. UNAVCO has not implemented operational changes other than requiring that employees comply with local, state, or federal masking guidelines for their work location.

Meeting Intellectual Community Needs

To serve the research needs of the broad Earth science community, GAGE is organized under three primary service areas: Geodetic Infrastructure, Geodetic Data Services, and Education and Community Engagement. GAGE users can access data and many educational products via the internet at no cost. Scientists making use of equipment, training, and other resources provided by GAGE typically are funded via awards from NSF, the U.S. Geological Survey (USGS), the National Aeronautics and Space Administration (NASA), and other agencies. NSF-sponsored users are typically supported by EAR, the Division of Ocean Sciences (OCE), and OPP. Funds permit ongoing operations and maintenance of continuous GPS regional networks, deployment of portable geodetic instruments and use of data managed by GAGE Data Services to solve major Earth science problems.

Demand for data, equipment, and other resources provided via GAGE remains high. In FY 2021:
- On average, there were approximately 8000 individual verified users accessing the GAGE real-time GPS/GNSS data streaming service at any given time.

[3] www.nap.edu/catalog/25536/management-models-for-future-seismological-and-geodetic-facilities-and-capabilities
[4] www.nsf.gov/pubs/2020/nsf20037/nsf20037.jsp

- Field experiments using equipment and field engineering assistance continue at an average annual level of approximately 100 projects.

GAGE facilitates three different summer internship programs at the community college, undergraduate, and graduate school levels that primarily focus on students from groups that are underrepresented in the Geosciences. The GAGE summer internship programs have consistently produced scientific and professional benefits for these students at different educational stages. In 2021, the programs were held in a hybrid format due to COVID-19, with a mixture of online and limited in-person activities. The program participants demonstrated strong growth in knowledge and awareness of geoscience career paths, as indicated in pre- and post-participation survey results. Interns also enhanced their technical skills across all of the programs, including computational and scientific communication skills. These findings have been consistent across in-person, virtual, and hybrid offerings of the program, indicating that the program has successfully adapted its career programming to a variety of formats.

Governance Structure and Partnerships

NSF Governance Structure
GAGE, together with SAGE, is overseen by a single Integrated Project Team (IPT) whose charge is to: 1) establish a collaborative team with a broad spectrum of expertise and perspective to help address current facility challenges and identify potential barriers to project success; 2) ensure effective and timely communications regarding facility activities and issues across NSF organizations by sharing knowledge and information on a regular and recurring basis; and 3) provide a formal mechanism to coordinate agency-wide oversight, take effective action, and remain accountable in support of the program of activities.

The IPT membership includes a core group consisting of the GAGE and SAGE managing program officer (PO), a representative from the Division of Acquisition and Cost Support, and a liaison from the Large Facilities Office LFO Liaison. The GAGE and SAGE PO serves as chair of the IPT. The IPT remains active through the planned five-year duration of the GAGE and SAGE awards. The IPT chair is responsible for uploading all IPT documentation into the official electronic records for the GAGE and SAGE awards. The IPT may periodically be assisted by other NSF staff as expertise is needed (e.g., Office of the General Counsel staff, Office of the Director staff).

External Governance Structure
The GAGE facility awardee, UNAVCO, Inc., is a 501(c)(3) nonprofit corporation governed by a nine-member Board of Directors elected by the UNAVCO institutional member representatives. The UNAVCO consortium currently has 119 full voting member institutions, representing nearly all U.S. university and nonprofit organizations with a major commitment to research and teaching programs in geodesy and related geoscience fields, and 111 non-voting associate member institutions. Six of the Board members are drawn from member institutions, and three serve as directors-at-large. 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 appoints a president of UNAVCO to a renewable two-year term. The president is responsible for UNAVCO operations, which are managed through the UNAVCO Corporate Headquarters in Boulder, CO, and at three regional offices in San Clemente, CA; Portland, OR; and

Anchorage, AK.

Partnerships and Other Funding Sources
The GAGE facility is primarily supported by EAR, with additional NSF support from OPP. Externally, NASA provides $1.15 million in support via interagency transfer each year. Beginning in FY 2021, GAGE received $930,000 from the USGS via interagency transfer for support of ShakeAlert, their earthquake early warning program, and NSF expects this partnership with the USGS to continue through the end of the GAGE award period. Additionally, UNAVCO will be leveraging the GAGE award to partner with commercial entities in support of autonomous vehicle navigation. That activity is expected to generate program income in FY 2022 of about $500,000, which will be used to support recapitalization of aging infrastructure.

Besides its role in providing the observational data essential for basic Earth science research, GAGE also provides real-time geodetic data in support of the missions of other agencies. GAGE provides O&M support for 58 NASA-funded stations and the GNSS network that enable 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. The National Oceanic and Atmospheric Administration (NOAA) utilizes data from GAGE for its management of the national reference frame for oceanic vessel navigation and support of survey professionals. USGS, NASA, NOAA, and other state and local agencies also utilize the GAGE portable geodetic station pool for support of field projects.

Funding

Total Obligations for GAGE
(Dollars in Millions)

	FY 2021	FY 2022	FY 2023	ESTIMATES[1]				
	Actual	(TBD)	Request	FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
GAGE O&M	$14.56	-	$14.55	$14.55	TBD	-	-	-
SAGE O&M	22.30	-	23.37	23.37	TBD	-	-	-
Consolidated Facility O&M[2]	-	-	-	-	TBD	TBD	TBD	TBD
Total	**$36.86**	**-**	**$37.92**	**$37.92**	**TBD**	**TBD**	**TBD**	**TBD**

[1] Outyear estimates are for planning purposes only. The current cooperative agreement ends September 2023.
[2] NSF is currently planning for GAGE and SAGE to be consolidated into a single geophysical facility in FY 2025.

NSF is currently implementing recommendations from the 2019 and 2020 reviews. These include innovations in multi-constellation instrumentation for more precise measurements of Earth's surface to improve studies of near-surface processes (e.g., water storage and flux); moving data services for the Facility to the cloud; and recapitalization of aging instrumentation. EAR is evaluating different strategies and scales of aging instrumentation and plans to phase in recapitalization over the existing award period.

Reviews

NSF externally reviews components of the GAGE facility on an annual basis. NSF conducted a full management review of GAGE in September 2021, and the panel commended UNAVCO for its strong overall performance in operating and maintaining GAGE. NSF reviewed the GAGE instrumentation services programs in late June 2020 and the data services programs in September 2019. Both reviews noted the outstanding management and the critical services these programs provide to the research community. As per the reviews' recommendations, EAR, in collaboration with SAGE, GAGE and the NSF Office of Advanced Cyberinfrastructure, is implementing a pilot program to move facility data services to the cloud. NSF plans to conduct a management review of the education and outreach program in FY 2022.

Renewal/Recompetition/Termination

In 2020, NSF announced that it is preparing for a competition for a future cooperative agreement to support a single, unified geophysical facility as the successor to GAGE and SAGE. NSF plans to evolve the different components of GAGE and SAGE through the competition for the unified facility to enable the community to advance the scientific priorities in the *Earth in Time* decadal survey. NSF is considering the recommendations contained in the portfolio review, as well as the interagency context in which the unified facility will operate, to formulate a strategy for continued support of this important community research resource. Divestment is not being considered at this time.

While the GAGE award was initially planned to end in 2023, NSF announced in a Dear Colleague Letter (NSF 21-097)[5] issued in June 2021 that it will extend the current awards for operations of both SAGE and GAGE to ensure continuity of services until 2025. This extension will allow NSF to work with agency partners to thoughtfully respond to the recommendations in the portfolio review.

[5] www.nsf.gov/pubs/2021/nsf21097/nsf21097.jsp?org=EAR

ICECUBE NEUTRINO OBSERVATORY (ICNO) **$7,660,000**
+$580,000 / 8.2%

IceCube Neutrino Observatory Funding
(Dollars in Millions)

FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Percent
$7.08	-	$7.66	$0.58	8.2%

Brief Description

The IceCube Neutrino Observatory (ICNO) cubic-kilometer detector has delivered world-leading scientific results—from measuring previously unexplored atmospheric neutrino oscillations to observing cosmic neutrinos with energies exceeding 10 peta-electron volts (PeV). The discovery of these cosmic neutrinos establishes ICNO's role in multi-messenger astrophysics for observing the extreme Universe. ICNO is the world's first gigaton, and largest high-energy, neutrino detector, comprising 5,160 digital optical modules (DOMs) deployed deep within the ice cap under the U.S. Amundsen-Scott South Pole Station in Antarctica. ICNO will continue to undergo an evolution in its scientific mission as it is upgraded with an additional 700 DOMs in the coming years.

Scientific Purpose

ICNO was designed to observe neutrinos from the most violent astrophysical sources in the Universe. Neutrinos—almost massless particles with no electric charge—can travel from their sources to Earth with essentially no attenuation and no deflection by magnetic fields.

In 2013, ICNO observed the first high-energy (over 100 tera-electron volt (TeV) and up to 10 PeV) astrophysical (cosmic) neutrinos—key messengers revealing an unobstructed view of the Universe at wavelengths where it is opaque to photons. In 2017, new data obtained by ICNO revealed some answers to a more than century-old quest for the origins of high-energy cosmic rays, tracing the path of a single, very high-energy neutrino back to a previously known but little-studied blazar—the nucleus of a giant galaxy that fires off massive jets of elementary particles, powered by a supermassive black hole at its core. While this evidence of the first known source of high-energy neutrinos and cosmic rays is compelling, more data are now

The IceCube Laboratory building at South Pole where all data-collecting computer servers are located. *Credit: USAP Photo Library, Sven Lidstrom, NSF.*

sought from similar or other sources. The ICNO results opened a new window to the Universe, providing novel insights into the engines that power active galactic nuclei and generate high-energy cosmic rays, gamma ray bursts, and other violent and energetic astrophysical processes. ICNO's exploration of scientific frontiers has already changed and expanded our understanding of the Universe.

Inquiries are underway concerning science questions that may arise from the study of neutrino properties, especially at the lower energies to which ICNO's Deep Core strings have enabled access. For example, to fill in the blanks of the Standard Model of particle physics, scientists have been conducting diligent searches with ICNO data for a hypothesized particle known as the "sterile neutrino." None of the searches found evidence for the eV-mass sterile neutrino hinted at by other experiments.

In the ten years since its completion, ICNO has isolated more than 150 high-energy cosmic neutrinos, with energies between 100 TeV and 15 PeV, from more than a million atmospheric neutrinos and hundreds of billions of cosmic-ray muons.[1] Among them is the first detection of a Glashow resonance event—one of the highest energy particles (6.3 PeV) was observed while distinguishing a cosmic antineutrino for the first time. These PeV neutrinos, the highest energy neutrinos observed to date, have a thousand times the energy of the highest energy neutrinos produced with earthbound accelerators and a billion times the energy of the neutrinos detected from supernova SN1987 in the Large Magellanic Cloud, the only neutrinos that had been detected on Earth from outside the solar system prior to the ICNO breakthroughs. However, the most surprising property of these cosmic neutrinos is their large flux rather than their high energy or their origination outside our galaxy.

Status of the Facility

ICNO operations include two staff members who carry out "winter-over" duties at the South Pole where the ICNO data are collected and transmitted daily to the University of Wisconsin (UW). These data are then managed and served to the IceCube Collaboration[2] by the UW staff, operating remotely. The summer crew is typically five to six members to complete more extended maintenance activities.

The Observatory includes a Deep Core Array (DCA) to detect low to medium energy neutrinos. A mid-scale research infrastructure award was issued in 2019 to upgrade the DCA with 700 new sensors that will measure the properties of tau neutrinos, the least understood fundamental particles discovered to date. As neutrinos travel through space, they change from one type to another—a quantum-mechanical process known as neutrino oscillation. The IceCube Upgrade will provide the first precision measurement of the number of tau neutrinos appearing due to these oscillations.

<u>Summary of COVID-19 Impacts</u>

During the COVID-19 pandemic, limitations on the number of personnel who could be deployed to Antarctica restricted the ICNO staffing primarily to two winter crew members, who were rotated during the Antarctic summer season. There were no additional summer crew in 2020 and only one in

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[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 referred to as medium range, and those over 100 TeV are referred to as high-energy neutrinos, which generally originate outside the Solar system.

[2] https://icecube.wisc.edu/collaboration/meet-the-collaboration/

2021 and 2022. The summer crew size for 2022/2023 season is yet to be determined. These crew size limitations have caused at least a three-year delay to the DCA upgrade project, which was originally targeted to start in the 2022-23 austral summer season. Options for initiating field work are being evaluated, and a new project baseline will be developed for consideration in FY 2022.

Meeting Intellectual Community Needs

More than 300 physicists from 52 institutions in 12 countries make up the IceCube Collaboration. Of these, about 130 are U.S. scientists supported by OPP and MPS Division of Physics (PHY). This international team is responsible for the ICNO scientific program, and many of the collaborators contributed to the design, construction, and now operation of the detector.

The ongoing DCA upgrade will extend ICNO's overall sensitivity to a lower energy range which will provide a bridge to studies at other neutrino observatories such as the Super-Kamiokande detector in Japan and other similar (much smaller than IceCube) detectors across the world. The DCA upgrade will also provide enhanced calibration capabilities to improve the pointing of neutrino events to astrophysical sources and improve the existing 10+ year data set.

Governance Structure and Partnerships

NSF Governance Structure

The ICNO facility is managed at NSF by an Integrated Project Team consisting of program directors and staff from OPP, MPS, BFA’s Large Facilities Office, the Cooperative Support Branch in the Division of Acquisition and Contract Support, and others in BFA.

External Governance Structure

The ICNO facility is governed by the lead institution, UW-Madison, and its sub-awardee institutions: University of Maryland College Park, University of Delaware, Michigan State University, Pennsylvania State University, University of Alabama, and Lawrence Berkeley National Laboratory.

ICNO is managed by UW and includes a broad science collaboration, currently consisting of 54 institutions worldwide (North America - 30, Europe - 20, Asia and Pacific - 4) in 13 countries (Australia, Belgium, Canada, Denmark, Germany, Japan, New Zealand, South Korea, Sweden, Switzerland, the United Kingdom, and the United States).

Partnerships and Other Funding Sources

Full O&M 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.—roughly in proportion to the number of Ph.D. researchers involved in the Observatory’s maintenance and operations (in 2020, this ratio was about 51perceent U.S. and 49 percent non-U.S.). The NSF support for O&M, research, and education and outreach is shared by OPP (lead) and PHY, as well as by other in-kind contributions from participating institutions.

The work in support of facility operations is performed by students, postdocs, and senior researchers, who are also participating in research using the data produced by ICNO.

Funding

Total Obligations for ICNO
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	ESTIMATES[1] FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Operations and Maintenance (GEO)	$3.56	-	$3.83	$3.83	$3.83	$3.83	$3.83	$3.83
Operations and Maintenance (MPS)	3.53	-	3.83	3.83	3.83	3.83	3.83	3.83
TOTAL	**$7.08**	**-**	**$7.66**	**$7.66**	**$7.66**	**$7.66**	**$7.66**	**$7.66**

[1] Outyear estimates are for planning purposes only. The current cooperative agreement ends March 2026.

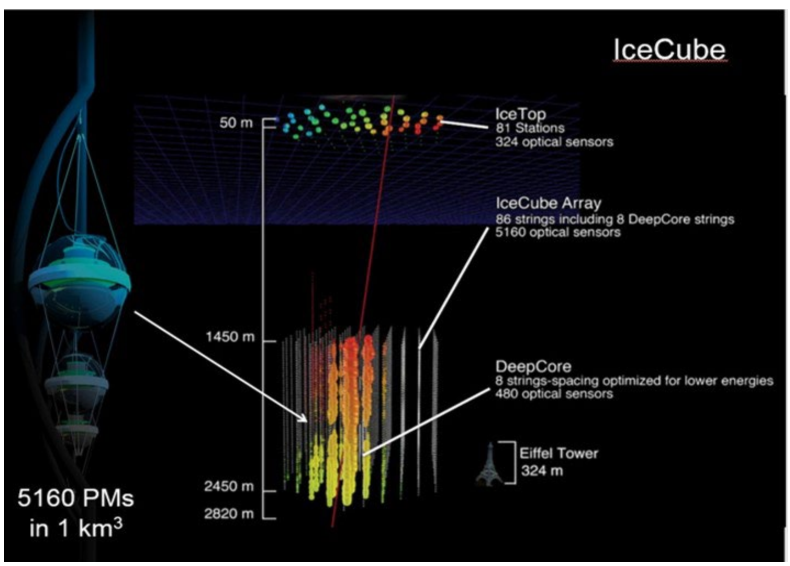
A new five-year cooperative agreement was awarded in 2021. The award increase reflects the higher cost to operate the larger number of strings in the sensor array.

Reviews

The previous cooperative agreement with UW required reviews of the ICNO O&M activities after the second and fourth project years. The mid-term O&M panel review was held (in person) in March 2019, and the second, NSF's staff "site visit" review was held virtually in March 2020. These reviews found that ICNO continues to be a very important element of the OPP and PHY programs, rated the O&M activities as excellent, and recommended continuing operation of ICNO for the remaining period of the previous cooperative agreement. However, with the severe COVID-19 pandemic impacts to the U.S. Antarctic Program operations, the IceCube Upgrade project was halted, and its re-baselining options were reviewed in March and November 2021. The most significant re-baselining review of the Upgrade project is now scheduled for April 2022.

Renewal/Recompetition/Termination

The ICNO full operation began in 2011 with an anticipated lifetime of the detector of 25-30 years. In anticipation of the ICNO O&M support cycle completion in 2021 and according to the LFO/SOP guidance, the O&M renewal proposal was solicited from the IceCube leadership. It was received in Summer 2020 and fully reviewed according to the NSF standard practice. In April 2021, the UW's ICNO O&M cooperative agreement was renewed for the next five years, 2021-2026. Currently there are no plans for divestment of this facility.



IceCube graphical diagram showing how neutrino's interaction within an ice sheet is developed and captured by detector strings. *Credit: IceCube/NSF photo*

INTERNATIONAL OCEAN DISCOVERY PROGRAM (IODP) $50,400,000
+$2,400,000 / 5.0%

International Ocean Discovery Program Funding
(Dollars in Millions)

FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
$48.00	-	$50.40	$2.40	5.0%

Brief Description

The *JOIDES Resolution (JR)* drillship represents NSF's primary contribution to IODP. The *JR* is a deep-ocean drilling vessel whose scientific operations are procured for NSF by means of a long-term lease held by the *JOIDES Resolution* Science Operator (JRSO), Texas A&M University. Besides NSF, the Ministry of Education, Culture, Sport, Science and Technology (MEXT) of Japan and the European Consortium for Ocean Research Drilling (ECORD) continue to provide drilling platforms to IODP.

Scientific Purpose

JOIDES Resolution on station conducting scientific ocean drilling during IODP Expedition 352 (July-September 2014). *Credit: Tom Fulton*.

IODP began in FY 2014 as the replacement for the Integrated Ocean Drilling Program, which succeeded the Ocean Drilling Program. IODP represents an international partnership of the scientists, research institutions, and funding organizations of 22 nations collecting geologic data and samples from beneath the ocean floor. IODP explores Earth's evolution and structure recorded in the ocean basins. IODP platforms provide sediment and rock samples (cores), *in situ* monitoring, sampling, measurement from borehole observatories, shipboard and shore-based descriptive and analytical facilities, downhole geophysical and geochemical measurements (logging), and opportunities to conduct experiments to determine *in situ* conditions beneath the sea floor.

Status of the Facility

The award with Texas A&M University supports facility operations during FY 2020-2024. In cooperation with the *JOIDES Resolution* Facility Board (JRFB), NSF convenes an annual external panel to examine facility performance and community responsiveness. Due to pandemic conditions, the most recent panel review was held in February 2020. The summary of this panel review follows:

"The JRSO Site Visit Panel concludes that the facility is being managed extremely well by JRSO, with continued positive evolution of management practices, facility enhancements, and efforts related to making data and publications more widely available to the scientific community. JRSO interacts extremely well with the JRFB and related panels to implement the IODP Science Plan."

After numerous international workshops, the IODP community has released a new science plan named *2050 Science Framework for Scientific Ocean Drilling.*[1] This plan guides multidisciplinary sub-seafloor research into the interconnected processes that characterize the complex Earth system and shape our planet's future. The *2050 Science Framework* has a 25-year outlook, requiring state-of-the-art approaches for scientific ocean drilling to achieve its objectives into the mid-21st century. Foundational Earth science research is described in seven Strategic Objectives and five Flagship Initiatives with Enabling Elements that encourage innovation and new discoveries. The Framework is supported by Enduring Principles that discuss access to data, the proposal process, planning and safety, diversity and inclusion, and international collaboration. The new Framework is available on the IODP website.

<u>Summary of COVID-19 Impacts</u>
The COVID-19 pandemic continues to have a significant impact on IODP, particularly on operations of the *JR* facility. Science expeditions conducted with a science party resumed in August 2021, immediately after three prior FY 2021 expeditions sailing with reduced technical staff and a minimal onboard scientist presence.

Meeting Intellectual Community Needs

A comprehensive online survey of the U.S. science community was undertaken from December 2016 to May 2017 with the support of the United States Advisory Committee (USAC), the advisory committee for the United States Science Support Program that supports US. Scientist participation in IODP. The survey assessed the success of the *JR* in meeting the needs of the IODP Science Plan. A total of 876 complete responses were received. In September 2017, 81 scientists convened for the *JR* Assessment Workshop to distill and analyze these survey responses, examine the science results of FY 2014-2017 *JR* operations, and make recommendations to NSF regarding whether the *JR* was still needed to address the remaining objectives of the ten-year science plan.

The report states: "the survey results underscore the scientific community's deep satisfaction with the *JOIDES Resolution* and its ability to continue to fulfill IODP objectives. Responses were strongly positive with respect to the ship's drilling systems, analytical systems, and logging systems, with each receiving favorable ratings from over 90 percent of the respondents … the vessel's operational time has recently increased from eight to 10 or more months per year, positioning IODP to achieve high-priority science goals at an accelerated rate."

[1] www.iodp.org/2050-science-framework

Governance Structure and Partnerships

NSF Governance Structure

The *JOIDES Resolution* facility provided by NSF to IODP is managed at NSF by an Integrated Project Team consisting of the NSF/OCE/ODP Program director, the GEO Senior Advisor for Facilities, and staff from BFA's Large Facility Office, the Cooperative Services Branch in the Division of Acquisition and Contract Support, and others in BFA.

GEO's Division of Ocean Sciences manages IODP operations of the *JR* and the IODP Support Office under the NSF Ocean Drilling Program. NSF's Ocean Drilling Program is located within the Integrative Programs Section, with one Program Officer dedicated to oversight. This Program Officer has responsibility for the awards supporting *JR* operations, the IODP Support Office, and the U.S. Science Support Program that funds U.S. scientist participation in IODP.

External Governance Structure

NSF provides the *JR* as the light IODP drillship through an award with Texas A&M University as the JRSO. MEXT provides the *Chikyu* as the heavy IODP drillship through the Japan Agency for Marine-Earth Science and Technology, while the British Geological Survey manages ECORD drilling contributions through single-use mission-specific platforms. 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.

The JRFB, one of three IODP governing bodies, is chaired by a U.S. scientist, with participation by NSF, other contributing international funding agencies, community scientists, and the facility operator. Scientific community members are selected from among nominations submitted through a process managed by the U.S. IODP Science Support Office, housed at Scripps Institution of Oceanography; representatives from the funding agencies, NSF and the facility operator are chosen by those organizations. The JRFB provides operational and management oversight of (1) the *JR* (via the operator—Texas A&M University), (2) the Science Support Office, and (3) the *JR* Facility Advisory Panels. The JRFB approves annual program plans and decides on ship tracks on behalf of IODP; NSF decides whether to accept these plans in executing its fiduciary and legal authority for the *JR*.

Partnerships and Other Funding Sources

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, with all participants except Japan providing financial contributions to the *JR* operations. Japan provides program support through substantial investment in the heavy drill ship *Chikyu* operations, with U.S. and Japanese scientists enjoying reciprocal rights on each drilling vessel.

Funding

Total Obligations for IODP
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	ESTIMATES[1] FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Operations & Maintenance	$48.00	-	$50.40	$50.40	$50.40	$50.40	$50.40	$50.40

[1] Outyear estimates are for planning purposes only. The current cooperative agreement ends September 2024.

The FY 2023 Request includes $50.40 million for IODP. The increase above FY 2021 is primarily associated with inflationary increases in drilling equipment, supplies, and other operational costs.

Reviews

Review of FY 2020 *JR* operations and awardee performance by an NSF panel would normally have occurred in February 2021. This review was postponed due to pandemic travel restrictions and the associated reduction in FY 2020 *JR* science operations. The next NSF Panel is scheduled to meet in summer 2022 to review both FY 2020 and FY 2021 *JR* operations and awardee performance.

Renewal/Recompetition/Termination

After NSB authorization and the NSF Director's approval, the current award was renewed for an additional five years of operation from FY 2020 through FY 2024.

The IODP Science Support Office award at the University of California, San Diego, was extended in 2018 for another five years after excellent performance and panel proposal review.

NSF does not plan to operate *JR* beyond 2028, which would slightly exceed the planned service life of the drillship. In response to a Dear Colleague Letter, NSF received Expressions of Interest in acquiring and operating a new, globally-ranging scientific drilling vessel to meet challenges posed by the *2050 Science Framework for Scientific Ocean Drilling*. Planning for a replacement drill ship to meet the needs of a new, U.S.-led program has begun. Currently, U.S. science community efforts are under way to define Science Mission Requirements for this new vessel.

LARGE HADRON COLLIDER (LHC) – ATLAS AND CMS

$20,500,000
+$500,000 / 2.5%

Large Hadron Collider Funding
(Dollars in Millions)

FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Estimate Amount	Percent
$20.00	-	$20.50	$0.50	2.5%

Brief Description

LHC, an international project at the European Organization for Nuclear Research (CERN) laboratory in Geneva, Switzerland, is the world's most powerful particle accelerator. It produces the highest energy particle beams ever created in a laboratory, making it the premier facility in the world for research in elementary particle physics. LHC is a superconducting accelerator ring approximately 16.5 miles in circumference, in which 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. LHC can also collide beams of heavy ions, such as lead.

Scientific Purpose

LHC probes the fundamental structure of matter to elucidate the basic forces that have shaped our Universe since the beginning of time and that will determine its fate. Among the possible unknowns are extra dimensions of space, unification of fundamental forces, and evidence for dark matter candidates in the Universe. Studies are carried out by colliding protons and heavy ions at extremely high energies and recording, reconstructing, and analyzing the by-products of these collisions using two large detectors: A Toroidal LHC ApparatuS (ATLAS) and the Compact Muon Solenoid (CMS).

The discovery of the Higgs boson in 2012 was one of the original goals of LHC and is one of the most important particle physics discoveries of the last 50 years. Now the scientific focus has shifted to understanding the detailed properties of the Higgs boson and other known processes to elucidate possible deviations from expectations — deviations that might indicate new phenomena. In addition, LHC continues to search for new particles and interactions, including supersymmetry, dark matter, and other unknown phenomena.

This scientific focus has motivated the High Luminosity (HL) upgrades to LHC and its detectors, which will allow for the collection of a much larger data sample. NSF is supporting upgrades to ATLAS and CMS as part of a large global effort (See the HL-LHC narrative for more information).

Status of the Facility

LHC is the only experimental particle physics facility operating at the high energy frontier. The facility and the planned HL-LHC upgrades are a high priority of the entire high energy physics community. The LHC energy upgrade in 2015 from 8 TeV to 13 TeV pushed the boundaries of our understanding into unknown territory. CERN is carrying out a multi-year program to increase the beam interaction rate that will culminate with HL-LHC operation beginning in 2027. This will produce a large data sample of rare events that could shed light on new physics. Installation of smaller-scale detector upgrades, completed in 2021, will enable ATLAS and CMS to keep pace with LHC's performance enhancements through 2025. A shutdown that CERN is currently scheduling to begin in 2025 (which may be delayed because of pandemic considerations) will enable the installation of major upgrades to the accelerator and detectors preparatory to ten years of HL-LHC operation, extending the scientific reach of the facility.

COVID-19 impacts on the operations of LHC have been relatively minor so far. Activities at CERN to prepare the ATLAS and CMS detectors for the next cycle of accelerator operations, starting in April 2022, were completed on schedule. U.S. scientists and international colleagues conducted hands-on detector support activities that followed carefully orchestrated protocols to ensure worker safety. Additionally, most NSF-supported activities associated with ATLAS and CMS detector operation are concentrated in the software and computing areas, which are well suited for remote work in a safe environment.

Meeting Intellectual Community Needs

Currently, more than 1,200 U.S. researchers participate in the ATLAS and CMS collaborations, including more than 100 post-doctoral fellows and more than 400 students, of whom about half are undergraduates. The U.S. researchers comprise about 20 percent of the total membership of the ATLAS and CMS collaborations. NSF supports about 20 percent of the U.S. ATLAS and CMS contingents (plus about 30 of the nearly 1,300 members of LHCb collaboration, which operates the separate LHCb experiment at LHC). Research at LHC is supported by NSF through the Division of Physics Elementary Particle Physics and Nuclear Physics programs.

In addition, a world-wide cyber infrastructure effort, the Worldwide LHC Computing Grid (WLCG), is dedicated to LHC data processing, allowing scientists to remotely access and analyze vast data sets. The U.S. ATLAS and CMS collaborations continue to lead the development and exploitation of distributed computing within their respective international collaborative efforts. The WLCG Tier 1 and Tier 2 computing centers (funded by DOE and NSF, respectively) enable the researchers at 98 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.

Governance Structure and Partnerships

<u>NSF Governance Structure</u>
NSF oversight is provided by a program officer in the MPS Division of Physics (PHY), who works cooperatively with staff from other MPS divisions, BFA, 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. The MPS facilities team and the Chief Officer for Research Facilities also provide high-level guidance, support, and oversight.

<u>External Governance Structure</u>
NSF/PHY staff and their Department of Energy (DOE) Office of Science counterparts meet twice yearly with CERN and funding agencies from other nations at Resource Review Board (RRB) meetings, where

technical and financial issues are discussed and decided. The ATLAS and CMS experiments are each funded by more than forty different agencies, including NSF and DOE. NSF and DOE coordinate U.S. investments in the LHC program through a Joint Oversight Group (JOG), which also meets at least semi-annually.

The U.S. ATLAS and U.S. CMS collaborations internally select leadership that represent the United States within the international ATLAS and CMS collaborations. The international leadership for each collaboration establishes its respective scientific goals and objectives and exercises overall governance. NSF supports detector operation through two awards—one to the University of Nebraska-Lincoln for CMS, and another to Stony Brook University for ATLAS. The current awards, which were implemented following thorough external review and comprehensive internal assessment during FY 2021, expire in December 2026 and January 2027, respectively.

<u>Partnerships and Other Funding Sources</u>
U.S. activities at CERN are enabled by a DOE/NSF/CERN agreement signed in 1997 ("Experiments Protocol I") and a Cooperation Agreement, signed in May 2015 and renewed every five years. An additional agreement signed in December 2015 ("Experiments Protocol II") further defined the framework for NSF participation in the particle physics programs of the ATLAS and CMS detector collaborations under the auspices of CERN. These activities include expanding the physics reach of the detectors through construction of technologically advanced enhancements able to take full advantage of the increase of the LHC accelerator's nominal luminosity by a factor of ten. The resulting increase in capabilities will facilitate and support the continued participation of the large U.S. particle physics community engaged at LHC during the HL-LHC era. The HL-LHC is slated to operate for ten years beginning in 2027.

Funding

Annual operations and maintenance funding covers the costs of NSF-provided detector components, software and computing, and contributions to a common fund to maintain shared detector infrastructure. Detector operation and maintenance are forecast to require future levels of effort like those needed to support the current apparatus. Data handling is an exception, in which extraordinary efforts by CERN, the experimental collaborations, and funding agencies are now underway on a global scale to support HL-LHC operation beyond 2027.

Total Obligations for LHC
(Dollars in Millions)

	FY 2021	FY 2022	FY 2023	ESTIMATES[1]				
	Actual	(TBD)	Request	FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Operations & Maintenance	$20.00	-	$20.50	$20.50	$20.50	$20.50	$20.50	$20.50

[1] Outyear estimates are for planning purposes only. The current cooperative agreements ended in December 2026 (CMS) and January 2027 (ATLAS).

The FY 2023 Request for the NSF LHC program is $20.50 million. Funds will support operation activities by U.S. university-based researchers participating in high energy physics at LHC. LHC is planned to restart in April 2022 and to resume full-time operation in July 2022. This follows the successful conclusion of the three-year data-taking period in December 2018, and the completion of detector maintenance and the installation of detector performance enhancements that began in 2019.

Reviews

NSF and DOE conduct separate and joint external reviews of operations and detector upgrade activities. Each agency is fully cognizant of the activities of the other partner, and recommendations from reviews are routinely used to inform ATLAS and CMS operations planning and the agencies' oversight thereof. Two JOG review meetings per year assess operational performance, scientific and financial status, management issues, and plans for future activities. DOE and NSF conducted joint external panel reviews of ATLAS and CMS operations at the end of January 2022. The most recent JOG was held in October 2021 and the next one is planned for March 2022.

Renewal/Recompetition/Termination

NSF awarded operations funding to CMS and ATLAS through five-year cooperative agreements beginning in FY 2022. The ATLAS award was a renewal of the prior five-year award. The CMS award was to a new awardee. The awards were implemented after NSF completed a proposal-driven review process that included external review and cost analysis of each detector's operations proposal. NSF has no ownership of any part of the facility. CERN has taken responsibility for disposal of all irradiated apparatus at the conclusion of experimental activity. No divestment is planned at this stage.

LASER INTERFEROMETER GRAVITATIONAL-WAVE OBSERVATORY (LIGO) $45,000,000 / $0

Laser Interferometer Gravitational-Wave Observatory Funding
(Dollars in Millions)

FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Percent
$45.00	-	$45.00	-	-

Brief Description

LIGO, the most sensitive gravitational-wave detector ever built, comprises two main facilities, one in Livingston Parish, Louisiana and one in Hanford, Washington. 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.

Scientific Purpose

Monitoring millisecond changes in the geometry of space-time using kilometer-scale laser interferometry, LIGO can map the rippling gravitational traces of energetic and violent events such as the coalescence of neutron stars and black holes. LIGO also searches for other sources of gravitational radiation due to phenomena such as the wobbling of fast-spinning neutron stars, vibration of cosmic strings, supernova explosions, and possibly the Big Bang itself. LIGO leads the expanding worldwide effort to study the cosmos through the direct observation of gravitational radiation. Two of LIGO’s historic accomplishments are the September 14, 2015, measurement of gravitational waves (GWs) arising from the collision and coalescence of a pair of black holes (the first direct detection of this phenomenon, described nearly one century previously by Einstein) and the August 17, 2017, detection of GWs from the collision of two neutron stars. The latter measurement was made by LIGO and the Europe-based Virgo detector, together with some 70 ground and space-based observatories that observed the electromagnetic signals emanating from this spectacular collision, thus inaugurating a new era of multi-messenger astrophysics. LIGO has since been a critical resource in support of NSF’s Windows on the Universe Big Idea. The 2017 Nobel Prize in Physics was awarded to LIGO pioneers Barry C. Barish, Kip S. Thorne, and Rainer Weiss "for decisive contributions to the LIGO detector and the observation of gravitational waves.” Since then, LIGO has observed more than 90 additional GW candidate sources.

Status of the Facility

The broader scientific community is eager for more GW detections. LIGO's event detection rate scales as the third power of its sensitivity, so LIGO prioritizes efforts aimed at improving performance over extended observing periods. Efforts are underway at both LIGO sites, under leadership of the Advanced LIGO Detector Project Manager (who reports to the LIGO Laboratory Director) to lead and coordinate the technical efforts intended to improve interferometer sensitivity. This is LIGO's highest priority. LIGO conducted a third observational run, begun in April 2019 and lasting about 11 months, at about 80 percent of Advanced LIGO's calculated design sensitivity. LIGO researchers are now working to further enhance the sensitivity of the apparatus in preparation for a planned fourth year-long observational run that is expected to begin as early as the Fall of 2022. LIGO sensitivity will be further augmented as the Advanced LIGO Plus (A+) upgrades are installed; they are predicted to increase LIGO's sensitivity by a factor of 1.6-1.9. Some of the A+ upgrades are expected to be completed prior to the start of the fourth run, further boosting performance.

Virgo and the Kamioka Gravitational Wave Detector (KAGRA) are foreign-led efforts comparable to LIGO to directly observe GWs. Both efforts lag in achieving sensitivities in the same range as LIGO. When fully commissioned, Advanced Virgo will have a sensitivity of about two-thirds that of Advanced LIGO. KAGRA—a more ambitious, but technically challenging effort under construction in Japan—may result in an even more sensitive apparatus (due to its location deep underground and its pioneering use of cryogenic optics), although the timescale for completion is at least a few years off. Virgo participated in joint observing during LIGO's observing run 3, at a sensitivity about half as great as the mean LIGO sensitivity. KAGRA also participated in the end of run 3 in 2020, albeit at very modest sensitivity. Both detector groups plan to participate with LIGO in the fourth observing run.

Other efforts complement LIGO's capabilities by searching for GWs in frequency bands outside LIGO's operating range (roughly 0-1000 Hz). NANOGrav (a U.S.-Canadian effort supported by NSF), along with similar efforts in Europe and Australia, is now searching for GW signals in the roughly nano-Hz to micro-Hz band. However, the expected global network of two U.S. LIGO sites, plus Virgo, KAGRA, and the anticipated LIGO-India facility (to be constructed and operated by the Government of India using interferometer components contributed by NSF) is the only experimental avenue for measuring GW source locations with sufficient angular resolution to allow complementary electromagnetic observations.

COVID-19 impacts on LIGO operation have been relatively minor. The third scientific observing run was terminated one month earlier than planned because of pandemic restrictions. LIGO has re-opened, with COVID-19 mitigation measures in place to ensure the safety of LIGO workers. However, COVID-19 has resulted in schedule delays for some maintenance and upgrade activities because of pandemic impacts on LIGO's staff and some of its industrial suppliers. Pandemic impacts have delayed commercial firms providing goods and services that LIGO needs to prepare for Run 4 and to complete the A+ upgrade. LIGO currently forecasts that these activities will be completed more than one year later than originally planned. LIGO's educational outreach program transitioned to entirely online activities for teachers and students.

Meeting Intellectual Community Needs

The LIGO Scientific Collaboration (LSC), an open collaboration that organizes the major international groups doing research supportive of LIGO, has more than 120 collaborating institutions in 19 countries with more than 1,400 participating scientists. The LSC plays a major role in many aspects of the LIGO effort. These include establishing priorities for scientific operation, carrying out data analysis and validation of scientific results, and contributing to improvements in instrumentation at the LIGO facilities. Additionally, LSC members are exploring future technologies, as well as participating with LIGO in activities that promote STEM education and public outreach programs. NSF supports LSC activities in the United States at a level of nearly $10 million per year through regular disciplinary program funds.

LIGO also publicly issues both human-readable and machine-readable alerts for candidate GW detections, reaching a vast and growing cadre of ground- and space-based observatories that are primed to make follow-up electromagnetic observations of multi-messenger astrophysical phenomena. Many other NSF-funded observatories are crucial participants in this observational community.

Governance Structure and Partnerships

NSF Governance Structure

NSF oversight is provided by a program officer in the MPS Division of Physics (PHY), who works cooperatively with staff from other MPS divisions, BFA, 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. The MPS facilities team and the Chief Officer for Research Facilities also provide high-level guidance, support, and oversight.

External Governance 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 is fully integrated into all LIGO activities. The LIGO management organization coordinates significant involvement by the user community, represented by the LSC, and arranges collaborative activities 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.

Partnerships and Other Funding Sources

- Advanced LIGO is a now-completed $205.0 million project funded by the MREFC account that supported the development and installation of interferometer components and computing hardware designed to increase LIGO sensitivity (relative to the initial apparatus) by about a factor of eight. The United Kingdom (UK), Germany, and Australia provided components and services to the Advanced LIGO project that are valued at about $20.0 million.
- LIGO-India, if realized, would be constructed through a transfer to India of Advanced LIGO components, valued at approximately $50.0 million, originally intended as a second Hanford interferometer. This transfer would enhance the source localization capabilities of the global GW network and bring significant scientific benefits to the international GW research community. NSF signed a Memorandum of Understanding with India’s Departments of Atomic Energy and Science and Technology in March 2016, agreeing to partner in this undertaking. The formal start of construction is pending approval by the Government of India Cabinet.
- In FY 2018 and FY 2019, NSF separately awarded $20.47 million to complete final designs and

construct the A+ upgrade. The UK is contributing about 10 million British Pounds, primarily for core optics and suspension system modifications. Additional key hardware and effort are being provided through in-kind contributions from Australia.

Funding

LIGO operation and maintenance is entirely supported by NSF; NSF is requesting $45.0 million for FY 2023. Current annual operating costs are $45.0 million. The annual budget was negotiated for the FY 2019-FY 2023 period following a 2018 NSF external review of LIGO's proposal for operation.

Total Obligations for LIGO
(Dollars in Millions)

	FY 2021	FY 2022	FY 2023	ESTIMATES[1]				
	Actual	(TBD)	Request	FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Operations & Maintenance	$45.00	-	$45.00	$45.00	$45.00	$45.00	$45.00	$45.00

[1] Outyear estimates are for planning purposes only. The current cooperative agreement ends in September 2023.

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 2021. Recommendations from annual reviews are routinely used to inform LIGO's operations planning and NSF's oversight thereof.

Renewal/Recompetition/Termination

NSF implemented a new five-year award for LIGO operations in October 2018. In accordance with NSF policy, MPS is developing an analysis for consideration by the Director to either compete the management of LIGO, review and fund a renewal proposal from the current management entity, or to divest the facility through stewardship transition or other means. Currently there are no plans for divestment of this facility. LIGO A+ development, design, and implementation are underway concurrently through a separate award, which targets full A+ operation in FY 2024.

THE NATIONAL ECOLOGICAL OBSERVATORY NETWORK (NEON) $70,000,000

+$5,000,000 / 7.7%

The National Ecological Obsevatory Network Funding
(Dollars in Millions)

FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Percent
$65.00	-	$70.00	$5.00	7.7%

Brief Description

Funded and overseen in the Directorate for Biological Sciences, NEON is the first observatory of its kind, designed to foster and enable advances in the basic understanding of the complexities of life on earth, from organisms and populations to the biosphere and from seconds to decades. Construction of the observatory was completed in 2019, and it is designed to operate for 30 years. The NEON infrastructure is distributed across the United States (including Alaska, Hawaii, and Puerto Rico), and includes 20 regional eco-climatic domains. NEON collects standardized observations on plants, animals, and biogeochemistry in air, land, and water at 81 sites across these domains using three types of approaches: on-the-ground organismal sampling by trained professionals, automated instrument measurements in the environment, and airborne remote sensing surveys. After the collection and processing of data from instrument and observational systems, NEON makes 181 data products available on a centralized data portal that is free for all to access and use; it also makes available open access data tutorials, code packages, and other resources that enable use of NEON data by scientists and the community at large throughout the U.S. and the world.

Scientific Purpose

NEON is designed to detect, and enable forecasting of, ecological change at continental scales over multiple decades. NEON enables research by the nation's scientists on the impacts of climate and land use change, water use, and invasive species on the Nation's living ecosystems at temporal and spatial scales that are relevant to human well-being. NEON allows researchers to explore large-scale dynamics affecting ecosystems by collecting consistent and standardized environmental and biological measurements across multiple sites nationwide. NEON's unique statistically determined design supports research on the dynamics of complex coupled systems needed for modeling and understanding rates of change on regional and continental scales. NEON's cyberinfrastructure gateway provides resources to support a wide range of scientists at any institution to conduct research at these important scales using its open access data.

Status of the Facility

Prior to March 2020, data were being collected as planned at all the terrestrial and aquatic sites across the 20 eco-climatic domains. Data collection in the ensuing year was somewhat compromised, as described below. The overall trend in use of NEON data from the data portal shows a significant increase in the number of users and data downloads, with an even greater increase in use of the Application Programming Interface (API) to access NEON data. In the year prior to the onset of COVID-19, NEON staff supported 304 engagement events reaching over 8,400 individuals. Events included presentations, site tours, conference attendance, trainings and outreach through social media, and in-person and virtual workshops targeting a wide range of public and STEM audiences. The groups engaged during these events are from different educational and/or career stages (e.g., high school, undergraduate, graduate student, postdoctoral fellows, scientists in academia, agencies), diverse geographic areas within the U.S., and multiple demographic groups including underrepresented groups and Minority Serving Institutions.

The COVID-19 pandemic had a significant impact on NEON operations during Calendar Year 2020. Operational sampling at all NEON sites was halted near the end of March and began resuming gradually in the second half of May. Since mid-June of 2020, the 81 NEON field sites and 18 Domain Support Facilities (DSFs) have cycled among three states—fully open, limited operation, or closed—depending on local governmental restrictions and safety assessments by Battelle, the current managing organization for NEON. As of November 30, 2021, all 18 DSFs were fully open; 73 field sites were fully open, 8 field sites were in limited operations, and none were closed. The NEON Headquarters in Boulder, Colorado is under restrictions with most employees working from home. The changing states had significant impacts on regular maintenance and data continuity, especially in the gathering of biological samples, an important component of the Observational Systems data. Closed sites continued to stream automated data that did not require human presence (e.g., atmospheric sampling), while biological sampling was suspended.

Meeting Intellectual Community Needs

Use of NEON data and assets is growing as more data become available. Research use of site data, soil and other samples, and remote sensing data continues to expand; data are streaming to the NEON Data Portal from tower sensors, aquatic sensors, and observational systems from all sites. Research has been supported through early exploration of NEON data via 15 Early-concept Grants for Exploratory Research (EAGER), standard awards through the Macrosystems Biology and NEON Enabled Science Programs and core research programs across the Agency, and multiple workshops awards. The EAGERs were intended to catalyze the use of NEON data and they have started yielding the types of publications that NEON is intended to inform. The NEON Airborne Observation Platform (AOP) has been used to assess major fires and, in partnership with the National Aeronautics and Space Administration (NASA), participated in the science development of the Hyperspectral Infrared Imager (HyspIRI) mission. Multiple NEON science presentations by funded researchers formed the corpus of continental-scale sessions at the 2021 Ecological Society of America meetings in addition to presentations at several other venues, such as the 2021 American Geophysical Union Fall Meeting. The number of presentations using Remote Sensing data continue to increase compared to previous years, spurred in large part by data from the three AOPs.

Governance Structure and Partnerships

<u>NSF Governance Structure</u>

The NEON program is managed in BIO, with the Office of the Assistant Director providing overall policy guidance and programmatic oversight. Direct oversight currently resides within the Division of Biological Infrastructure (DBI) allowing for enhanced long-term programmatic oversight of the project within the context of project management and infrastructure support. Within DBI, the Division Director and Deputy Division Director provide overall oversight of the project as a component of BIO's Centers, Facilities, and Additional Research Infrastructure Cluster.

Programmatically, the NEON project is managed by a cognizant program officer in DBI who oversees the operations award. Another program officer in DBI and program officers in the Division of Environmental Biology (DEB) assist with oversight for science implementation. In addition, the program is supported by a project manager with experience in the management of large research infrastructure projects. A NEON Environmental Assessment Team that includes the project manager and colleagues from the Office of the General Counsel provides ongoing technical advice on National Environmental Policy Act compliance and NSF's compliance with other relevant policies.

An integrated project team (IPT) has been established and is chaired by the NEON cognizant program officer. The IPT includes representatives from the Office of Legislative and Public Affairs, BFA's Large Facility Office (LFO), BFA's Division of Acquisition and Cooperative Support (DACS), BFA's Division of Institution and Award Support - Cost Analysis and Pre-Award Branch, the Office of the General Counsel, and as needed, the Office of the Director.

Additional strengthening of the BIO NEON program and NEON Project Oversight is ongoing and includes visits in coordination with LFO and DACS to assist with strategic coordination of project activities and understanding NSF review and reporting requirements.

<u>External Governance Structure</u>

Management of the NEON project was transferred to Battelle in the spring of 2016 when the existing NEON, Inc. Board of Directors was replaced by Battelle employees. Within Battelle, the NEON Chief Scientist provides overall scientific leadership and serves as the Principal Investigator for the award. The NEON Chief Scientist is supported by a Project Operations Manager. A Science, Technology, and Education Advisory Committee (STEAC), composed of members of the NEON user community, provides strategic guidance and advice to Battelle, and helps ensure that NEON will enable frontier research and education. The work of the STEAC is complemented by several Technical Working Groups, comprising over 170 science, education, and engineering experts, that advise Battelle on technical aspects of the project and other issues that have scientific, educational, engineering, or operational implications.

<u>Partnerships and Other Funding Sources</u>

The NEON project is funded through an award to Battelle. While NSF funds provide the operations costs, several federal agencies (NASA, the National Oceanic and Atmospheric Administration, the Department of Energy, the United States Forest Service, the Environmental Protection Agency, the United States Department of Agriculture, the National Park Service, the Bureau of Land Management, the United States Geological Survey) provide significant in-kind services, including sites for deployment of NEON infrastructure. Funding for research using NEON is provided through a special program and in other BIO core programs across its divisions, as well as by programs in GEO and CISE. Formal agreements have been signed with the European Union, including the Integrated Carbon Observing System Ecosystem Thematic Center, Infrastructure for Analysis and Experimentation on Ecosystems, and Czech Climate Change Research Center, and Australia's Terrestrial Ecosystem Research Network. Areas of coordination with the above include planning, design, construction, deployment, environmental assessment, data management, geospatial data exchange, cyberinfrastructure, research, and modeling. Several of the 81 NEON field sites are located on land administered or owned by other federal agencies and private organizations, providing opportunities for partnering around common research interests. Private organizations, including the Heinz Center, National Geographic Society, NatureServe, the Ecological Society of America, and the American Geophysical Union, are assisting to broaden the impact of NEON science and education to the next generation of scientists and educators.

Funding

Total Obligations for NEON
(Dollars in Millions)

	FY 2021 Actual	FY 2022 TBD	FY 2023 Request	ESTIMATES[1] FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Operations & Maintenance	$65.00	-	$70.00	$70.00	$70.00	$70.00	$70.00	$70.00

[1] Outyear estimates are for planning purposes only. The current cooperative agreement ends in October 2023.

The NEON program in BIO provides all support for operations, which are estimated at approximately $70.0 million in FY 2022. 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 $70.0 million.

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 confirmed delivery of observatory capacity. Reviews of full O&M are held annually. The 2020 review of O&M emphasized evaluation of data availability, accessibility, and quality; impacts of and responses to natural disasters and the pandemic; Battelle's cost performance; and the facility's cyberinfrastructure. The 2021 annual review was substituted by a review of a supplemental proposal to extend Battelle's period of performance through October 31, 2023. The supplemental proposal review was completed by an external panel of experts and focused on science outcomes enabled by the facility, responses to the pandemic, Battelle's cost performance, and the facility's cyberinfrastructure, resulting in an NSB-approved two-year extension to the active O&M award and facilitating the ongoing competition that was delayed by the pandemic (see below). 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.

Renewal/Recompetition/Termination

Construction was completed in May 2019 after delays caused by ongoing permitting and compliance issues, natural disasters, and other external factors.

The initial operations period of the NEON observatory was extended to allow time for Battelle to optimize operations and maintenance activities and to identify operational efficiencies and cost-saving opportunities. Funding of operations and maintenance was approved (August 2017) for three years, beginning on November 1, 2017 (costs not-to-exceed $192.50 million), with an option for the director to issue a fourth year of funding (costs not-to-exceed $70.0 million). This operations and maintenance phase allowed Battelle to develop a firm cost baseline for funding full operations over the long-term. In July 2019, the NSF Director alerted the National Science Board of her intention to exercise the option for a fourth year of funding. A Dear Colleague Letter (DCL) was released (July 26, 2019) announcing NSF's intention to compete the management of NEON operations and maintenance and encouraging organizations to submit requests for information. At the issuance of the DCL, BIO anticipated the timeline of the competition to be approximately 2 years. The COVID-19 pandemic has delayed implementation of some activities in the competition timeline, resulting in the postponement of proposal submission by 2 years. Thus, NSF, based on positive annual reviews of operations by panels of external experts and other data, has asked Battelle to operate NEON through October 2023, allowing the Agency time to execute a robust competition. NSF aims to have a new CA for NEON O&M in place by November 1, 2023. The anticipated lifetime of the NEON project is thirty years.

NATIONAL HIGH MAGNETIC FIELD LABORATORY (NHMFL) $40,490,000
+$14,360,000 / 55.0%

National High Magnetic Field Laboratory Funding
(Dollars in Millions)

FY 2021 Actual[1]	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
$26.13	-	$40.49	$14.36	55.0%

[1] Excludes $12.0 million obligated in FY 2020 for FY 2021 operations.

Brief Description

NHMFL is the world's premier high-magnetic-field laboratory, featuring an extensive collection of unique magnet systems and comprehensive support services. The laboratory is an internationally recognized leader in magnet design, development, and construction, including the development of new high-field superconducting magnets. NHMFL offers its users consistent and reliable high magnetic fields, such as the 45-tesla continuous-field magnet, the non-destructive pulsed-field magnet (100 tesla), the 36-tesla magnet for Nuclear Magnetic Resonance, the highest-field superconducting magnet for Fourier Transform-Ion Cyclotron Resonance (FT-ICR) mass spectrometry (21 tesla), and the highest field for magnetic resonance imaging (MRI) studies of living animals (21.1 tesla). These unique facilities are available to thousands of users each year and help define and advance the science frontiers in many disciplines through measurements with state-of-the-art resolution and accuracy. NHMFL is operated by a consortium of three institutions, each of which house NHMFL facilities: Florida State University (FSU), University of Florida (UF), and Los Alamos National Laboratory (LANL).

Scientific Purpose

NHMFL provides the highest magnetic fields and necessary services for scientific research conducted by users from a wide range of disciplines, including physics, chemistry, biology, biochemistry, neuroscience, energy, and environmental sciences. Research conducted by users of NHMFL investigates topics that include quantum phenomena in graphene and other two-dimensional materials, superconductors, and topological materials; electron and nuclear spins of solid, molecular, and biological materials; the structure and dynamics of the macromolecular components of life; and properties and functionalities of various materials essential in energy production, storage, and use.

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. Over the last several years, NHMFL has contributed to major scientific accomplishments in superconductivity and the frontier field of topological materials, an entirely new class of quantum materials prominently distinguished by the 2016 Nobel Prize in Physics. For example, in 2019 NHMFL's high magnetic fields allowed scientists to discover one of the most important phenomena in the field of superconductivity in the past three decades, a phenomenon called re-entrant superconductivity.[1] This phenomenon had never been seen at high fields, and its

[1] www.nationalmaglab.org/news-events/news/rare-lazarus-superconductivity

occurrence was completely unexpected. Re-entrant superconductivity displays properties that suggest it could be a particularly robust component in quantum computers of the future. Other recent prominent results from NHMFL include the first confirmation of the existence of a three-dimensional topological insulator state, and the first evidence of a long-sought quantum phenomenon known as the chiral anomaly.

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 use of other nuclei that would result in new insights into mapping the brain and neuroscience. NHMFL's MRI at high magnetic fields (21.1 tesla) has enabled *in vivo* imaging of brain function and cancer research in rats.

NHMFL's 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 opened new probing capabilities for chemists and biologists.

Status of the Facility

<u>Status with respect to Scientific Community</u>

- A 2013 report by the National Academies of Science, Engineering, and Medicine, *High Magnetic Field Science and Its Application in the United States: Current Status and Future Directions*,[2] found that very high magnetic fields are necessary for many crucial research experiments in condensed matter physics, chemistry, and biology. The success of these experiments may have major impacts on health care and other technologies. High magnetic fields in very large volumes are also required for accelerators in high-energy physics, and in plasma research aimed at the realization of controlled nuclear fusion. Based on these needs, this report provided several recommendations with respect to specific scientific priorities for new magnet developments. In direct response to one of these recommendations, NSF has provided funding[3] for the development and design of a 40-tesla all-superconducting magnet, building on recent advances in high-temperature superconducting magnet technology. Additional recommendations from this report, e.g., for a 60-tesla DC hybrid magnet and higher-field pulsed magnets, may inform NSF's and NHMFL's planning for next-generation capabilities.
- The 2013 report, alongside several other community reports, also highlighted the need to combine high magnetic fields with synchrotron facilities. To this end, NHMFL is partnering with the Cornell High Energy Synchrotron Source (CHESS) on the construction of a new High Magnetic Field Beamline (HMF) that will offer the highest currently available direct-current magnetic fields at any synchrotron facility in the world. The HMF project, led by Cornell University, is being implemented through an NSF Mid-scale Research Infrastructure—Track 2 award, and its future operations (planned to begin in 2025) will be integrated into NSF's Center for High-Energy X-ray Sciences (CHEXS) at CHESS.

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[2] www.nap.edu/catalog/18355/high-magnetic-field-science-and-its-application-in-the-united-states

[3] Funding provided through NHMFL O&M award ($4.20 million in FY 2018) and two separate awards, DMR-1938789 ($4.20 million in FY 2020 for conceptual design) and DMR-2131790 Mid-scale Research Infrastructure-1 ($15.8 million in FY2021 for final design).

COVID-19 Status

Starting in early March 2020, NHMFL imposed access restrictions on its facilities at all three sites (FSU, UF, and LANL) due to health concerns related to the COVID-19 pandemic. These restrictions progressed from travel restrictions to limited access to the NHMFL sites as the COVID-19 pandemic evolved and new mandates were put in place by the Centers for Disease Control and Prevention, as well as state and local authorities. All three NHMFL partner institutions (FSU, UF, and LANL) are responding to changing guidance from both state and national levels by developing plans for ramping-up activities back to normal. All three NHMFL sites are providing on-site access to a limited number of users based mainly on scientific need, and critical need for on-site access. While the on-site user activity is currently below normal, NHMFL's user program remains operational, taking advantage of remote operations for many of the available instruments.

Meeting Intellectual Community Needs

NHMFL is the largest magnet laboratory in the world with the highest-powered magnets and more than 2,000 users annually. The annual number of NHMFL users, which includes senior investigators, postdoctoral researchers, and students, continues to grow with about 20 percent each year being new users. The condensed matter physics, chemistry, and biology user communities have experienced significant growth in recent years.

In September 2017, DMR organized a workshop on Exploring Quantum Phenomena and Quantum Matter in Ultrahigh Magnetic Fields to further identify, assess, and prioritize scientific needs of new large-scale instruments and facilities that include ultrahigh magnetic fields for quantum materials research, and to explore the broader impacts on other areas of materials research, as well as other disciplines. The workshop report[4] affirmed the benefits of both DC- and pulsed-field capabilities for quantum materials research. NSF plans to commission a follow-on report approximately one decade from the 2013 report to provide further recommendations for long-term directions in high magnetic field science and technology.

NHMFL provides a unique interdisciplinary and convergent learning environment. The Center for Integrating Research & Learning at NHMFL conducts education and outreach activities, which include a Research Experiences 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. Since the onset of the pandemic, much of NHMFL's education and outreach programming has shifted online: several of the summer programs for teachers and students, as well as the annual Open House event that routinely draws thousands of visitors, are now being conducted in a virtual format, and NHMFL is offering live virtual classroom outreach and at-home educational resources.

Governance Structure and Partnerships

NSF Governance Structure

NHMFL is supported and managed by the MPS Division of Materials Research (DMR), with the DMR program officer as the primary contact for most of the laboratory. The Division of Chemistry (CHE) contributes support for the FT-ICR Facility. The Division of Acquisition and Cooperative Support and the Large Facilities Office within BFA provide financial and administrative support and assist with

[4] www.arxiv.org/ftp/arxiv/papers/2103/2103.09155.pdf

agency oversight. The MPS Facilities team, together with the NSF Chief Officer for Research Facilities, also provide high-level guidance, support, and oversight.

External Governance Structure

NHMFL is operated under a cooperative agreement through a consortium of three institutions: FSU, UF, and LANL. FSU, as the primary awardee, 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.

Partnerships and Other Funding Sources

The State of Florida contributes approximately $12.0 million per year to support NHMFL. While there is no formal partnership at the federal agency level, the Department of Energy (DOE) supports NHMFL through LANL, which contributes approximately $2.0 million per year to the NHMFL. Additional funding, at the level of $4.0 to $6.0 million per year, comes from individual investigator awards, which support activities at NHMFL.

NHMFL collaborates with more than 60 private-sector companies as well as with several national laboratories. These include those supported by DOE, 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 and is playing a key role in the design and construction of a new 45-tesla hybrid magnet to be located at the High Field Magnet Lab at Radboud University in Nijmegen, the Netherlands; each project was funded by the respective international institution. Collaborations also exist with the International Thermonuclear Experimental Reactor in France, and national magnet laboratories in several countries, including the Netherlands and Germany.

Funding

Total Obligations for NHMFL
(Dollars in Millions)

	FY 2021	FY 2022	FY 2023	ESTIMATES[1]				
	Actual	(TBD)	Request	FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Operations & Maintenance (DMR)	$24.25	-	$36.18	$36.09	$36.09	$36.09	$36.09	$36.09
Operations & Maintenance (CHE)	1.88	-	2.10	1.73	1.73	1.73	1.73	1.73
Special Projects (DMR+OMA)[2]	-	-	2.21	-	-	-	-	-
Total	**$26.13**	**-**	**$40.49**	**$37.82**	**$37.82**	**$37.82**	**$37.82**	**$37.82**

[1] Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in December 2022.

[2] Reflects additional funding for research infrastructure and O&M costs, including additional costs for repairs and maintenance.

The current NSF award for the operation of NHMFL spans CY 2018-2022. Over the five-year award period, DMR's O&M support (initially on the order of $35.0 million per year) is escalated by three percent annually, and CHE provides $1.73 million annually. The actual budget each year varies due to forward funding and supplemental funding actions. The FY 2023 budget request represents estimates for operations under a new award, including $36.18 million from DMR and $2.10 million from CHE. Funding for special projects also includes additional deferred maintenance projects, upgrades necessary for the continued effective operations of the facility, such as replacement of magnet coils and updates to basic power, water, and chiller services. The execution of projects will be prioritized based on the outcome of ongoing facility condition assessments.

Reviews

NSF monitors annual plans and reports, including user metrics, and conducts regular monthly teleconferences with the NHMFL director along with numerous *ad hoc* communications and discussions. NSF conducts annual external site visit 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. Recommendations from annual reviews are routinely used to inform NHMFL's operations planning and NSF's oversight thereof.

Recent reviews include:

- External Safety Review at all three sites of the NHMFL (July and September 2018).
- Site visit review with external panel of experts, September 2019.
- Virtual site visit review with external panel of experts, October 2020.
- Virtual site visit review with external panel of experts, July 2021.

Renewal/Recompetition/Termination

The current award, in an amount not to exceed $184.05 million, for the operation of NHMFL started on January 1, 2018, and will end on December 31, 2022. MPS developed an analysis of considerations for potential renewal, competition, or divestment of the facility at the end of the current award. Based on that analysis, the NSF Director approved the recommendation to request a renewal proposal for the period 2023-2027. NSF has received the NHMFL renewal proposal, and it is currently under review. Currently there are no plans for divestment of this facility.

OCEAN OBSERVATORIES INITIATIVE (OOI) **$51,000,000**

+$5,700,000 / 12.6%

Ocean Observatories Initiative Funding
(Dollars in Millions)

			Change over FY 2021 Actual	
FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Amount	Percent
$45.30	-	$51.00	$5.70	12.6%

Brief Description

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] OOI consists of a system of five arrays of instrumented platforms located at critical locations in the ocean, a fleet of autonomous underwater vehicles, 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 (RCA) in the ocean basin off the coast of Oregon and Washington.
- Two Coastal Arrays:
  - Endurance Array with one mooring line off the Washington coast and one off the Oregon coast.
  - Pioneer Array (PA) deployed 55 nautical miles south of Martha's Vineyard, MA.

Data from the OOI instruments are processed, stored, displayed, and served by the OOI cyberinfrastructure.[2]

Scientific Purpose

OOI provides the oceanographic research and education communities with continuous, interactive access to the ocean through an integrated network of observatories. Deployed in critical parts of the global and U.S. coastal ocean, OOI's instrumentation captures climate, carbon, ecosystem, and geodynamic changes on the time scales at which they occur. Data streams from the air-sea interface through the water column to the seafloor are available to educators and researchers in any discipline, making oceanography available to citizens and scholars who might never go to sea. Science themes for OOI include the ocean carbon cycle and its response to global change, ocean acidification, the impact of climate variability and ocean circulation, coastal ocean dynamics, ecosystem response, and the interplay of tectonically driven fluid flow on the carbon cycle, deep ocean ecosystems, and earthquakes.

[1] www.oceanobservatories.org/
[2] www.oceanobservatories.org/data-portal/

Status of the Facility

The RCA cabled digital still camera, redeployed in 2015 by the Canadian ROV ROPOS, lights up the active hydrothermal vent called El Gordo in the international District Hydrothermal Field, located at the summit of Axial Seamount nearly a mile beneath the ocean surface. *Credit: UW/NSF-OOI/CSSF*.

OOI began full operations in FY 2016. A maintenance cruise is conducted annually at each Global Array and the RCA and bi-annually at each Coastal Array to install refurbished and re-calibrated instruments and deploy replacement gliders. A subsample of the data collected on the instruments at the Global and Coastal Arrays is transmitted ashore in near-real time via satellite communications and all data are stored onboard the in-water instruments until retrieved during the maintenance cruises. The subsampling interval has a complex dependence on the parameter being measured as well as on the available bandwidth and battery lifetime. All data collected by the RCA are transmitted ashore in real-time via the underwater fiber-optic cable. The OOI cyberinfrastructure supports data handling, processing, and serving through the OOI data portal.

The OOI Facility Board (OOIFB, described below under External Governance) conducted a survey of users during FY 2019 and provided NSF with a report that was shared with Woods Hole Oceanographic Institution (WHOI), the managing organization, and the broader OOI team, comprising staff at each of the participating organizations. Report recommendations were used to inform the redesign of the OOI data portal user interface and the OOI website. The OOI team continues strong efforts to engage the community of scientific users, including a hybrid Town Hall and a virtual booth at the Fall 2021 American Geophysical Union meeting in New Orleans, LA.

NSF is collaborating with the science community on the relocation of the PA. The PA was originally planned to be relocated every five years to a new region of scientific interest. It has now been in place since 2016, and by working together with the stakeholders through a series of Innovation Labs, NSF has decided the new location of the PA will be in the Mid-Atlantic Bight region-the coastal area roughly from Massachusetts to North Carolina. The relocation efforts will be conducted in three phases: 1) Planning: July 2021 – April 2022; 2) Engineering: May 2022 – December 2022; and 3) Implementation: January 2023 – April 2024. The PA will be deployed in its new location and configuration by mid-2024.

<u>Summary of COVID-19 Impacts</u>

COVID-19 has impacted the OOI team by limiting the access of team members to the laboratories required for equipment refurbishment activities. In addition, planned at-sea marine infrastructure recovery and deployment activities have been limited due to requirements for personnel testing and isolation before embarking on the ships. The number of OOI team members embarked on the ships for the maintenance cruises was reduced to meet requirements to mitigate the potential spread of COVID-19. Despite the limitations, in 2021 the OOI team was able to conduct maintenance cruises for all of the arrays and thereby significantly mitigated the potential for loss of valuable in-water infrastructure. There were some limited instances in 2021 where reduced battery power required adjustments to the instrument sampling rates, resulting in reduced data flow.

Meeting Intellectual Community Needs

The overarching scientific themes of OOI, developed in close collaboration with and in response to the needs of the science community, span six multi-disciplinary domains, with each theme incorporating 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.
- *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 modify the mineralogy of oceanic crust and sediments, lead to the formation of hydrothermal vents that support unique micro- and macro-biological communities, can form economically-important mineral deposits, and concentrate 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 remains 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 is largely unexplored.

The science community is continuing its use of the OOI data through downloads of both raw data and derived products. In October 2020, OOI launched a new data discovery tool, Data Explorer, designed based on input from the science community, that allows users to explore, use, and visualize OOI data in new ways that will help advance understanding of the ocean, its processes, and how it is changing.

Feedback from users in the scientific community has been positive, and both the number of users and amount of downloaded data have increased in FY 2022.

Governance Structure and Partnerships

NSF Governance Structure

OOI is managed and overseen by a two-person team in OCE that receives advice and oversight support from BFA, the Office of the General Counsel, the Office of Legislative and Public Affairs, CISE, and the Large Facilities Office.

External Governance Structure

A new cooperative agreement for O&M of OOI started in FY 2019 with WHOI as the awardee. The OOI program director at WHOI is responsible for overall operations and maintenance, including data management, and serves as the Principal Investigator on the award from NSF. WHOI has subawards with three Implementing Organizations:

- Oregon State University (OSU) – Endurance Coastal Array and the OOI Cyberinfrastructure Data Systems Center
- University of Washington – RCA

The OOIFB, established by NSF in FY 2017, comprises ocean science community representatives and is charged with providing independent input and guidance to NSF regarding the management and operation of OOI. The OOIFB assists in the process of communicating the community science use perspective to NSF and to the project teams involved in deploying and operating OOI. A subcommittee of the OOIFB called the Data Systems Committee (DSC) evaluates and recommends improvements to the data services policies and practices of OOI that will lead to more efficient and effective scientific use of OOI data. The DSC will be conducting a follow-up to the FY 2019 community survey in FY 2022 to gather updated information from the science community on the utility of the OOI data portal.

Coastal Endurance Surface Buoy with sea lions. *Credit: Coastal Endurance Array Team, OSU.*

Funding

Total Obligations for OOI
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	ESTIMATES[1] FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Operations & Maintenance	$45.30	-	$51.00	$51.00	$51.00	$51.00	$51.00	$51.00

[1] Outyear estimates are for planning purposes only. The current cooperative agreement ends September 2023.

The FY 2023 Request includes $51.0 million for OOI, with an increase above FY 2021 planned to continue the recapitalization of the primary in-water infrastructure. The projected cost for recapitalization of the OOI facility is $8.5 million and includes the planned replacement of the G2 ocean and coastal gliders, with upgraded vehicles. Additional upgrades for OOI will support near-real time collection, analysis, and distribution of the OOI data to the public through cyberinfrastructure and data user portal.

Reviews

A mid-award review was conducted in November 2020 and covered all aspects of the OOI Program including: Management, Refurbishment, Deployment and Recovery, Community Engagement, Cyberinfrastructure, and Science Products.

In its report, the review panel commented: "The Panel unanimously recommends that the NSF renew the contract [executed as a cooperative agreement] with WHOI to operate the OOI infrastructure. We find that the current project team is maintaining and operating the infrastructure in an effective manner and has successfully managed operational difficulties and budgetary uncertainties. The Program has successfully engaged science users to build the Program's platforms and data into proposals for new projects. Observations from OOI are now appearing in the scientific literature at a rate comparable to other large geoscience facilities. The OOI has already supported transformational science and continues to serve as the foundation for future discoveries by the scientific community. It is also in an excellent position to advance engineering and technology needed for ocean exploration using remote observatories."

NSF completed a tailored Business Systems Review (BSR) of the WHOI OOI Program in October 2021. The BSR Team determined that the administrative business systems supporting the OOI facility are in alignment with federal regulations and meet compliance requirements. The report noted some areas that could be further strengthened to better meet NSF's expectations. These findings have been acknowledged by the Awardee institution and will serve as agenda items in future Annual Reviews.

Renewal/Recompetition/Termination

NSF completed the process of recompeting the O&M award through an open, merit-based external peer-review process, resulting in an award to WHOI as the Program Management Office, which started October 1, 2018 and runs through September 30, 2023. NSF is evaluating the inputs received from the mid-award performance review and the BSR with an expectation of making a decision whether to renew or recompete the O&M award in early 2022. Currently there are no plans for divestment of this facility.

SEISMOLOGICAL FACILITY FOR THE ADVANCEMENT OF GEOSCIENCE (SAGE) $23,370,000 +$1,070,000 / 4.8%

Seismological Facility for the Advancement of GEosciences Funding
(Dollars in Millions)

FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Percent
$22.30	-	$23.37	$1.07	4.8%

Brief Description

The Seismological Facility for the Advancement of Geoscience (SAGE) is a distributed, multi-user facility that enables a diverse principal investigator (PI) community to make advances in understanding Earth processes that would otherwise not be possible, through broad access to seismic instrumentation, field training and support, and data services. SAGE provides the development, deployment and operation of modern digital seismic instrumentation and related geophysical instrumentation, including magnetotellurics and infrasound. The facility operates a global network of seismic stations; provides field and technical resources; supports data archiving, quality control, and distribution; and provides education and outreach activities that serve a wide range of audiences. SAGE deploys geophysical instruments globally—on the land, including in polar regions, and under the oceans.

Scientific Purpose

SAGE data and services advance fundamental studies in earthquake and fault processes, Earth structure and evolution, volcanoes and magmatic systems, glacier and ice sheet dynamics, and near-surface Earth processes, like landslides, hydrology, and sedimentation. Data from SAGE are also used for studies of solid earth geohazards research, as well as monitoring of natural and anthropogenic hazards, such as global real-time earthquake monitoring, and nuclear test ban verification.

Status of the Facility

SAGE is currently in year four of a five-year award, and the capabilities provided by the facility have evolved based on input from a series of community engagement activities held in 2015, including an NSF-sponsored workshop entitled "Future Seismic and Geodetic Facility Needs in the Geosciences".[1] The Division of Earth Sciences (EAR) in GEO continues to evaluate NSF's geophysical facilities to best enable emerging research directions. In 2018, EAR commissioned a National Academies of Science, Engineering, and Medicine-led decadal survey that identified the top research priorities for the Earth sciences for the next decade. Released in July 2020, *A Vision for NSF Earth Sciences 2020-2030: Earth in Time*[2] reaffirmed the importance of NSF's seismic and geodetic facilities in advancing Earth science research over the next decade.

[1] www.iris.edu/hq/files/workshops/2015/05/fusg/reports/futures_report_high.pdf
[2] www.nap.edu/catalog/25761/a-vision-for-nsf-earth-sciences-2020-2030-earth-in

As part of the decadal survey process, a workshop entitled *Management Models for Future Seismological and Geodetic Facilities and Capabilities* was held to review the strengths and weaknesses of different management models for NSF geophysical facilities.[3] Following the release of the workshop report EAR announced that, at the time of the next competition for their management and operation, the current SAGE and Geodetic Facility for the Advancement of GEoscience (GAGE) facilities would be consolidated into a single facility with a single operator.[4]

In FY 2020, after announcement of the consolidated facility, GEO commissioned a portfolio review from a subcommittee of its Advisory Committee to inform planning for a consolidated geophysical facility. The portfolio review is also an important input to an ongoing effort to plan seismic research and related infrastructure in the U.S. over the next decade, so that NSF's geophysical facility will address the science priorities highlighted in the decadal survey. Additionally, the portfolio review report, which was completed in FY 2021, emphasizes the importance of developing partnerships in support of elements of SAGE and GAGE that are mission critical for other Federal agencies. EAR is working to define the best path forward for a future facility and undertaking efforts to expand existing federal partnerships.

Summary of COVID-19 Impacts

SAGE has continued to operate remotely during the COVID-19 pandemic, with most staff teleworking and data continuing to flow. Restrictions on travel and social distancing precluded decommissioning and removal of the Alaska Transportable Array (ATA) as had been planned during 2020. Instead, ATA operated in a "bare-bones" capacity and was removed in 2021.

Meeting Intellectual Community Needs

SAGE users include scientists who perform research using instruments and/or data provided via SAGE; educators who make use of teaching materials and training made available via SAGE; other Federal agencies and international groups that make use of resources and/or data provided via SAGE for multiple operational purposes; and interested members of the public and private sector.

SAGE users can access data and many educational products via the internet at no cost. Scientists making use of equipment, training, and other resources provided by SAGE typically are funded by awards from NSF, the U.S. Geological Survey (USGS), and other agencies. NSF-sponsored users are usually supported by EAR, the Division of Ocean Sciences (OCE), or OPP.

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, Data Services, and Education and Public Outreach.

Demand remains high for data, equipment, and other resources provided by SAGE. In fiscal year 2021:

[3] www.nap.edu/catalog/25536/management-models-for-future-seismological-and-geodetic-facilities-and-capabilities
[4] www.nsf.gov/pubs/2020/nsf20037/nsf20037.jsp

- The total amount of data downloaded from the SAGE Data Management Center increased by 11percent compared to the same period in FY 2020.
- At least 70 field experiments used equipment and support provided by SAGE worldwide; and
- More than 150,000 classroom activities were downloaded by K-16 educational projects.

Governance Structure and Partnerships

NSF Governance Structure
SAGE, together with GAGE, is overseen by a single Integrated Project Team (IPT) whose charge is to: 1) establish a collaborative team with a broad spectrum of expertise and perspective to help address current facility challenges and identify potential barriers to project success; 2) ensure effective and timely communications regarding facility activities and issues across NSF organizations by sharing knowledge and information on a regular and recurring basis; and 3) provide a formal mechanism to coordinate agency-wide oversight, take effective action, and remain accountable in support of program activities.

The IPT membership includes a core group consisting of the SAGE and GAGE managing program officer (PO), a representative from the Division of Acquisition and Cost Support, and a liaison from the Large Facilities Office. The GAGE and SAGE PO serves as chair of the IPT. The IPT will remain active through the planned five-year duration of the GAGE and SAGE awards. The IPT chair is responsible for uploading all IPT documentation into the official electronic records for the GAGE and SAGE awards. The IPT may periodically be assisted by other NSF staff as expertise is needed (e.g., Office of the General Counsel staff, Office of the Director staff).

External Governance Structure
SAGE is managed and operated by the Incorporated Research Institutions for Seismology (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, who collectively elect the nine members of the IRIS Board of Directors. 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.

Partnerships and Other Funding Sources
The core SAGE facility is managed for NSF by IRIS, under a single award overseen by EAR. IRIS has received funding under the SAGE award for additional activities, including support for specific PI-driven research in Antarctica, organization of relevant workshops, and operation of regional seismic networks.

Besides its role in providing the observational data essential for basic Earth science research, SAGE also plays a significant role providing real-time seismic data to USGS and the National Oceanic and Atmospheric Administration for global earthquake, volcano, and tsunami monitoring, and international seismic monitoring of compliance with the Comprehensive Test Ban Treaty. The Global Seismographic Network (GSN) component of SAGE is managed as a partnership among USGS, NSF, and IRIS.

SAGE is heavily involved in partnership activities, many international in nature. Installation and operations of the GSN have put IRIS in contact with scientists, as well as government and non-government organizations, around the world. Many international GSN stations are designated as the official stations for nuclear test ban treaty monitoring in their host countries. SAGE also provides multi-use resources for other government agencies that have responsibilities for development of a nuclear test ban monitoring capability and for monitoring global seismicity. For these purposes, agencies in partnership with NSF have provided substantial support for accelerated development of the GSN, shared operation and maintenance of the GSN, and accelerated development of the Portable Seismology Instrument pool.

Funding

Total Obligations for SAGE

(Dollars in Millions)

	FY 2021	FY 2022	FY 2023	ESTIMATES[1]				
	Actual	(TBD)	Request	FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
SAGE O&M	$22.30	-	$23.37	$23.37	TBD	-	-	-
GAGE O&M	14.56	-	14.55	14.55	TBD	-	-	-
Consolidated Facility O&M[2]	-	-	-	-	TBD	TBD	TBD	TBD
Total	**$36.86**	**-**	**$37.92**	**$37.92**	**TBD**	**TBD**	**TBD**	**TBD**

[1] Outyear estimates are for planning purposes only. The current cooperative agreement ends September 2023.

[2] NSF is currently planning for GAGE and SAGE to be consolidated into a single geophysical facility in FY 2025.

NSF is currently implementing recommendations from the 2019 and 2020 management reviews. These include innovating SAGE's portable sensor pool to include additional nodal instruments for studies of processes in Earth's near surface, moving data services for the Facility to the cloud and recapitalization of aging instrumentation. A pilot cloud service program was initiated in 2020 in partnership with GAGE and the program plans to expand this capability over the existing award period. The program is evaluating different strategies and scales of aging instrumentation and plans to phase in recapitalization over the existing award period.

Reviews

NSF externally reviews components of the SAGE facility on an annual basis. NSF conducted a full management review of SAGE in September 2021, and the panel commended IRIS for its strong overall performance in operating and maintaining SAGE. NSF reviewed the SAGE instrumentation services programs in late June 2020 and the data services programs in September 2019. Both reviews noted the outstanding management and the critical services these programs provide to the research community. As per the reviews' recommendations, EAR, in collaboration with SAGE, GAGE and the NSF Office of Advanced Cyberinfrastructure, is implementing a pilot program to move facility data services to the cloud. NSF plans to conduct a management review of the education and outreach program in FY 2022.

Renewal/Recompetition/Termination

The previous SAGE award is in a no-cost extension period to complete activities associated with ATA. The divestment of ATA began in FY 2020 and was completed at end of FY 2021. Final project closeout, including warehouse cleanout and equipment repairs, is underway and expected to be completed in the first half of 2022.

In 2020, NSF announced that it is preparing for a competition for a future cooperative agreement to support a single, unified geophysical facility as the successor to SAGE and GAGE. NSF envisions that a successor facility will provide access to a suite of geophysical instrumentation, data services, and education and outreach capabilities that sustain scientific progress and address future opportunities to advance understanding of Earth processes. NSF plans to evolve the different components of GAGE and SAGE through the competition for the unified facility to enable the community to advance the scientific priorities in the *Earth in Time* decadal survey. NSF is considering the recommendations contained in the portfolio review, as well as the interagency context in which the unified facility will operate, to formulate a strategy for continued support of this important community research resource. Divestment is not being considered at this time.

While the SAGE award was initially planned to end in 2023, NSF announced in a Dear Colleague Letter (NSF 21-097)[5] issued in June 2021 that it will extend the current awards for operations of both SAGE and GAGE to ensure continuity of services until 2025. This extension will allow NSF to work with agency partners to thoughtfully respond to the recommendations in the portfolio review.

[5] www.nsf.gov/pubs/2021/nsf21097/nsf21097.jsp?org=EAR

FEDERALLY FUNDED RESEARCH AND DEVELOPMENT CENTERS (FFRDCS)

GREEN BANK OBSERVATORY (GBO) $10,830,000
+$1,930,000 / 21.7%

Green Bank Observatory Funding
(Dollars in Millions)

			Change over FY 2021 Actual	
FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Amount	Percent
$8.90	-	$10.83	$1.93	21.7%

Brief Description

GBO is a major NSF research facility and a 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 radio transmissions are restricted by law. Having telescopes within this quiet zone allows detection of faint astronomical signals that would otherwise be overwhelmed by anthropogenic radio signals.

Scientific Purpose

The main scientific instrument at GBO is the 100-meter Robert C. Byrd Green Bank Telescope (GBT), which became fully operational in 2002. 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 that continues to enable important advances in virtually all areas of modern astrophysics, including Solar System and planetary astronomy; star formation and evolution; interstellar physics and chemistry; pulsar studies of long-wavelength gravitational waves; physics of black holes, neutron stars, and other compact objects; and galaxy formation and evolution. GBT provides excellent response to point sources, such as pulsars, and as a filled aperture, it also offers very high sensitivity to faint extended emissions of the kind associated with comets, molecular clouds, and distortions of the cosmic microwave background. GBT is complementary to and synergistic with interferometric arrays, such as the Karl G. Jansky Very Large Array (VLA), the Very Long Baseline Array (VLBA), and the Atacama Large Millimeter/submillimeter Array (ALMA). It also plays a critical supporting role as a highly sensitive element of very long baseline interferometry, achieving the highest angular resolution, as well as a bistatic radar receiver for rapid and sensitive imaging of near-Earth objects and asteroids. GBT's focal plane is ideal for rapid, wide field imaging using multi-pixel cameras.

Status of the Facility

GBT observations have continued remotely throughout the COVID-19 pandemic period. Public activities, meetings, and conferences have been paused or migrated to remote formats since mid-March 2020. Observer training workshops and scientific community workshops are also continuing remotely. A phased return to on-site work is occurring and being closely monitored; currently most of the staff are on site, with physical distancing, sanitization, and personal protective equipment measures in place. Education and public outreach activities, and associated revenues, have been impacted severely, due to the closing of the Green Bank Science Center and the lodging facilities for visitors.

GBO conducts regular inspections of and maintenance on numerous components of its telescopes and site infrastructure. The last full structural inspection of the GBT by an independent engineering firm was completed in 2021. That report identified key areas for future maintenance work and upgrades. Additional inspections are scheduled in 2024.

Meeting Intellectual Community Needs

Approximately 500 scientists use GBT each year for research that spans virtually every field of modern astrophysics. GBT is flexible and easy to use and can rapidly respond to new ideas from the scientific community. It is straightforward for a small group to build and install a new instrument on this world-class research facility. State-of-the-art instruments now under development in collaboration with university groups will keep GBT equipped with the latest technology. Graduate students using GBT gain vital hands-on experience with a major telescope, an increasingly rare opportunity and critical for their training.

In November 2021, the National Academies' report on the Decadal Survey of Astronomy and Astrophysics, "Pathways to Discovery (Astro2020),"[1] recommended ongoing support for three key capabilities: long term timing of pulsars, development of new instrumentation, and mitigation of radio-frequency interference. The GBT is already involved in these activities and is poised to play a key role in all three areas.

GBT is currently used for observations approximately 6,500 hours per year. Of these, approximately 4,500 hours are available as Open Skies, or NSF-sponsored observing time, and are allocated through community-based peer review. The "oversubscription rate", or the ratio of the Open Skies time requested to the time granted, has been in the range 2-3 since FY 2015. Non-open-skies time (about 2,000 hours) at GBT is provided to GBO partners (see Partnerships section below) who make significant financial contributions to facility operations.

GBO also conducts a variety of education and public outreach programs and activities that have impact regionally and across North America. The Green Bank Science Center enables these programs and activities with its auditorium, classrooms, and large exhibit hall, visited by nearly 50,000 people every year. Thousands of K-12 teachers and students participate in educational programs using the variety of radio telescopes available at GBO. Since the onset of the pandemic, much of GBO's education and public outreach programming has shifted online, including virtual visits and at-home educational activities, as well as biweekly Zoom webinars for its scientific community.

The scientific direction and operations of the Observatory are assessed through regular NSF reviews, input from various community workshops, and AUI governance and external advisory committee meetings. Development and upgrade efforts are driven by community needs and priorities, address

[1]www.nationalacademies.org/our-work/decadal-survey-on-astronomy-and-astrophysics-2020-astro2020

certain key recommendations of the NSF external merit review panel that evaluated the most recent renewal proposal, and align with strategic initiatives such as the NSF Windows on the Universe Big Idea. Thus, GBO is poised to address community needs and enable important advances in astronomy in the coming years.

Governance Structure and Partnerships

NSF Governance Structure

Oversight from NSF is provided by a program officer in the Division of Astronomical Sciences (AST), who 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 the General Counsel, as well as the Division of Acquisition and Cooperative Support and the Large Facilities Office within BFA. The MPS Facilities team, together with the NSF Chief Officer for Research Facilities, also provide high-level guidance, support, and oversight.

External Governance Structure

GBO is managed and operated through a cooperative agreement with AUI, a non-profit research management organization consisting of an Executive office overseen by a Board of Trustees, with input from several internal and external committees. 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.

Partnerships and Other Funding Sources

External contributions represent approximately 30-35 percent of the total operations budget of GBO. These contributions come mostly from non-federal partners, including Breakthrough Listen (BL),[2] the Gordon and Betty Moore Foundation,[3] and individual contracts for GBT observing time. The NSF-funded North American Nanohertz Observatory for Gravitational Waves (NANOGrav) Physics Frontiers Center also contributes to annual operations costs. Partnerships with BL and NANOGrav are anticipated to continue through 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.

[2] www.breakthroughinitiatives.org/initiative/1
[3] www.moore.org/

Funding

Total Obligations for GBO
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	ESTIMATES[1] FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Operations & Maintenance	$8.90	-	$9.12	$9.55	$9.55	$9.55	$9.55	$9.55
Special Projects[2]	-	-	$1.71	-	-	-	-	-
TOTAL	**$8.90**	**-**	**$10.83**	**$9.55**	**$9.55**	**$9.55**	**$9.55**	**$9.55**

[1] Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in FY 2024.

[2] Reflects additional funding for research infrastructure and O&M costs, including additional costs for repairs and maintenance.

NSF conducted a community-based review of the AST portfolio in response to a recommendation of the 2010 National Academies of Science, Engineering and Medicine Decadal Survey of Astronomy and Astrophysics.[4] In 2012, that portfolio review recommended divestment of GBT in order to sustain balance in the AST program.[5] NSF subsequently undertook a full environmental review of options for the future of GBO, culminating in NSF's July 2019 Record of Decision (ROD)[6] to pursue continued GBO operations with reduced NSF funding and increased partner contributions. Following the ROD, NSF awarded a new cooperative agreement to AUI for GBO O&M for the five-year period FY 2020-FY 2024. While GBO's total annual O&M costs are projected to remain stable to ensure continued effective operation of the facility, NSF's share should decrease as new viable funding partnerships and collaborations are developed. The current funding picture will be examined within the context of the most recent Decadal Survey, Astro2020, which highlighted the importance of ongoing support for the GBT for key activities described above

The FY 2023 request 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. This includes a GBO evaluation that is near completion, and includes replacement and fortification of the track and foundation, which are showing signs of degradation

Reviews

NSF conducts annual reviews of the program operating plan and reports, including external advice from community representatives. Recommendations from these annual reviews with external panelists are routinely used to inform GBO's operations planning and NSF's oversight thereof. Under the new cooperative agreement, annual reviews have been held in December 2020 and December 2021.

Renewal/Recompetition/Termination

NSF's current cooperative agreement with AUI for operations and management of GBO spans the five-year period October 1, 2019 – September 30, 2024. NSF plans to conduct a comprehensive review of GBO operations in the second half of the five-year reward to assess choices regarding renewal, competition, or divestment of the facility beyond FY 2024.

[4] www.nap.edu/catalog/12951/new-worlds-new-horizons-in-astronomy-and-astrophysics
[5] www.nsf.gov/mps/ast/portfolioreview/reports/ast_portfolio_review_report.pdf
[6] www.nsf.gov/mps/ast/env_impact_reviews/greenbank/greenbank_rod.jsp

Views showing the Green Bank Telescope in the Fall (left) as well as the unblocked aperture and fully steerable structure (right). *Credit: GBO/AUI.*

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH (NCAR) $116,200,000

+$12,100,000 / 11.6%

National Center for Atmospheric Research Funding
(Dollars in Millions)

FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
$104.10	-	$116.20	$12.10	11.6%

Brief Description

NCAR is an NSF-sponsored Federally Funded Research and Development Center devoted to service, research, and education in support of the atmospheric and related science research community. NCAR operates world-class observational facilities and computing infrastructure, conducts extensive in-house research, maintains vigorous programs of education, outreach, and the promotion of diversity, and cultivates extensive national and international collaborations. NCAR also carries out research and development on behalf of other organizations, most commonly other U.S. Government agencies.

Major NCAR facilities include the Mesa Laboratory in Boulder, CO; the recently renovated Research Aviation Facility in nearby Broomfield, CO; the NCAR-Wyoming Supercomputing Center in Cheyenne, WY; and the Mauna Loa Solar Observatory on Mauna Loa, HI.

Scientific Purpose

The NCAR mission is to understand the behavior of the atmosphere and related Earth and geospace systems; to support, enhance, and extend the capabilities of the university community and the broader scientific community, nationally and internationally; and to foster the transfer of knowledge and technology for the betterment of life on Earth. NCAR fulfills this mission with highly integrated programs organized around three overlapping primary areas of activity: cutting edge airborne and ground-based observational facilities, community weather and climate models with many thousands of users, and petascale high-performance computing. These are accompanied by a broad portfolio of programs supporting education, career development, public engagement, and increasing diversity in the geosciences. NCAR scientists also collaborate extensively with the academic, private, and government sectors. NCAR's programs are guided by the NCAR Strategic Plan, which emphasizes three overlapping priorities: 1) enhancing and building on NCAR's core strengths in fundamental research in the atmospheric and related sciences; 2) promoting integrated Earth System Science; and 3) advancing actionable science, to help address society's most pressing environmental challenges.

Status of the Facility

NCAR is operated for NSF by the University Corporation for Atmospheric Research (UCAR), a consortium of 120 member universities in the U.S. and overseas. Several significant infrastructure improvement projects have recently been completed, including a full overhaul of the primary heating and cooling systems at the Mesa Laboratory that will result in considerable increases in efficiency and reduced operating costs. A major renovation of the Research Aviation Facility at the Rocky Mountain Metropolitan Airport has provided new, state-of-the art laboratory, engineering, and technical space in support of the two NSF-owned, NCAR-operated research aircraft and the community of scientists and engineers that use them.

Mesa Lab. *Credit: Copyright University Corporation for Atmospheric Research (UCAR), by Carlye Calvin, licensed under a Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) License, via OpenSky.*

The installation of a powerful new supercomputer at the NCAR-Wyoming Supercomputing Center in FY 2022 will result in a more than threefold increase in the computing speeds available to users in the Earth System Science research community. The new system will be called 'Derecho' following a statewide naming competition among Wyoming school students.

Summary of COVID-19 Impacts

The majority of NCAR's programs have continued without interruption during the COVID-19 pandemic, with most community workshops, visitors' programs and other collaborations taking place remotely. Observational field campaigns involving NCAR's ground-based facilities and aircraft have, however, been severely impacted due to travel restrictions and other logistical challenges. These are now being resumed with appropriate COVID safety protocols, and it is anticipated that full operations will be possible by FY 2023.

Meeting Intellectual Community Needs

NCAR provides the user community with models, cyberinfrastructure, observing facilities, and collaborative opportunities, in addition to education, outreach, and training that are essential to the research community. FY 2021 highlights include:

- Every year, NCAR hosts a wide variety of community events including workshops, colloquia, conferences, symposia, and tutorials. In FY 2021, 95 events (600 individual sessions) were hosted: 31 workshops, 54 tutorials, five conferences, and five colloquia. These events reach an estimated total audience of 25,000 people.
- Students, scientists, engineers, weather forecasters, and other professionals from around the country and the world visit NCAR to collaborate with scientific, educational, or technical staff. They participate in community workshops and strategic discussions, conduct independent research, and participate on and/or oversee student, post-doctoral and professional projects. In FY 2021, NCAR hosted 220 visitors from 104 different institutions in 37 U.S. states and 15 countries.
- The Weather Research Forecast Model (WRF) continued to have strong user interest, with cumulative WRF registrations over 56,000 as of the end of FY 2021, and new model registrations averaging over 4,000 per year for the past three years. NCAR hosted the 2021 WRF/MPAS (Model for Prediction Across Scales) Users' Workshop (virtual) in June 2021 with 543 registered participants. NCAR also conducted online virtual WRF tutorials in January and July 2021, capped at 60 students each.

- The Community Earth System Model (CESM) continues to embrace open and transparent model development practices. As such, all model versions are readily available to the broader community on GitHub. This practice replaces the need for frequent model releases.
- The 26th annual CESM Workshop was held virtually in June 2021, bringing together researchers from around the world, including graduate students and early career scientists from universities and federal laboratories. It continues to be the only Earth System modeling workshop in the world, offering new cross-cutting working groups in addition to the regular CESM working groups. This year's workshop had 667 participants—the largest attendance in the workshop's history.
- NCAR's 534-petaflop high-performance computer (Cheyenne) and its GLobally Accessible Data Environment (GLADE) were used by more than 1,900 individuals at over 275 universities. During the year, daily utilization of the primary NCAR supercomputer averaged 84 percent (with 97.4 percent availability). In addition, NCAR maintains and provides simplified access to multi-terabyte datasets relevant to the atmospheric research community. The NCAR Research Data Archive (RDA) delivered more than 7.2 PB of data to 13,500 unique users. In FY 2021, 270 peer-reviewed articles and books cited RDA data sets.
- In FY 2021, pandemic travel restrictions continued to restrict field projects, with several planned campaigns being reduced or postponed. The NCAR-operated NSF Gulfstream G-V flew 121 research hours in support of three local airborne campaigns. In addition, NCAR provided lidar and radar data to a small university-led educational campaign in Fort Collins, CO. NCAR observing facilities staff supported eight universities, involving 12 investigators and 15 students.
- In response to the pandemic, NCAR hosted a biweekly virtual workshop, "Elements of a GEO REU" for PIs, and 10 career development workshops for 16 summer REU sites reaching 250 students.
- With additional funding from NSF, early career faculty, internship and postdoctoral fellowships were extended, and some additional positions supported to reduce disruptions to the careers of these groups of researchers particularly affected by the pandemic.

Governance Structure and Partnerships

NSF Governance Structure

NSF oversight is provided by a team of program officers in the Division of Atmospheric and Geospace Sciences (AGS) working cooperatively with staff from GEO, BFA, and the Office of the General Counsel. Within BFA, the Large Facilities Office and Division of Acquisition and Cooperative Support provide advice and guidance to program staff and assist with agency oversight and assurance. Programmatic oversight and a major part of NCAR's funding is provided by AGS. The award with UCAR, through which NCAR is managed and funded, contains terms and conditions that support AGS's oversight of the NCAR program and includes requirements for UCAR's management of the Center. These include a provision that UCAR submit for AGS approval an annual program operating plan that provides details about how resources will be used in that fiscal year. In addition, NCAR summarizes its past year's accomplishments in an annual scientific report and UCAR must report annually on its management of NCAR. Close coordination between AGS, UCAR, and NCAR helps ensure that scientific and facility priorities remain consistent with those of NSF. AGS program officers and management interact regularly with NCAR leadership and staff at all levels to ensure that NCAR's services and facilities support the evolving needs of PIs funded through AGS core programs. Additional oversight is applied for significant infrastructure upgrades, NCAR-managed community field campaigns, and other complex projects. While project oversight typically involves monthly videoconferences attended by relevant UCAR/NCAR personnel, the core NSF NCAR Integrated Project Team and other program staff as appropriate, frequent ad hoc interactions by e-mail, telephone, and video conference form the basis of AGS's oversight of NCAR and UCAR.

The NSF Gulfstream V research aircraft. *Credit: Copyright, University Corporation for Atmospheric Research (UCAR), by Chad Slattery, licensed under a Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) License, via OpenSky.*

External Governance Structure

As a consortium of universities and the manager of the national center, UCAR has the responsibility to engage the atmospheric and related sciences community, including universities and the broader scientific community, in its governance, planning and program implementation. Strong involvement of the external community is essential for effective NCAR science and facility planning, especially on longer time scales.

Formal mechanisms by which NCAR and UCAR receive community advice and input include a dedicated subcommittee of the UCAR Board of Trustees; standing external advisory committees for each NCAR laboratory, the NCAR Director and certain targeted initiatives; advisory panels for the allocation of computational and observational resources; governance bodies for the community models; and *ad hoc* panels providing advice on matters such as technical requirements for the next supercomputing upgrade. NSF staff often attend these meetings as observers, receive their reports, and discuss their findings, recommendations, and any necessary actions with NCAR/UCAR management. NSF may supplement this information with other activities such as community workshops or studies conducted by the National Academies of Sciences, Engineering, and Medicine.

Partnerships and Other Funding Sources

To support, enhance, and extend the capabilities of the university community and the broader scientific community, NCAR leverages NSF support with funding provided by other federal agencies and non-federal sources. In addition to NSF's $104.10 million investment in FY 2021, NCAR received approximately $40.80 million in support from other federal agencies, primarily the National Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, the Department of Energy, the Department of Defense, and the Federal Aviation Administration. NCAR's non-Federal sources of income included State and local governments, universities, commercial organizations, and non-profits. This additional funding extended NCAR's core research into a wide variety of user-driven applications, such as wildfire management, road and aviation safety, public health, and renewable power generation.

Funding

Total Obligations for NCAR

(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	ESTIMATES[1] FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Aircraft Support	$11.07	-	$12.50	$12.50	$12.50	$12.50	$12.50	$12.50
Computational Infrastructure	34.28	-	38.20	38.20	38.20	38.20	38.20	38.20
Other Facility Support	23.35	-	26.00	26.00	26.00	26.00	26.00	26.00
Research and Education Support	35.40	-	39.50	39.50	39.50	39.50	39.50	39.50
TOTAL	**$104.10**	**-**	**$116.20**	**$116.20**	**$116.20**	**$116.20**	**$116.20**	**$116.20**

[1] Outyear estimates are for planning purposes only. The current cooperative agreement ends September 2023.

Annual support for NCAR is determined by NSF's priorities, the amount authorized by the NSB, and the availability of funds. Most major recurrent infrastructure costs are accommodated within this core funding—including periodic technology upgrades to the NCAR supercomputers, periodic aircraft inspections and maintenance, and buildings upgrades and maintenance. Additional funding may be provided for specific projects, such as the renovation of the NSF-owned NCAR Research Aviation Facility. Supplemental funding was also provided in FY 2021 to help mitigate the impacts of the pandemic on postdoctoral researchers and early career staff. Additional funding requested in FY2023 would support infrastructure upgrades to reduce NCAR's Carbon footprint; new initiatives in computational facilities and research; and an increased emphasis on actionable research to improve the nation's resilience to climate change and extreme events such as wildfire, drought, floods, and hurricanes.

Reviews

NSF conducts a comprehensive review of NCAR's science programs, facilities, and management at the mid-point of each five-year award. The 2021 review comprised four site visits by teams of 10-12 external experts. The visit focuses were: (1) Observing Science and Facilities; (2) Computation and Data Science and Facilities; (3) Community Modeling and Data Assimilation and (4) Management. The first three visits occurred between May and June 2021, and the fourth was held in August 2021. NSF is working with NCAR's management to review the site visit findings and incorporate them into NCAR's program plans. A Business Systems Review is planned during FY 2022.

Renewal/Recompetition/Termination

The current five-year award to manage and operate NCAR was made to UCAR with a start date of October 1, 2018. This award may be extended by an additional five-year term subject to satisfactory performance by the awardee. A determination of satisfactory performance will be informed primarily by the findings of the recent comprehensive mid-term scientific and management reviews. If recommended, UCAR may be invited to submit a renewal proposal for a second five-year term that will be reviewed by an external panel.

NATIONAL RADIO ASTRONOMY OBSERVATORY (NRAO) $98,110,000

-$100,000 / -0.1%

National Radio Astronomy Observatory Funding [1]

(Dollars in Millions)

FY 2021 Actual[2]	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
$98.21	-	$98.11	-$0.10	-0.1%

[1] Funding includes the base operations for NRAO and ALMA.

[2] Includes $10.08 million for ngVLA development.

Brief Description

NRAO is a Federally Funded Research and Development Center that conceives, designs, builds, operates, and maintains radio telescopes used to study all types of astronomical objects, from bodies in our own Solar System to galaxies in the distant Universe. Operating synergistically with optical, infrared and x-ray telescopes, NRAO's state-of-the-art, general-purpose facilities enable discovery over a broad range of key problems in modern astrophysics. NRAO operates the North American component of the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile, the Karl G. Jansky Very Large Array (VLA) near Socorro, New Mexico, the Very Long Baseline Array (VLBA) throughout the Continental United States, Hawaii, and the U.S. Virgin Islands, and the Central Development Laboratory (CDL) in Charlottesville, Virginia.

Scientific Purpose

Since 1956, NRAO has provided world-class radio telescope facilities for use by the U.S. and international scientific community. NRAO also provides both formal and informal programs in education and public outreach for teachers, students, the general public, and the media. A brief overview of NRAO's facilities and the science they enable is given below.

<u>Atacama Large Millimeter/submillimeter Array</u>

ALMA is the world's preeminent facility for millimeter- and submillimeter-wave astronomy, providing one to two orders of magnitude improvement over previous facilities in all areas of millimeter- and submillimeter-wave observations, including sensitivity, angular resolution, and image fidelity. It consists of 66 precision 12-meter and 7-meter antennas located at 5,000 meters elevation in the Atacama Desert in Chile. ALMA is a general-purpose facility enabling transformational research into the physics of the cold Universe, regions that are optically dark but shine brightly in the millimeter/submillimeter portion of the electromagnetic spectrum. Within the broad range of science accessible with ALMA, the top-level objectives include imaging the redshifted dust continuum and molecular-line emission from evolving galaxies as early as a redshift of z~10 (only 500 million years after the Big Bang), determining the chemical composition and dynamics of star-forming gas in normal galaxies like the Milky Way but at z~3 (about 4 billion years after the Big Bang), and measuring the gas kinematics in young disks in nearby molecular clouds and detecting the tidal gaps induced by planet formation.

Karl G. Jansky Very Large Array

The VLA is the world's leading centimeter-wavelength radio telescope, consisting of 27 identical 25-meter antennas separated by up to 35 km on the Plains of San Agustin in New Mexico. Following a major upgrade completed in early 2013, the VLA provides one to three orders of magnitude improvement over all previous performance aspects except angular resolution. The VLA is one of the world's most sensitive and flexible instruments for centimeter-wavelength continuum and imaging spectroscopy over a very large range of wavelength (0.6 to 30 cm, plus narrow windows at 90 cm and 400 cm). Among a broad range of scientific capabilities, the VLA addresses four primary science themes: studying the formation and evolution of stars, galaxies, and active galactic nuclei; following the rapid evolution of energetic phenomena; imaging young stars and massive black holes in dust-enshrouded environments; and measuring the strength and topology of cosmic magnetic fields.

Very Long Baseline Array

The VLBA is the world's preeminent facility for high-precision astrometric studies and high-resolution imaging. The VLBA includes 10 identical 25-meter antennas that can work together as a continent-sized telescope with baselines up to 8000 km. The VLBA is unique in its ability to do extremely high-angular-resolution imaging and spectroscopy in the wavelength range of 3 mm to 30 cm and can carry out astrometry with precision that is about two times better than that achieved by the European Gaia spacecraft for stars. The VLBA enables a wide range of science returns including mapping the structure and dynamics of the Galaxy, searching for planets around low-mass stars, accurately measuring the masses of supermassive black holes, precisely determining the expansion rate of the Universe, determining Earth orientation parameters, and improving the International Celestial Reference Frame. The U.S. Naval Observatory (USNO) relies on VLBA data for mission-critical measurements of Earth orientation, data necessary for accurate functioning of GPS.

Central Development Laboratory

The CDL supports NRAO's existing facilities, and provides technology and expertise needed to build the next generation of radio astronomy instruments and facilities. The CDL is a world leader in designing, developing, and producing enabling technologies, including low noise amplifiers, millimeter and sub-millimeter detectors, optics, and electromagnetic components such as feeds and phased arrays, digital signal processing, and new receiver architectures. CDL produces these components not only for NRAO's telescopes, but also for the worldwide astronomical community. CDL develops techniques for producing higher quality, lighter weight, and more cost-effective components, and supporting rapid prototyping and more efficient R&D activities.

Status of the Facility

COVID-19 impacts in 2020 varied for the facilities under NRAO's responsibility. During the earliest stages of the pandemic, all staff worked from home. From approximately June 2020, staff for North American facilities worked onsite. The VLA and VLBA never ceased science operations but establishing procedures for safe operations delayed activities somewhat early in the pandemic. ALMA science observations were halted at the beginning of the pandemic in March 2020 but were resumed as of March 17, 2021.

Meeting Intellectual Community Needs

NRAO's observing facilities for radio astronomy are available to any qualified researcher, regardless of affiliation or nationality, based on merit-reviewed scientific proposals. NRAO facilities annually serve over 2500 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 is among the top three astronomical facilities worldwide for the highest publication citation numbers.

NRAO facilities continue to enable a remarkable array of ground-breaking discoveries, from the detection of a massive flare from our nearest stellar neighbor, to imaging the magnetic field around the supermassive black hole and associated jet in galaxy M87, to the detection of unusually massive and surprisingly mature galaxies and black holes in the very early universe. Even in a pandemic year, the VLA, VLBA, and ALMA continued to produce significant scientific discoveries. For example, using data from VLA sky surveys twenty years apart, astronomers were able to detect jets of relativistic charged particles from near supermassive black holes that had been launched during that interval, providing insight into how these important and enigmatic phenomena are created. Closer to Earth, ALMA showed for the first time that volcanoes are responsible for the sulfur dioxide gas in the atmosphere of Jupiter's moon, Io. These observations allow the differentiation of different processes on the surface of Io, and how they affect its atmosphere. Astronomers using the VLBA made the first direct geometric measurement of the distance to a magnetar within the Milky Way galaxy. These observations will enhance our understanding of one of the most extreme and magnetic objects in the universe and help determine whether magnetars are responsible for the enigmatic "Fast Radio Bursts". 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 November 2021 the National Academies released the report from its Decadal Survey for Astronomy and Astrophysics, *Pathways to Discovery* (Astro2020)[1]. Many of the activities and initiatives being led by NRAO support recommendations in Astro2020. The report identifies time-domain astronomy (TDA) and multi-messenger astrophysics (MMA) as one of three scientific pillars ("New Messengers and New Physics") for the upcoming decade, and NRAO facilities provide access for radio observations of MMA events. NRAO is also continuing to lead development efforts for the next generation Very Large Array, a sensitive next-generation radio observatory also discussed in Astro2020.

Governance Structure and Partnerships

<u>NSF Governance Structure</u>

A program officer in the MPS Division of Astronomical Sciences (AST) 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 and NRAO Program Officer participate in the international ALMA Board and attend governance and advisory committee meetings for NRAO and its managing organization, Associated Universities Inc. (AUI). To address issues as they arise, AST has a dedicated Integrated Project Team that includes representatives from other NSF offices, such as the Office of the General Counsel, OISE, and the Division of Acquisition and Cooperative Support and the Large Facilities Office within BFA. The MPS

[1] www.nationalacademies.org/our-work/decadal-survey-on-astronomy-and-astrophysics-2020-astro2020

Facilities team and the NSF Chief Officer for Research Facilities also provide high-level guidance, support, and oversight.

External Governance Structure

NRAO is managed and operated through a cooperative agreement with AUI, a non-profit research management organization consisting of an Executive office overseen by a Board of Trustees, with input from several internal and external committees. AUI 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 members from NSF, AUI, and the U.S. community. 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.

Partnerships and Other Funding Sources

NRAO supplements NSF/AST support with funding provided by other NSF sources, other federal agencies, and non-federal 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 provides approximately 50 percent of the funding for the VLBA.

ALMA is supported by an international partnership, comprising the United States and its partners Canada and Taiwan ("North America" or NA), the European Southern Observatory (ESO), and Japan and its partners Taiwan and South Korea (East Asia (EA)). NA and ESO are equal (37.5 percent) partners and EA contribute 25 percent. Canada contributes approximately 2.72 percent of operations (i.e., 7.25 percent of the 37.5 percent NA share). Taiwan contributed about 4 percent of NA construction but contributes operations funding through the EA partnership.

International agreements establish the terms under which the ALMA partnership operates and define the roles of the ALMA Board, the regional funding authorities, their Executives, and the Joint ALMA Observatory (JAO). A revised international agreement, fully incorporating Japan in ALMA operations, was signed in December 2015. The international ALMA Board acts as a supervisory and regulatory body responsible for exercising oversight and budgetary and policy control. Board membership includes one or more representatives from NSF. The regional funding authorities (the "Parties") have each designated an Executive to carry out and manage tasks and responsibilities on behalf of the Parties. AUI is NSF’s Awardee for the O&M of NRAO and is the NA ALMA Executive. ESO serves as its own Executive. The EA ALMA Executive is the National Astronomical Observatory of Japan (NAOJ).

View of the Very Large Array. *Credit: NRAO/AUI/NSF.*

Funding

The program solicitation for NRAO O&M (including ALMA) identified a planning budget of approximately $863 million over a ten-year award period (FY 2017 – FY 2026), though the annual budget increased by about $3-$4 million following the reintegration of VLBA into NRAO in FY 2019.

Total Obligations for NRAO
(Dollars in Millions)

	FY 2021	FY 2022	FY 2023	ESTIMATES[1]				
	Actual	(TBD)	Request	FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
NRAO[2]	$49.53	-	$44.45	$42.81	$43.97	$45.19	$45.19	$45.19
Operations and Maintenance	*39.45*	-	*40.53*	*42.81*	*43.97*	*45.19*	*45.19*	*45.19*
Special Projects [3]	*10.08*	-	*3.92*	-	-	-	-	-
ALMA Operations	48.68	-	53.66	54.77	56.96	59.24	59.24	*59.24*
Operations and Maintenance	*48.68*	-	*50.63*	*54.77*	*56.96*	*59.24*	*59.24*	*59.24*
Special Projects [4]	-	-	*3.03*	-	-	-	-	-
Total	**$98.21**	**-**	**$98.11**	**$97.58**	**$100.93**	**$104.43**	**$104.43**	**$104.43**

[1] Outyear funding estimates are for planning purposes only and includes increases in cost due to local inflation. The current cooperative agreement ends in FY 2026.

[2] Operations funding for VLBA is included in NRAO total funding at $3.43 million per year.

[3] FY 2021 actual includes funding for the ngVLA program office. FY 2023 request includes special projects for research infrastructure and O&M costs, including additional costs for repairs and maintenance.

[4] Reflects additional funding for research infrastructure and O&M costs, including additional costs for repairs and maintenance.

The FY 2023 Request funds NRAO and the U.S. share of ALMA O&M costs, including ongoing support for education and public outreach programs as well as development programs such as planning for a next-generation centimeter wavelength facility ngVLA. Additional funding was provided to NRAO in FY 2021 in support for the ngVLA program office. The FY 2023 request includes additional funding for research infrastructure costs and O&M related to repairs and maintenance projects. Funding for special projects also includes additional deferred maintenance projects, upgrades necessary for the continued effective operations of the facility, such as replacement of observatory dome mechanisms, removal of possible asbestos-containing materials and fortification of telescope tracks. The execution of projects will be prioritized based on the outcome of ongoing facility condition assessments.

Reviews

NSF conducts annual reviews of the NRAO Program Operating Plan and strategic planning documents, ALMA operations, and the AUI Management Report. Recommendations from these annual reviews with external panelists are routinely used to inform NRAO's operations planning and NSF's oversight of the facility. A comprehensive management review was conducted in December 2021 by an external panel of experts.

Renewal/Recompetition/Termination

Following a solicitation issued in FY 2014, the O&M of NRAO, including VLA, North American contributions to ALMA, and associated development laboratories, administration, and management functions, was competed and the NSB authorized a 10-year award to AUI for the period October 1, 2016 - September 30, 2026. MPS plans to develop an analysis, per NSF policy, in 2024 for consideration by the NSF Director to either compete the management of NRAO, review and fund a renewal proposal from the current management entity, or to divest components of the facility through stewardship transition or other means.

NATIONAL SOLAR OBSERVATORY (NSO) $27,740,000

+$3,550,000 / 14.7%

National Solar Observatory Funding[1]
(Dollars in Millions)

FY 2021 Actual	FY 2022 TBD	FY 2023 Request	Change over FY 2021 Actual	
			Amount	Percent
$24.19	-	$27.74	$3.55	14.7%

[1] Includes operations for NSO and DKIST.

Brief Description

As a Federally Funded Research and Development Center, NSO is NSF's central institution for support of ground-based solar astronomy in the United States. Headquartered on the campus of the University of Colorado, Boulder, NSO provides leadership to the global solar astronomy community through operations of NSF's Daniel K. Inouye Solar Telescope (DKIST). DKIST is the largest and most advanced solar telescope on the planet, poised to answer fundamental questions in solar physics by providing transformative improvements over current ground-based facilities.

NSO also operates the NSO Integrated Synoptic Program (NISP), which consists of the Global Oscillations Network Group (GONG) facility and the Synoptic Long-term Investigations of the Sun (SOLIS) telescope. 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 NISP for use by individual researchers and other government agencies through the NSO Digital Library.

Scientific Purpose

The mission of NSO is to advance our knowledge of the Sun, both as an astronomical object and as the dominant external influence on the Earth, by providing forefront observational capabilities to the scientific research community. NSO operates a diverse fleet of ground-based optical and infrared solar telescopes and auxiliary instrumentation, allowing solar physicists to probe all aspects of the Sun, from the deep solar interior to the photosphere and chromosphere, and out to the outer corona and its interface with the interplanetary medium.

NSF's flagship solar telescope, DKIST, enables 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 and their impact on planets. Solar activity can affect life on Earth through phenomena generally described as space weather and may impact the terrestrial climate.

Other NSO assets also provide data to space weather researchers in their efforts to understand solar eruptions and their effect upon the Earth, and to apply that knowledge to the protection of satellites, astronauts, land-based power systems, and Earth's climate. GONG operations are a critical element of operational space weather prediction and provide data enabling refinement of forecasting models for solar activity.

Status of the Facility

Although delayed due to impacts of the COVID-19 pandemic, construction of DKIST at the summit of Haleakalā on Maui, Hawaiʻi, was completed in November 2021. The DKIST operations commissioning phase (OCP) began in December of the same year. Science observations from the first peer-reviewed proposal cycle will be made through the first half of CY 2022, including the possibility of one or more coordinated observing campaigns with other observatories. The second call for observing proposals is expected in the latter half of CY 2022. Throughout 2022, there will also be considerable time for the development, testing and verification of instrument configurations and combinations on the telescope. The anticipated start of steady-state observations is FY 2023. The DKIST Data Center is in Boulder, Colorado at the NSO headquarters where the observational data will be curated and made publicly available after an initial proprietary period.

NSO has been in the process of transitioning away from its two primary user facilities at Kitt Peak, Arizona and Sacramento Peak, New Mexico, which began operations in 1962 and 1969, respectively. Although these two sites were once the best ground-based facilities available to the U.S. solar research community on a peer-reviewed proposal basis, there are currently better ground-based facilities both inside and outside the United States. As part of the transition, NSO is currently providing site infrastructure support at the Sunspot Solar Observatory (formerly Sacramento Peak Observatory) to New Mexico State University (NMSU), which is responsible for the science operations of the Dunn Solar Telescope, while also performing site cleanup activities. As of January 2019, NSO has vacated its site at the Kitt Peak National Observatory (KPNO), and the remaining building there (the McMath-Pierce Solar Telescope) is currently being converted into an astronomy outreach center to be operated by NSF's National Optical-Infrared Astronomy Research Laboratory (NOIRLab). NISP's SOLIS telescope was removed from KPNO and is being relocated to Big Bear, California, which is an existing site for solar astronomy and the location of one of NSO's GONG stations. Construction of a new SOLIS telescope enclosure began on June 28, 2021. The relocation was delayed due to COVID-19 but is now expected to be complete early in 2022.

Due to COVID-19, on March 17, 2020, all work-related travel for NSO staff ceased, and the observatory initiated 100 percent telework at all NSO sites to comply with stay-at-home orders issued by the governors of Colorado, New Mexico, and Hawaii. In late October 2020, NSO headquarters in Boulder, Colorado began operating under Phase 1 of their operations restart plan. Phase 1 includes telework for non-essential employees. Only essential workers are allowed on site with safety measures in place. In early July 2021, NSO headquarters began operating in Phase 2 of their operations restart plan. Phase 2 includes most staff on telework with some non-essential, high-priority activities allowed on site. On-site activities must be scheduled, and the number of people allowed on-site is limited.

DKIST construction was completed in a modified Phase 1. The Operations Commissioning Phase has begun with observatory staff following established COVID safety guidelines and protocols. The GONG facility is operational. GONG sites are operated remotely and were minimally impacted by COVID-19 shutdowns. Sunspot Solar Observatory is operational under a similar Phase 1 status.

Meeting Intellectual Community Needs

NSO data, including NISP data, are made available to the user community via the Virtual Solar Observatory. DKIST data will be made available via the DKIST Data Center located at NSO's Boulder headquarters. The relevance of DKIST's science drivers was reaffirmed by the National Academy of Sciences, Engineering, and Medicine's 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: *A Science for a Technological Society*.[2] Both reports identified the completion of DKIST as a priority for the solar research community. More recently, the National Academies released the report from its 2020 Decadal Survey for Astronomy and Astrophysics entitled: *Pathways to Discovery in Astronomy and Astrophysics for the 2020s*.[3] In the report, the committee noted the importance of both global observations of our Sun, such as those provided by NSO's GONG facility, as well as detailed observations such as those enabled by DKIST, which, it stated, "will revolutionize observations of the Sun's atmosphere."

Governance Structure and Partnerships

<u>NSF Governance Structure</u>

NSF oversight of NSO and DKIST is handled by program officers in the MPS Division of Astronomical Sciences (AST). The program officers work 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, support, and oversight.

<u>External Governance Structure</u>

NSO is managed by the Association of Universities for Research in Astronomy Inc. (AURA), which comprises 47 U.S. member institutions and three international affiliate members. The NSO director reports to the president of AURA, who is the principal investigator on the current cooperative agreement with NSF. AURA receives management advice from its Solar Observatory Council, composed of members of its scientific and management communities. NSO relies upon a User's 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. NSF program officers for NSO have frequent (at least weekly) discussions and interactions with NSO management, especially the NSO Director. In addition to NSF reviews of the project, the program officers attend the semi-annual meetings of the Solar Observatory Council and the periodic Users Committee meetings as *ex officio* observers. The program officers conduct periodic site visits to NSO facilities and attend community science meetings to keep abreast of the latest happenings in the solar community.

<u>Partnerships and Other Funding Sources</u>

NSO partners include the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), industrial entities, and universities and institutes that collaborate with NSO on solar instrumentation development. NOAA contributes approximately $1 million per year to GONG operations under an interagency agreement with NSF. NMSU operates the Dunn Solar Telescope at Sunspot Solar Observatory through a consortium of universities, while

[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.nap.edu/catalog/26141/pathways-to-discovery-in-astronomy-and-astrophysics-for-the-2020s

NSO continues to maintain the site infrastructure. NSO has partnered with Big Bear Solar Observatory to operate the SOLIS facility once it is installed in Big Bear, California.

Funding

NSF identified a total planning budget of roughly $202 million for NSO O&M over the 10-year term of the current NSO cooperative agreement, June 1, 2015 – September 30, 2024. This includes DKIST operations but does not include the cost of DKIST construction. This also does not include the costs associated with the transition of former NSO facilities on Sacramento Peak and Kitt Peak. The budget projections for FY 2022 and beyond have been slightly increased from prior projections based upon NSO's comprehensive midterm review (see Reviews section), which identified additional budget needs over the remainder of the current award period.

Total Obligations for NSO
(Dollars in Millions)

	FY 2021	FY 2022	FY 2023	ESTIMATES[1]				
	Actual	(TBD)	Request	FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
NSO	$4.65	-	$7.06	$6.24	$6.24	$6.24	$6.24	$6.24
Operations and Maintenance	*4.65*	-	*5.88*	*6.24*	*6.24*	*6.24*	*6.24*	*6.24*
Special Projects[2]	-	-	*1.18*	-	-	-	-	-
DKIST Operations[3]	$19.54	-	$20.68	21.30	21.30	21.30	21.30	21.30
Operations and Maintenance	*19.54*	-	*19.58*	*21.30*	*21.30*	*21.30*	*21.30*	*21.30*
Special Projects[4]	-	-	*1.10*	-	-	-	-	-
Total	**$24.19**	**-**	**$27.74**	**$27.54**	**$27.54**	**$27.54**	**$27.54**	**$27.54**

[1] Outyear funding estimates are for planning purposes only. The current cooperative agreement ends September 2024.
[2] Includes research infrastructure funding for transition activities at Sacramento Peak Observatory.
[3] FY 2021 Actual includes $2.0 million to another awardee for cultural mitigation activities as agreed to during the compliance
[4] Reflects additional funding for research infrastructure to optimize community access.

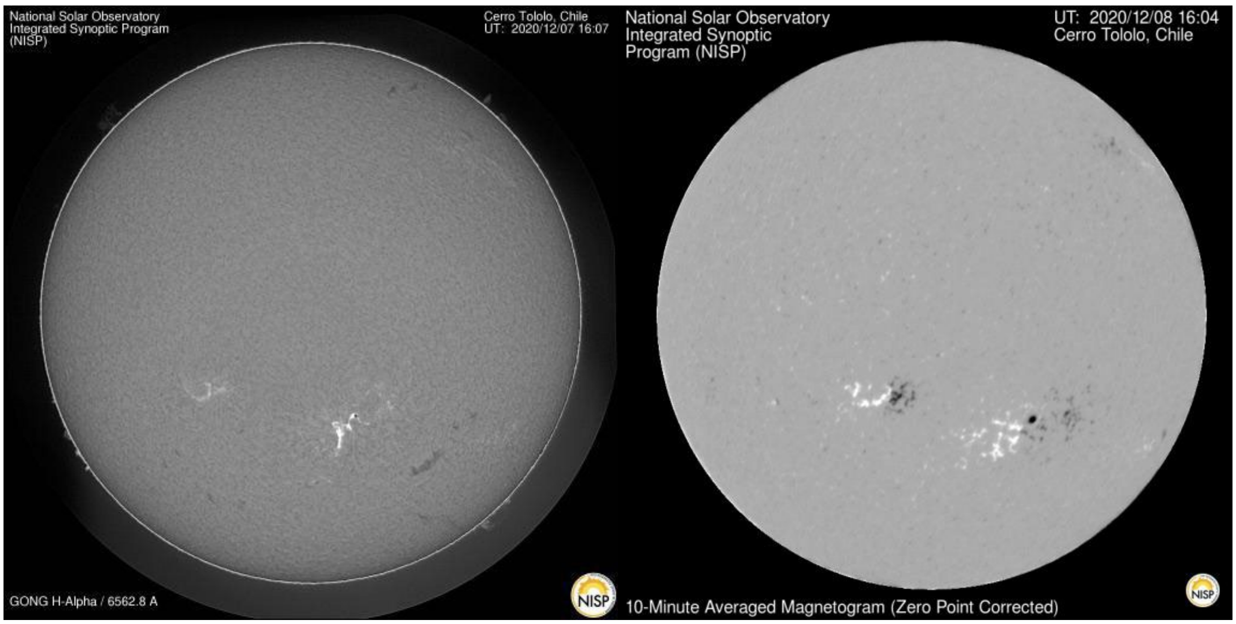
The total NSF obligations for NSO include additional funding for work performed under the operations award, including a supplement for about $300,000 per year since FY 2018 to maintain the infrastructure at Sacramento Peak in collaboration with NMSU. Combined with additional funding from the state of New Mexico, these supplemental funds have ensured that the Dunn Solar Telescope and associated instrumentation remain available for continued research.

Reviews

- NSF conducts regular reviews of NSO's Annual Progress Report and Program Plan (APRPP). A review of the current (FY 2020-FY 2021) APRPP was held virtually on April 8, 2021.
- In July 2019, a comprehensive midterm review of NSO's midterm progress report and long-range plan for the second five years of the cooperative agreement was conducted. The results of this external review were presented to the NSB in February 2020.
- DKIST passed its final construction review in July 2021. The external panel was charged by NSF to examine project management and performance; cultural and environmental compliance; safety and security; and final project acceptance. The panel's report highlighted the excellent work done by the construction team in completing construction under the challenging conditions imposed by COVID-19.

Renewal/Recompetition/Termination

The National Science Board approved the renewal of the NSO/DKIST cooperative agreement in August 2014. The renewed award for management and operations of NSO began June 1, 2015 and will run through September 30, 2024. NSF plans to conduct a comprehensive assessment of NSO operations in mid-2022 to review the options regarding renewal, competition, or divestment of the facility beyond FY 2024, in accordance with NSF policy. The NSF-NSO-NMSU partnership has resulted in partial operation of the Dunn Solar Telescope and the Visitor Center at NSO's Sacramento Peak Observatory in Sunspot, New Mexico as part of the divestment of operations costs of that facility. The effectiveness of this partnership, as well as potential costs of site restoration, will be evaluated in the assessment planned for 2022.



Sample images produced by the GONG facility. Sample Hα image (left) and 10-minute average longitudinal magnetogram (right) from Cerro Tololo GONG station on 8 December 2020. Images show a two-ribbon flare (X-ray class C7.4) in the new solar cycle (Cycle 25) active region AR 12790. *Credit: NSF/AURA/NSO/NISP.*

NSF'S NATIONAL OPTICAL-INFRARED ASTRONOMY RESEARCH LABORATORY (NOIRLAB) $70,900,000 +$10,580,000 / 17.5%

NSF's National OIR Astronomy Research Laboratory Funding[1]
(Dollars in Millions)

FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Percent
$60.32	-	$70.90	$10.58	17.5%

[1] Funding includes the base operations for Gemini and Rubin Observatory.

Brief Description

NOIRLab integrates into a single center Vera C. Rubin Observatory[1] operations (excluding the Rubin Observatory construction project), the International Gemini Observatory, and the programs and activities that were previously associated with NSF's National Optical Astronomy Observatory (NOAO). The components of the former NOAO—the Kitt Peak National Observatory (KPNO) and Cerro Tololo Inter-American Observatory (CTIO), now collectively known as the Mid-Scale Observatories (MSO), as well as the Community Science and Data Center (CSDC) in Tucson, Arizona—have been subsumed into NOIRLab as of October 1, 2019. NSF's NOIRLab is a strategic priority for the MPS Division of Astronomical Sciences (AST) to facilitate U.S. leadership in optical-infrared (OIR) astronomy, and in the process to optimize scientific synergies. NOIRLab promotes efficient operations among NSF-funded nighttime OIR assets and will provide a cornerstone for future NSF investment in the next generation of OIR facilities.

Scientific Purpose

As a Federally Funded Research and Development Center (FFRDC), NSF's NOIRLab has a crucial role in U.S. astronomy: its purpose is to coordinate and integrate the observational, technical, and data-management capabilities across all NOIRLab programs and to develop and sustain domestic and international partnerships with a view to advancing OIR astronomy for the entire U.S. community. NOIRLab's mission is to enable breakthrough discoveries in ground-based optical and infrared astronomy and astrophysics.

NOIRLab will be the foundational hub of U.S. ground based OIR astronomy in the era of Rubin Observatory, multi-messenger astrophysics (MMA), and data intensive science. NOIRLab will also contribute to NSF's implementation of recommendations from the recently released *Pathways to Discovery in Astronomy and Astrophysics for the 2020s* Decadal Survey (Astro2020)[2]. NOIRLab 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. A brief overview of NOIRLab's scientific programs and component observatories is given below.

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[1] Prior to the passage of the Vera C. Rubin Observatory Designation Act (P.L. 116-97), the project was known as the Large Synoptic Survey Telescope.
[2] www.nationalacademies.org/our-work/decadal-survey-on-astronomy-and-astrophysics-2020-astro2020

Vera C. Rubin Observatory

Since 2014, NSF, in partnership with the Department of Energy (DOE), has been constructing Vera C. Rubin Observatory, 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, 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 image of the sky ever and issuing alerts for changing and transient objects within 60 seconds of their discovery. For more information on the construction project, see the MREFC section of this Research Infrastructure Theme within the NFS-Wide Investments chapter.

International Gemini Observatory

Over the last two decades, NSF has been a leading partner in operations of the two 8.1-meter Gemini telescopes, Gemini-North and Gemini-South, located on Maunakea in Hawaiʻi at an altitude of 4,200 meters and on the 2,700-meter summit of Cerro Pachón in Chile, respectively. 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 switch instruments in response to changing atmospheric conditions. Gemini's flexible observing modes and new instrumentation also make it ideal for reacting rapidly to opportunities that arise in the new era of MMA. NOIRLab is developing software and hardware aimed at enhancing Gemini's ability to respond to transient and MMA phenomena discovered by NSF facilities such as Rubin Observatory, the Laser Interferometer Gravitational-Wave Observatory (LIGO), and the IceCube Neutrino Observatory.

Mid-Scale Observatories (MSO)

NOIRLab's 4-meter class telescopes at KPNO in Arizona and CTIO in Chile (see table below) have been a critical resource for research in OIR astronomy for several decades. These telescopes have been revitalized in recent years through the development of new instruments and observing modes.

Primary Telescopes Comprising the Mid-Scale Observatories Program				
	WIYN	**Mayall**	**Blanco**	**SOAR**
Location	KPNO, Arizona	KPNO, Arizona	CTIO, Chile	CTIO, 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[3] and general PI-led astronomy, in partnership with National Aeronautics and Space Administration (NASA)	Survey science with Dark Energy Spectroscopic Instrument (DESI)[4], in partnership with DOE	General PI-led astronomy with an emphasis on survey projects with Dark Energy Camera (DECam).	General PI-led astronomy with an emphasis on time domain astronomy follow-up programs

[3] Refers to the NASA-NSF Exoplanet Observational Research (NN-EXPLORE) Exoplanet Investigations with Doppler spectroscopy (NEID) instrument, which was commissioned in mid-2021.

[4] The instrument was commissioned in May 2021 and the DESI five-year survey began shortly thereafter.

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 leading role in the brokering of time-domain alerts from Rubin Observatory through its Arizona-NOIRLab Temporal Analysis and Response to Events System and Astronomical Event Observatory Network (AEON) collaborations with the University of Arizona, the Gemini Observatory, the Las Cumbres Observatory, [5] and the Zwicky Transient Facility. [6]

Education and Public Outreach
NOIRLab 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. NOIRLab maintains a diverse education program that includes teacher training programs based in Tucson, Arizona and La Serena, Chile, week-long school visit programs in Hawaii and Chile (Gemini's *Journey Through the Universe* program in Hawaiʻi has been running for almost two decades), visitor centers at Kitt Peak and Cerro Tololo, and a web-based information portal. With supplementary support from NSF, NOIRLab 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, will include a Science on a Sphere visualization system, along with interactive exhibits and an astronomy classroom.

Status of the Facility

NOIRLab facilities have been significantly impacted by the COVID-19 pandemic. CTIO, KPNO, and Gemini-South suspended operations from March 16 through late October 2020, when a phased restart of operations became possible as infection rates fell. Gemini-North operations were suspended only until mid-May, after which science observations were able to resume, since COVID infection rates were relatively low in Hawai'i. Since that time, operations have continued unabated at all NOIRLab sites, albeit with reduced on-site support and delays to some non-essential maintenance work. Remote observing is possible at almost all NOIRLab facilities, and some instrument teams have been able to work at the sites. The observatories have been remarkably productive given travel restrictions and the limitations set by safe workforce practices. After some COVID-related delays, two major new instruments at Kitt Peak, NEID and DESI, were successfully commissioned in mid-2021 and both have begun their respective survey projects. The new Gemini facility instrument GHOST has, in the meantime, been safely delivered to the telescope in Chile and the instrument team expects to begin commissioning in mid-2022.

Meeting Intellectual Community Needs

Developing closer ties among the U.S. OIR ground-based facilities has been a recommendation of numerous National Academies of Sciences, Engineering, and Medicine (National Academies) studies and other advisory reports, including the 2010 Decadal Survey of Astronomy and Astrophysics,[7] the

[5] www.lco.global/
[6] www.ztf.caltech.edu/
[7] www.nap.edu/catalog/12951/new-worlds-new-horizons-in-astronomy-and-astrophysics

2012 AST Portfolio Review,[8] and the 2015 National Academies study on the OIR system.[9] Coordination among components of the U.S. OIR system has continued to be a theme in more recent community assessments. The creation of NSF's NOIRLab is responsive to this guidance.

In 2018, the Astronomy and Astrophysics Advisory Committee (AAAC), which advises NSF, NASA, and DOE on synergistic activities in astronomy, set up a subcommittee to consider the evolving roles of Gemini, the Blanco telescope, and the SOAR telescope in the era of Rubin Observatory and MMA. The AAAC subcommittee recognized the strategic importance of all three telescopes (Gemini, Blanco, and SOAR) in Rubin Observatory follow-up, time-domain astronomy, and MMA in the coming decade. This advice has driven NSF's and NOIRLab's activities at these telescopes; NSF 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 project, and both SOAR and Blanco are being incorporated into the AEON network for the purposes of time domain astronomy (TDA) and MMA follow-up.

Many of the activities and initiatives being led by NOIRLab support the recommendations in the Astro2020 released in November 2021. The report identifies "New Messengers and New Physics" as one of three scientific pillars for the upcoming decade, highlighting the importance of TDA and MMA observations. NOIRLab is already busy developing tools, services and instrumentation in support of TDA and MMA (ANTARES and AEON), and with NSF supplemental support is re-commissioning two instruments on Blanco and SOAR specifically for TDA and MMA follow-up. Astro2020 recommends U.S. involvement in future thirty-meter class Extremely Large Telescopes (ELTs) provided that various funding, site selection, management, governance, and public access conditions are met; development of a U.S. ELT Program Office at NOIRLab is already underway in support of potential NSF involvement in one or more ELT projects. The report also encourages maximizing science by developing databases and software tools for use with archival data from all ground-based OIR telescopes; NOIRLab's CSDC provides these services for existing NSF-funded facilities and is considering the possibilities of expanding services to other observatories.

NOIRLab's facilities, telescopes, and data systems are open to all qualified astronomers regardless of institutional affiliation. NOIRLab 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. NOIRLab currently employs approximately 500 people in Arizona, Hawaii, and Chile, including engineers, technicians, support scientists, administrative support staff, postdoctoral fellows, and interns. As NSF builds toward Rubin Observatory operating at full capacity starting in mid-2024, the need for new staff at NOIRLab to support operations is expected to steadily increase in the forthcoming years.

Governance Structure and Partnerships

<u>NSF Governance Structure</u>

In consultation with community representatives, four AST Program Officers, working as a team, carry out continuing oversight and assessment of NOIRLab and its component programs, Rubin Observatory operations, Gemini, MSO, and CSDC. The team makes use of regular detailed reporting: annual program operating plans; long-range plans; quarterly finance, technical, risk and milestone

[8] www.nsf.gov/mps/ast/ast_portfolio_review.jsp

[9] www.nap.edu/catalog/21722/optimizing-the-us-ground-based-optical-and-infrared-astronomy-system

reports; and retrospective annual performance and management reports. A set of pre-defined Key Performance Indicators has been established to measure performance; these are defined in a Performance Evaluation and Measurement Plan which is reviewed and updated annually. To address issues as they arise, AST also leads an Integrated Program Team (IPT) for NOIRLab, which includes representatives from other NSF offices, including the Office of the General Counsel, BFA's Division of Acquisition and Cooperative Support, and BFA's Large Facilities Office. AST leadership, the MPS Facilities Team and the NSF Chief Officer for Research Facilities also provide high-level guidance, support, and oversight.

External Governance Structure

NOIRLab is managed for NSF by the Association of Universities for Research in Astronomy, Inc. (AURA), which comprises 47 U.S. institutions and three international affiliates and is overseen by the AURA Board of Directors. All NOIRLab activities associated with Rubin Observatory operations, Gemini, MSO, and CSDC are currently managed by AURA through cooperative agreements with NSF. AURA and the NOIRLab Director receive management advice from AURA's NOIRLab Management Oversight Council, which meets three times a year and is composed of members of the broad scientific and management communities. MSO and Gemini also have Users' Committees, comprising community scientists, to advise the respective observatory directors on all aspects of the user experience at each corresponding facility.

- *Vera C. Rubin Observatory Governance Structure:* The operation of this new observatory includes a management board with members from the NSF managing organization and DOE lead laboratory, 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 community expectations for Rubin Observatory's key 10-year survey initiative.
- *International Gemini Observatory Governance Structure:* Gemini Observatory is governed by the Gemini Board, the roles and responsibilities of which are codified in the International Gemini Agreement. This board meets at least twice a year and acts as the primary forum for interactions and decisions among the participants in the International Gemini Agreement; it ensures that Gemini is managed and operated in accordance with the Agreement, and it is the body with overall budgetary and policy control over the observatory. 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 Gemini Finance Committee.

Partnerships and Other Funding Sources

NOIRLab and its component programs support several important national and international partnerships on behalf of NSF:

- Operations of the Gemini Observatory are supported by the Gemini international partnership, which includes NSF, the National Research Council (NRC) of Canada, the Agencia Nacional de Investigación y Desarrollo (ANID) of Chile, the Ministério da Ciência Tecnologia, Inovações e Comunicações (MCTIC) of Brazil, the Ministro de Ciencia, Tecnología e Innovación Productiva (MINCYT) of Argentina, and the Korea Astronomy and Space Science Institute (KASI) of South Korea. These six agencies are signatories to the International Gemini Agreement, which the partnership recently renewed for another six years (2022-2027).
- The SOAR telescope is supported by MCTIC of Brazil, NOIRLab, the University of North Carolina Chapel Hill, and Michigan State University; a new five-year SOAR agreement was signed in 2020.
- The WIYN telescope is supported by a consortium comprising the University of Wisconsin, Indiana University, and NOIRLab; the University of Missouri, Purdue University, University of California

Irvine, and Penn State University are operational partners. NSF's continued participation is built around a partnership with NASA, which is providing NEID, a state-of-the-art instrument for extrasolar planet studies under the NN-EXPLORE program.

- Key agreements between NSF and DOE have supported not only the construction of 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 telescope. 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 NOIRLab. NOIRLab receives approximately $12 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 NOIRLab'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.

Funding

NSF funding for NOIRLab includes support for Rubin Observatory pre-operations, Gemini Observatory operations and development, and MSO and CSDC operations along with associated special projects. Awards for NOIRLab component programs are organized under one overarching cooperative agreement with AURA.

Total Obligations for NOIRLab
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	ESTIMATES[1] FY 2024	FY 2025	FY 2026	FY 2027	FY 2028
Vera C. Rubin Observatory Operations	$6.09	-	$20.30	$33.80	$36.09	$36.34	$35.71	35.71
Gemini Observatory O&M[2]	24.27	-	24.61	23.67	23.67	23.67	23.67	23.67
Mid-Scale Observatories & CSDC	29.95	-	25.99	21.13	21.13	21.13	21.13	21.13
Operations & Maintenance	*20.51*	-	*21.13*	*21.13*	*21.13*	*21.13*	*21.13*	*21.13*
Special Projects [3]	*9.44*	-	*4.86*	-	-	-	-	-
Total	**$60.31**	**-**	**$70.90**	**$78.60**	**$80.89**	**$81.14**	**$80.51**	**80.51**

[1] Outyear funding estimates are for planning purposes only. A new NOIRLab-wide cooperative agreement is expected for the period FY 2023 through FY 2027.

[2] FY 2023 request contains $1.63 million for additional research infrastructure and O&M, including costs for repairs and maintenance.

[3] Special projects funding contains support for the Windows on the Universe Center for Astronomy Outreach, ongoing activities at the WIYN telescope, and potential future participation in the U.S. Extremely Large Telescope program, as well as research infrastructure including additional costs for repairs and maintenance.

The colorful band of the Milky Way is poised above the 8.1-meter Gemini South telescope of NSF's NOIRLab in this arresting image, which depicts bright patches of stars threaded through with winding lanes of dust. The Galactic Center hangs directly above the telescope, framing one of the most powerful astronomical observatories in the southern hemisphere. *Credit: Gemini Observatory/NSF's National Optical-Infrared Astronomy Research Laboratory/AURA/Kwon O Chul.*

Rubin Observatory pre-operations funding began in FY 2018 to support the ramp-up of activities associated with observatory operations; information on plans for full operations of Rubin Observatory (in partnership with DOE) can be found in the Rubin Observatory MREFC construction narrative. The FY 2023 Request for Gemini Observatory covers NSF's partnership share of O&M costs as well as an additional contribution to Gemini's Instrument Development Fund (IDF; partners contribute on a best-efforts basis). The FY 2023 Request for MSO and CSDC supports all NOIRLab Directorate-level activities, O&M of KPNO and CTIO not otherwise funded by other national or international entities or partners, user support services, data archiving, and software development at CSDC. Special projects include continued operational support of the NN-EXPLORE exoplanet program at WIYN, the operations of the Windows on the Universe Center for Astronomy Outreach, and development of next-generation OIR telescope instrumentation and software as well as planning for a potential U.S. Extremely Large Telescope Program. Funding for special projects also includes additional deferred maintenance projects, upgrades necessary for the continued effective operations of the facility, such as replacement of observatory dome mechanisms, removal of possible asbestos-containing materials and updates to water systems. The execution of projects will be prioritized based on the outcome of ongoing facility condition .

Reviews

NSF has, in the past, conducted annual reviews of program operating plans, progress reports, and strategic planning documents for NOIRLab's component observatories, and now continues to do so for the entire NOIRLab enterprise. Quarterly reports outlining progress against milestones and Key Performance Indicators are reviewed by NSF's NOIRLab IPT. Within the last three years, detailed communications, staffing, risk management and change management plans that describe the transition to NOIRLab have also been reviewed, either internally by the NOIRLab IPT, or by external panels of experts. In February 2021, NSF conducted its first NOIRLab-wide review of performance and program operating plans with support from an external panel of experts in program management, observatory operations, and astronomy. Audits and reviews of NOIRLab's annual budgets, indirect cost rates, overhead rates, and accounting systems are conducted annually by BFA.

Renewal/Recompetition/Termination

The latest recompetition of the O&M awards for MSO/CSDC and Gemini separately concluded in 2015, resulting in awards through the ends of FY 2020 and CY 2022, respectively. A renewal of funding for MSO, CSDC, and the NOIRLab Directorate for a further two years (FY 2021-FY 2022), authorized by the NSB in July 2020, has allowed NSF to synchronize the award periods for all existing programmatic components of NOIRLab, which also includes Rubin Observatory pre-operations. In February 2022, NSF reviewed a five-year proposal for the renewal of all NOIRLab programs (MSO, CSDC, Gemini and Rubin Observatory operations) for the period FY 2023-FY 2027.[10] The next opportunity to begin a competition of NOIRLab as an integrated organization would then be around FY 2025. Currently there are no plans for divestment of any NOIRLab facilities, although evaluation of the future of current MSO facilities will necessarily be part of any future proposal.

[10] The Gemini operations award would begin at the start of CY 2023, after the end of the current award.

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 R&RA account.

For information on projects funded through this account, refer to the MREFC section of this Research Infrastructure Theme within the NSF-Wide Investments chapter.

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.

CROSS-THEME TOPICS

For definitions of common acronyms used throughout NSF's FY 2023 Budget Request, see the NOTES found at the beginning of the entire document on pages iii-iv.

Ongoing Major Investments

STEM Education and Workforce

NATIONAL NANOTECHNOLOGY INITIATIVE (NNI)

Total Funding for NNI
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request
BIO	$39.95	-	$39.95
CISE	14.67	-	14.05
EDU[1]	6.04	-	2.50
ENG	206.45	-	231.75
MPS	340.13	-	133.50
SBE	0.40	-	0.40
OISE	0.10	-	0.10
TIP[2]	4.00	-	10.05
Total	**$611.74**	**-**	**$432.30**

[1] Formerly known as Directorate for Education and Human Resources (EHR).

[2] FY 2021 funding for TIP is shown for comparability across fiscal years.

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; efficient catalysts for industry; molecular medicine; imaging and understanding of the brain; quantum qubits and systems; nanosensors to monitor health, the environment, and human-machine interactions; hardware designed by and for artificial intelligence (AI) systems; efficient and large-scale nanomanufacturing; more resilient materials and system architectures; and sustainable development for water, energy, and food resource utilization. An increased focus will be on using nanotechnology as a foundation for other emerging technologies, and for reducing and mitigating climate change, including research on the capture, sequestration, and reuse of CO_2. A continuing research focus will be on understanding the structure and nanoscale behavior of the novel SARs-COV2 virus and supporting foundational concepts for vaccine development. NSF contributes to the NNI goals and five Program Component Areas (PCAs) outlined in the current draft of the 2026 NNI Strategic Plan.[1] Funding by PCA is shown at the end of this discussion.

FY 2023 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

[1] www.nano.gov/2021strategicplan

through 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 2023. Overall, NSF's total NNI funding in the FY 2023 Request is $432.30 million. Several new directions planned for FY 2023 include research connected to longer-term aspects of COVID-19, mitigation of climate change, advanced manufacturing, AI and quantum systems including their use for creating smart materials and systems, the bioeconomy, sustainability, advanced wireless, and quantum biology. Nanotechnology research will contribute and synergize with NSF's Big Ideas, particularly with URoL, FW-HTF, HDR, and GCR, as well as with research supporting emerging technologies such as semiconductors for AI and advanced wireless. NSF sponsors an annual NSE grantee conference to assess the progress in nanotechnology and facilitate identification of new research directions.[2]

In FY 2023, NSF support will increasingly focus on convergence research and education activities in confluence with other priority areas. NSF will strengthen partnerships of the Nanosystems Engineering Research Centers 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 use-inspired research, e.g., through Grant Opportunities for Academic Liaison with Industry (GOALI); and Industry-University Cooperative Research Centers (IUCRC); as well as translation, e.g., through the NSF Innovation Corps (I-Corps™); Partnerships for Innovation (PFI), and Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs. For example, the 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]

National Academies of Sciences, Engineering, and Medicine (the National Academies) report to Congress in 2020 provides guidance on research priorities, partnerships, and future growth, including: "Finding 1.2 - The National Quantum Initiative (NQI) is, in large part, an important outgrowth of the National Nanotechnology Initiative (NNI)," "Impacts of NNI to date: Impressive, tangible outcomes that

[2] 2021 Nanoscale Science and Engineering Grantees Conference: www.nsf.gov/crssprgm/nano/ and www.nseresearch.org/2021/

[3] NSF/WTEC 2010, Springer, available on www.nsf.gov/crssprgm/nano/ and http://scienceus.org/wtec/docs/nano2.pdf

[4] NSF/WTEC 2013, Springer, available on www.nsf.gov/crssprgm/nano/ and http://scienceus.org/wtec/docs/nbic2.pdf

[5] www.nsf.gov/crssprgm/nano/

[6] www.src.org/nri/energy-efficient-computing-workshop.pdf

[7] www.semiconductors.org/issues/research/research/

have emerged from these coordination efforts, including the recent formation of the NQI."[8,9]

Investments by Program Component Area

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.[10] NSF supports funding in all five PCAs.

NNI Funding by Program Component Area
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request
1. Foundational Research	$336.34	-	$261.30
2. Nanotechnology-Enabled Applications, Devices, and Systems	109.52	-	100.97
3. Research Infrastructure and Instrumentation	30.43	-	26.68
4. Education and Workforce Development	23.24	-	21.50
5. Responsible Development	62.21	-	21.85
Total	**$561.74**	**-**	**$432.30**

<u>PCA 1: Foundational Research</u>
The first PCA will be funded at a total of $261.30 million in FY 2023. It includes funding for the discovery and development of fundamental knowledge pertaining to new phenomena in the physical, biological, and engineering sciences that occur at the nanoscale. Also included is funding for research aiming to understand scientific and engineering principles related to nanoscale systems, structures, processes, and mechanisms; research on the discovery and synthesis of novel nanoscale and nanostructured materials including biomaterials and modular structures; quantum biology for understanding natural phenomena and interfaces; water nanofiltration systems; and research directed at identifying and quantifying the broad implications of nanotechnology for society, including social, economic, ethical, and legal implications. It includes foundational research on COVID-19 and climate change understanding and mitigation, and nano-Ethical, Legal and Societal Implications (ELSI). Most of the research is sponsored in individual and small group research across NSF directorates. A subset of Engineering Research Centers (ERC), Science and Technology Centers (STCs), Centers for Chemical Innovation (CCIs) and other center programs support various aspects of nanoscale science and engineering. About 60 percent of the Materials Research Science and Engineering Centers (MRSECs) pursue NSE-related fundamental research.

NSF has invested in understanding the nanoscale machines that make up the nucleus of a cell and control cell function through its programs in Understanding the Rules of Life: Epigenetics, the Physics Frontiers Center program, and core programs in Molecular and Cellular Biosciences (Genetic Mechanisms) as well as Chemistry (Chemistry of Living Processes). In FY 2023, NSF will also continue its efforts in nanobiotechnology associated with synthetic biology and synthetic cells through core programs in BIO - Molecular and Cellular Biosciences (MCB) and ENG - Chemical, Bioengineering, Environmental, and Transportation Systems (CBET).

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[8] www.nationalacademies.org/our-work/quadrennial-review-of-the-national-nanotechnology-initiative
[9] www.nap.edu/resource/25729/A%20Quadrennial%20Review%20NNI%20Presentation%20slides%20v15.pdf
[10] www.nano.gov/about-nni/what/vision-goals

This PCA includes foundational research supporting the Nanotechnology Signature Initiatives (NSIs) on: Sustainable Nanomanufacturing, Nanoelectronics including semiconductors, Nanotechnology for Sensors and Sensors for Nanotechnology, as well as research on the Nanotechnology-Inspired Grand Challenge for Future Computing.

- *Sustainable Nanomanufacturing:* Investments support foundational concepts for new nanomanufacturing methods at the confluence with digitization, biotechnology, AI, and cognitive sciences. Research in synthetic cells will lead to scalable and reproducible cell and organ production for biomanufacturing and biomedicine applications. Another new direction is manufacturing of quantum systems, nanomachines and nano biostructures. Methods for nanomanufacturing design are in synergy with the Materials Genome Initiative.
- *Nanoelectronics and Semiconductors:* Research is aimed at discovering and using novel nanoscale fabrication processes and innovative concepts to produce revolutionary materials, devices, systems, and architectures to advance the field of electronics beyond Moore's Law. NSF will continue related investments in quantum systems and advanced wireless technology.
- *Nanotechnology for Sensors and Sensors for Nanotechnology*: Research is aimed at the use of nanoscale principles and 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. It supports materials and technologies that enable new sensing of biological, chemical, and nanoscale materials. Programs on biosensing and biophotonics in CBET support this effort.
- *Nanotechnology-Inspired Grand Challenge for Future Computing*: Research is planned on the NNI Grand Challenge related research on "Brain-like Computing" and "Intelligent Cognitive Assistants". An example of an active center is the STC on Integrated Quantum Materials at Harvard University. and the MRSEC on Quantum and Spin Phenomena in Nanomagnetic Structures at the University of Nebraska, Lincoln.

PCA 2: Nanotechnology-Enabled Applications, Devices, and Systems

The FY 2023 Request includes $100.97 million for research that applies the principles of nanoscale science and engineering to create novel devices and systems, to achieve improved performance or new functionality, including metrology, scale up, manufacturing technology, and nanoscale reference materials and standards. Core programs in the ENG, MPS, and CISE directorates support development of new principles, design methods, and constructive solutions for nanomaterials and nanodevices. A special focus is on smart, autonomous nanoscale-based devices and systems. PCA 2 includes applications-, device-, or systems-focused research related Sustainable Nanomanufacturing, Nanoelectronics (semiconductors), Nanotechnology for Sensors and Sensors for Nanotechnology, and the Nanotechnology-Inspired Grand Challenge for Future Computing. The Future Manufacturing solicitation announced in 2020 will continue into 2022 and 2023.[11] The goal of Future Manufacturing is to support fundamental research and education of a future workforce to overcome scientific, technological, educational, economic, and social barriers to enable new manufacturing capabilities that do not exist today. Besides core nanoscience-related programs on water filtration and applications, the Nanosystems ERC for Nanotechnology Enabled Water Treatment Systems (NEWT), led by Rice University and funded between 2015 and 2024, aims at developing high-performance water treatment systems that will broaden access to clean drinking water from a variety of unconventional sources (briny well water, seawater, wastewater), and enable industrial wastewater reuse at remote locations such as oil and gas fields. Other ERCs perform research in portable

[11] www.nsf.gov/funding/pgm_summ.jsp?pims_id=505737

nanosensors, new nanomanufacturing processes, and new nano-electronic materials. IUCRCs focus on solar energy conversion, metrology, novel catalysts and bioplastics, and novel high voltage/temperature materials and structures.

PCA 3: Research Infrastructure and Instrumentation

The FY 2023 Request includes $26.68 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.

NSF has funded awards totaling about $16.0 million per year for the National Nanotechnology Coordinated Infrastructure (NNCI) sites for FY 2015–2024. Other STCs, ERCs, CCIs, nano-HUB nodes, and MRSECs have a focus on supporting the NNI, including the Center for Cellular Construction at the University of California-San Francisco (annual award since 2016 of approximately $5 million per year), two Nanosystems ERCs, one each on nanobiotechnology and cell technology, and a CCI at University of Wisconsin (annual award of $4 million per year) which investigates the fundamental molecular mechanisms by which nanoparticles interact with biological systems. The funding also includes workforce development activities at these centers and sites. NSF will increase coordinated research on its Mid-scale Research Infrastructure priority area. The Major Research Instrumentation (MRI) Program[12] serves to increase access to multi-user scientific and engineering instrumentation, including instrumentation needed for NSE activities, for research and research training in the Nation's institutions of higher education and not-for-profit scientific/engineering research organizations.

PCA 4. Education and Workforce Development

In FY 2023, NSF will fund education and workforce development activities in all areas of nanoscale science and engineering, including engaging the public, at $21.50 million. Typical activities supported by the Directorate for STEM Education, ENG's Division of Engineering Education and Centers, and other divisions are fellowships, single investigator awards, and centers.

The NSF INTERN program[13] supports about 65 NSE-related internships for students in industry and government labs. Illustrations of projects at the undergraduate and graduate levels are "Supporting Micro and Nano Technicians through Hybrid Teaching Methods,"[14] the Nanotechnology Applications and Career Knowledge (NACK) Resource Center,[15] the Micro Nano Technology Education Center (MNT-EC),[16] and "Nano-Makerspace to Make and Explore in the World of the Small"[17]. The Boston Museum of Science hosts a nationwide NSE communication competition for undergraduate and graduate students.[18]

[12] www.nsf.gov/funding/pgm_summ.jsp?pims_id=5260
[13] www.nsf.gov/INTERN
[14] Award DUE-2100402 (https://nsf.gov/awardsearch/showAward?AWD_ID=2100402)
[15] Award DUE-2000725 (https://nsf.gov/awardsearch/showAward?AWD_ID=2000725)
[16] Award DUE-2000281 (https://nsf.gov/awardsearch/showAward?AWD_ID=2000281)
[17] Award DUE-1723511 (https://nsf.gov/awardsearch/showAward?AWD_ID=1723511)
[18] www.mos.org/quantum-matters-competition

PCA 5. Responsible Development

In FY 2023, NSF will continue its funding for Environment, Health, and Safety (EHS), ELSI, and diversity/equity/inclusion/access, as well as nanotechnology research integrity, safety, and reproducibility at $21.85 million. Requests for research are primarily directed at understanding nano-bio phenomena and processes, as well as environment, health, societal, 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 CCI: Center for Sustainable Nanotechnology at the University of Wisconsin.[19] Support will be increased for diversity and equity by inclusion and access for underrepresented groups, women and persons with disabilities interested in nanoscale science and engineering, for various knowledge and technology fields to be explored in conjunction with nanotechnology, and for broad geographical representation in all 50 states.

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).
- Nanoelectronics and semiconductors—NSF, NIST, Department of Defense (DOD), DOE, Intelligence Community (IC)/Director of National Intelligence (DNI), and NASA.
- NSF collaborates with other 14 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.
- INTERN program supports NSE-related internships at DOD/AFRL.
- OECD (Working Group on Bio, Nano, and other Converging Technologies)

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

NETWORKING AND INFORMATION TECHNOLOGY RESEARCH AND DEVELOPMENT (NITRD)

NITRD Funding

(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request
BIO	$79.00	-	$79.00
CISE	1,007.13	-	1,150.78
EDU[1]	17.60	-	29.59
ENG	164.59	-	179.26
GEO	23.00	-	30.00
MPS	298.45	-	226.81
SBE	34.90	-	30.94
TIP[2]	80.45	-	380.04
OISE	0.33	-	-
IA	9.07	-	1.00
Total	**$1,714.52**	**-**	**$2,107.42**

[1] Formerly known as Directorate for Education and Human Resources (EHR).

[2] FY 2021 funding for TIP is shown for comparability across fiscal years.

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, NSF leadership also co-chair the Machine Learning and Artificial Intelligence (MLAI) as well as the Future Advanced Computing Ecosystem (FACE) Subcommittees, enabling close coordination between NITRD, MLAI, and FACE.

FY 2023 NITRD Funding

NSF's FY 2023 Budget Request includes support for NITRD at a level of $2,107.42 million. NITRD activities represent approximately 20.1 percent of NSF's FY 2023 Budget Request to Congress.

The PCAs are reviewed annually to ensure they remain relevant and reflect the most up-to-date R&D needs of the Nation. For FY 2023, the NITRD Subcommittee performed a comprehensive review of the PCA definitions, resulting in several major updates including the renaming of the Large-Scale Networking PCA to Advanced Communication Networks and Systems as well as updates to the definitions of most PCAs.

Investments by Program Component Area (PCA)

The following information focuses on FY 2023 NSF investments, both new and continuing, by PCA.

NITRD Funding by Program Component Area
(Dollars in Millions)

	FY 2021 Actual[1]	FY 2022 (TBD)	FY 2023 Request
Advanced Communication Networks and Systems (ACNS)	$187.79	-	$221.40
Artificial Intelligence R&D (AI)	401.68	-	491.16
Computing-Enabled Human Interaction, Communications, Augmentation (CHuman)	102.49	-	102.62
Computing-Enabled Networked Physical Systems (CNPS)	81.49	-	141.47
Cyber Security and Privacy (CSP)	105.33	-	129.28
Education and Workforce (EdW)	95.70	-	132.65
Enabling-R&D for High-Capability Computing Systems (EHCS)	197.68	-	180.76
Electronics for Networking and Information Technology (ENIT)	-	-	104.18
High Capability Computing Infrastructure and Applications (HCIA)	200.44	-	209.20
Intelligent Robotics and Autonomous Systems (IRAS)	47.76	-	63.36
Large-Scale Data Management and Analysis (LSDMA)	224.80	-	250.06
Software Productivity, Sustainability, and Quality (SPSQ)	69.35	-	81.28
Total	**$1,714.52**	**-**	**$2,107.42**

[1] FY 2021 Actual funding is not restated to reflect the creation of the new ENIT Program Component Area.

Advanced Communication Networks and Systems (ACNS) ($221.40 million)
ACNS will include CISE investments in the NSF-wide Smart and Connected Communities (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. ACNS will also include NSF investments in the Spectrum Innovation Initiative supporting fundamental spectrum research in increased spectrum efficiencies, flexibility, and adaptability and leading to the creation of advanced wireless technologies and systems beyond 5G. Additionally, in collaboration with other federal agencies and the private sector, ACNS will include NSF investments on Resilient and Intelligent Next-Generation (NextG) Systems (RINGS), transforming emerging NextG wireless and mobile communication, networking, sensing, and computing.

AI R&D ($491.16 million)
AI R&D will include investments in fundamental research advancing AI. A key focal point of 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 major 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.

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; EDU investments in AI-enabled teaching and learning systems; 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; 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; and TIP investments in Regional Innovation Engines, which leverage multiple disciplines, institutions, and sectors to advance emerging technologies, including AI, and address major societal and economic issues in areas such as the bioeconomy and climate science.

<u>Computing-Enabled Human Interaction, Communications, Augmentation (CHuman) ($102.62 million)</u>
CHuman will include investments 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 investments 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 investments 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.

<u>Computing-Enabled Networked Physical Systems (CNPS) ($141.47 million)</u>
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 investments in the NSF-wide 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 also includes TIP investments in the Convergence Accelerator (CA) which accelerates use-inspired, solutions-oriented research and piloting in specific areas of national importance; in FY 2023, the CA will launch a regional approach supporting regional cohorts pursuing location-specific challenges in agriculture, energy, and transportation, to name a few. CNPS will additionally include BIO investments in expanding and enhancing access to the national resource of digital biological and paleontological data and ENG investments in advanced and future manufacturing, including cyber-manufacturing.

<u>Cyber Security and Privacy (CSP) ($129.28 million)</u>
CSP will include investments in the NSF-wide SaTC program and other related cybersecurity and privacy research. The investments 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. CNPS also includes collaboration between CISE, SBE, and TIP on investments to advance democracy-affirming technologies, enabling practical privacy solutions. In addition, CSP includes investments in programs that strengthen pathways for the national cybersecurity workforce, including support for innovation at the K-12 level, community colleges, and four-year universities.

Education and Workforce (EdW) ($132.65 million)

EdW will include collaboration between CISE and EDU on investments across all education levels, including at the undergraduate level through IUSE: Computing in Undergraduate Education, which supports efforts to re-envision the role of computing in interdisciplinary collaboration within American institutions of higher education. CISE and EDU will also invest at the K-12 levels through Computer Science for All: Researcher-Practitioner Partnerships, which supports the R&D needed to bring computer science and computational thinking to all schools at the preK-12 levels. CISE and EDU will also support workforce development in cybersecurity, enabling a growing cadre 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. As part of this investment, EdW will fund programs that strengthen pathways for the national cybersecurity workforce, including support for innovation at the K-12 level, in community colleges, and at four-year universities. EdW will additionally include BIO investments in advancing America's ability to incorporate and apply biological knowledge to economic development and other issues of societal importance, and TIP investments that offer experiential and entrepreneurial opportunities to students and researchers at all levels pursuing studies in emerging technologies. In general, EdW investments will continue to promote racial equity through a broad suite of activities that support broadening participation in STEM research and education, and that study the causes of, impacts on, and practices for addressing inequity in STEM participation.

Enabling-R&D for High-Capability Computing Systems (EHCS) ($180.76 million)

In alignment with the FACE Strategic Plan[1], EHCS will include investments which support (i) research advances in new computing technologies, architectures, and platforms for the future; (ii) the development and deployment of advanced computing systems and services, while maximizing the benefits of these systems and services through deep integration with science and engineering research; and (iii) formulation of approaches for the federation of advanced computing systems and services to realize a National Discovery Cloud (NDC). 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.

Electronics for Networking and Information Technology (ENIT) ($104.18 million)

ENIT will include CISE, ENG, and MPS investments in biological computation, nanoscale science and engineering, quantum information science and engineering, and neuromorphic computing as well as other disruptive technologies. ENIT will also include CISE, ENG, and MPS investments in the underlying fundamental physical and materials science; design and design automation of electronic devices,

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[1] www.nitrd.gov/pubs/Future-Advanced-Computing-Ecosystem-Strategic-Plan-Nov-2020.pdf

circuits, and systems, systems architectures, and related software; and the fabrication and characterization of tools and facilities required for advanced microelectronics and semiconductor technologies. In addition, in collaboration with private industry, ENIT will include CISE, ENG, MPS, and TIP investments that advance research on the design and manufacture of future semiconductor technologies.

<u>High Capability Computing Infrastructure and Applications (HCIA) ($209.20 million)</u>
HCIA will include CISE investments on the development and deployment of software and algorithms for advanced computing systems and services. HCIA will include CISE investments in the NDC for Climate that will federate access to compute resources from multiple sources, including NSF-funded advanced computing resources, edge resources located at NSF major facilities, and at other compute- and data-intensive NSF research facilities, as well as commercial cloud computing resources. These investments will also build on 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 investments in advanced cyberinfrastructure for the geosciences; GEO investments in the operations and maintenance of the National Center for Atmospheric Research's Wyoming Supercomputer facility and associated modeling efforts; and BIO investments 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. HCIA investments will further understanding of climate science and clean-energy technologies by enabling data science, artificial intelligence and machine learning, and predictive and high-end computational modeling and simulation.

<u>Intelligent Robotics and Autonomous Systems (IRAS) ($63.36 million)</u>
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.

<u>Large-Scale Data Management and Analysis (LSDMA) ($250.06 million)</u>
LSDMA will include investments in HDR, which supports 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 include CISE investments in the NDC for Climate that will incorporate systems to curate, federate, and provide access to data from multiple sources, be they NSF-funded large facilities, resources from industry/non-profits, or the data contribution of individual researchers, to enable new scientific discoveries by supporting the broad examination and reexamination of collected data, and the scientific analysis of combinations of heterogeneous data. LSDMA will additionally include ENG investments in 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 investments in integrative modeling of complex biological processes.

<u>Software Productivity, Sustainability and Quality (SPSQ) ($81.28 million)</u>
SPSQ will include investments 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 include CISE investments in the NDC for Climate that will democratize access to advanced compute, data, software, and networking resources. SPSQ will also include investments 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. Likewise, through Designing Accountable Software Systems (DASS), CISE and SBE will enable a deeper understanding of the bidirectional relationship between software systems and the complex social and legal contexts within which software systems must be designed and operate.

NSF BIG IDEAS

Since 2017, NSF began building a foundation for the Big Ideas through pioneering research and pilot activities. Over time those investments have matured. In 2023, NSF will continue to identify and support emerging opportunities for U.S. leadership in Big Ideas that serve the Nation's future.

NSF Big Ideas Funding[1]
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request
Research Ideas[2]:			
Harnessing the Data Revolution for 21st Century S&E (HDR)	$191.79	-	$182.11
Navigating the New Arctic (NNA)	40.11	-	35.20
The Future of Work at the Human-Technology Frontier (FW-HTF)	172.89	-	175.80
Understanding the Rules of Life: Predicting Phenotype (URoL)	113.92	-	93.50
Windows on the Universe (WoU)	74.80	-	61.85
Enabling Big Ideas:			
Growing Convergence Research (GCR)	15.99	-	16.00
NSF INCLUDES	20.75	-	50.50
Mid-Scale Research Infrastructure (Mid-Scale RI)[3]	106.49	-	126.25

[1] NSF's Big Ideas may have funding overlap and thus should not be summed. The funding displayed may also have overlap with other topics and programs.

[2] Each of the Research Big Ideas include $30.0 million in stewardship funding in the FY 2023 Request.

[3] Funding for Mid-Scale RI is split between the R&RA and MREFC accounts. For the FY 2021 Actual, the split is $32.45 million R&RA and $74.04 million MREFC. For the FY 2023 Request the split is $50.0 million R&RA and $76.25 million MREFC.

About the Big Ideas

Five of the Big Ideas are research ideas, which 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 projects endeavor 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)

HDR engages 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.

- FY 2022 stewardship investments are focused in three areas:
  1. *Fundamental research in data science and engineering*. HDR primarily supports this area through the Transdisciplinary Research In Principles Of Data Science (HDR TRIPODS) program. In FY 2019, Phase I HDR TRIPODS awards were made to 15 projects, supporting the development of small, collaborative "data science research projects." In FY 2022, Phase II awards will enable a subset of the most successful of these smaller projects to expand with new partners into

larger data science efforts of increased scope and impact.

2. *A cohesive, federated, national-scale network of data-intensive science and engineering research institutes.* In FY 2019, NSF issued more than 100 conceptualization awards spanning 28 projects that supported interdisciplinary teams to conceptualize and pilot new modalities for collaboration and convergence beyond traditional disciplinary and organizational boundaries. These projects paved the way for funding five major interdisciplinary HDR Institutes for Data-Intensive Research in Science and Engineering in FY 2021. In FY 2022 and FY 2023 these HDR Institutes will continue to support convergence between science and engineering research communities as well as expertise in data science foundations, systems, applications, and cyberinfrastructure. By creating a portfolio of interrelated institutes, NSF aims to accelerate discovery and innovation in all areas of data-intensive science and engineering and formulate innovate data-intensive approaches to address critical national challenges.
3. *Development of a 21st-century data-capable workforce.* NSF supports data science education and workforce development through the Data Science Corps (DSC) program. A second round of DSC awards in FY 2021 resulted in eight awards that will continue through FY 2023. A focal point of the education and workforce development portfolio is to enable the participation of individuals with diverse backgrounds and perspectives in building a diverse workforce trained in data management, data analytics, and data-driven decision-making.

- In FY 2023, HDR funds will be used to continue the projects launched in FY 2021 and FY 2022 in each of the three areas noted above, and to encourage activities enhancing communication and convergence among these institutes and projects, bringing together expertise in data science foundations, systems, applications, and cyberinfrastructure. Together, the NSF-funded teams will 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.

<u>Navigating the New Arctic (NNA)</u>

NNA is 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.

- In FY 2021, NSF made 77 NNA awards, including 56 new projects, half of which were collaborations. Several of these projects are studying how the changing environment will affect rivers, lakes, watersheds, and adjacent communities. In FY 2022, NSF issued a revised NNA solicitation with a focus on larger-scale convergent social, built, and natural environment systems science projects; advancing observation networks including knowledge co-production; communication and education projects; computation and data systems; and community-coordination activities.
- In FY 2023, the NNA program will focus on enabling advances and building on outcomes of prior supported activities. The solicitation published in FY 2022 will remain active for proposals in FY 2023. NSF will continue to coordinate and leverage NNA-related activities with external stakeholders, including other federal agencies through the Interagency Arctic Research Policy Committee (IARPC) chaired by the NSF Director; the NSF-funded, Navigating the New Arctic Community Office; 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.

<u>The Future of Work at the Human-Technology Frontier (FW-HTF)</u>

FW-HTF catalyzes 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 ubiquitous learning to enhance the use of technology.

- In FY 2022, the Future of Work Big Idea supported (1) a set of forward-looking, convergent awards across industries, geography, and institutions as well as (2) the building of a new interdisciplinary research community. Awards represent a wide range of workers and future of work domains including construction and infrastructure, precision and digital agriculture, medicine and healthcare, intelligent and co-robotic manufacturing, and inclusive work for neurodiversity and disabilities. Several projects examine how workers and robots could collaborate intelligently and effectively on construction sites, in infrastructure inspection, nursing profession, seafood process, and recycling. New transition-to-scale awards emphasized research that would adapt and escalate the foundational basis for implementation and deployment in future workplaces and work contexts across industries and/or geographical locations. The Future of Work effort was also responsive to emerging problems and priorities, funding a set of supplements and NSF's Rapid Response Research awards in response to COVID-19.
- FY 2023 activities will leverage previous investments made through the Future of Work to support convergent research that is use-inspired, driven by challenges in improving work and the workforce through development of innovative technologies along with new structures and cultures of work that support and empower a diverse and inclusive workforce. Through the development of larger teams and partnerships, this research will improve ways to engage workers as co-contributors in the process of technological development and impel greater productivity, innovation in work practices, and the design and development of new industries and services. Special emphasis will be placed on ways in which the human-technology partnership can result in work solutions that are environmentally supportive and sustainable. The program promises to support the growth of U.S. businesses and entrepreneurs and STEM workforce development through research to improve reskilling, upskilling, and lifelong learning for future jobs and workplaces.

<u>Understanding the Rules of Life (URoL): Predicting Phenotype</u>

URoL is developing a predictive understanding of how key properties of living systems emerge from complex biological interactions. Advances in understanding life at fundamental levels will enable re-engineering of cells, organisms, and ecosystems, and the discovery of innovative biochemicals and biomaterials to sustain a vibrant bioeconomy, strengthen society, predict the behavior of living systems, and modify them to benefit humankind.

- Beginning in FY 2018, NSF’s URoL Big Idea has supported 99 proposals in a series of new interdisciplinary research programs designed to elucidate rules at different hierarchical scales: Building a Synthetic Cell, for "minimal rules"; Epigenetics, for "rules of complexity"; Microbiomes: Theory and Microbiomes: Interactions, for "rules of interaction"; and Emergent Networks for “rules of emergence.” Projects supported by URoL share a number of common features: they address a fundamental question in the life sciences; they focus on science at different scales (e.g., spatial, temporal, levels of biological organization, or complexity); they produce results designed to be broadly generalizable beyond the system under investigation, so that a rule can be formulated; and they enable the forecasting or prediction of change in a biological system in the context of others, including Earth, human, natural, and/or human-engineered systems. In FY 2022, a revised solicitation on emergent networks was released, and a series of meetings and workshops was sponsored to gain community input on how knowledge of the Rules of Life can be leveraged for future uses.

- URoL activities in FY 2023 will build upon previous investments by seeking ways to Use the Rules of Life to address societal challenges, including those identified as Administration priorities. These activities will exploit lessons learned at all levels of biological organization, including the role of complex environmental inputs on genotype-to-phenotype relationships, and will support networks of researchers, technology developers, and educators across convergent URoL domains.

Windows on the Universe (WoU)

WoU uses powerful new syntheses of different messengers and different 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.

- The WoU Big Idea continues to be implemented through a dedicated program, NSF PD 18-5115: "Windows on the Universe: The Era of Multi-Messenger Astrophysics (WoU-MMA)." In FY2021, the WoU-MMA program made 73 awards through WoU-MMA stewardship and foundational funding. The awards spanned the full range of WoU investment areas: accelerating the theoretical, computational, and observational activities within the scientific community; building dedicated mid-scale experiments and instrumentation; and exploiting current facilities and developing the next generation of observatories. WoU also partnered with CISE's Office of Advanced Cyberinfrastructure and the HDR Big Idea to invest in awards to enhance cyberinfrastructure for multi-messenger astrophysics. WoU awards have included investments in workforce development as well as diversity, equity, and inclusion activities.
- To continue advancing the WoU science goals, the successful meta-program approach will continue in FY 2023. New targeted solicitations are also being explored to address specific scientific needs and opportunities. In this era of the Vera C. Rubin Observatory, IceCube Neutrino Observatory, and the Large Interferometer Gravitational-Wave Observatory, the electromagnetic follow-up of multi-messenger events will require a concert of facilities and space missions which through WoU, NSF will invest by continuing to build partnerships within and outside of NSF, extending existing partnerships with DOE, and exploring new partnerships with other federal agencies and private organizations.

Enabling Big Ideas

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

NSF INCLUDES is transforming education and career pathways to help broaden participation in science and engineering and build a diverse, highly skilled American workforce.

- NSF INCLUDES is a comprehensive, national initiative to advance equity and inclusion and broaden participation in STEM at scale by providing infrastructure for effective, collaborative change. NSF INCLUDES is continuing efforts to develop, strengthen, and sustain the National Network and communicate progress. Five new NSF INCLUDES Alliances were awarded in FY 2021. A total of thirteen Alliances have been funded since FY 2018. Each Alliance engages a range of strategic partners to address broadening participation challenges for specific groups of people, specific disciplines, and specific components of the STEM education system. NSF INCLUDES supports projects that advance the contributions of African Americans, Alaska Natives, Hispanics, Native Americans, Native Hawaiians, Native Pacific Islanders, persons with disabilities, persons from economically disadvantaged backgrounds, and women and girls from many academic and professional disciplines across the STEM education continuum. The NSF INCLUDES National Network has grown from just over 1,000 members in FY 2019 to nearly 4,000 members in FY 2021.

Research briefs, podcasts, webinars, publications, and convenings have been developed and shared broadly to build capacity for the work of broadening participation and raise the visibility of the National Network and its impact. Federal agency partners meet quarterly to share information and coordinate synergistic efforts.

- Planned investments for FY 2023 include: a) continuing to expand and strengthen the National Network through connections to networks with similar goals and by funding pilot projects, planning grants, and alliances; b) supporting the expansion of the NSF INCLUDES Coordination Hub, which leads and serves the National Network; c) supporting sustainability and scale of innovative, systemic strategies developed by currently funded projects; and d) advancing evidence-based approaches to broadening participation through shared measures and evaluation. An annual National Network survey and new evaluation contract were launched in FY 2021, along with the NSF INCLUDES Shared Measures platform. These activities will facilitate rigorous, formative evaluation of NSF INCLUDES' progress toward leveraging collaborative change strategies to increase diversity and inclusion and broaden participation in STEM fields and will provide an inventory of outcomes and broadening participation, collaborative change, institutional transformation, and system change indicators to measure progress and advance the adoption and adaptation of proven and promising approaches to realizing an inclusive STEM workforce.

<u>Growing Convergence Research (GCR)</u>

GCR deeply integrates ideas, approaches, tools, and technologies from widely diverse fields of science and engineering to advance fundamental understanding and the Nation's ability to meet pressing societal challenges.

- GCR supports five-year, complex convergence research projects, reviewing the progress made in the first two years to determine which will continue for three more years. In FY 2021, GCR funded eight new projects spanning 18 institutions and involving over 50 researchers, bridging two dozen disciplines. Projects included: fundamental science for the next generation of medical devices, such as ultra-miniature diagnostic devices, neuroprosthetics aimed at delaying the effects of degenerative diseases, and novel approaches to providing respiratory support in cases of lung failure; research to advance sustainability, including the sustainability of food systems, understanding and managing complex physical-biological systems, creating innovative ecological forecasts, and approaches for restoring degraded landscapes that deal with water cycling and supply, ecosystem nutrition, and carbon sequestration; and novel computing paradigms based on cultured biological neural networks to propel machine learning and artificial intelligence to the next level. In FY 2021, GCR also continued four projects that began in FY 2019. These included creating new scientific paradigms to enable sustainable bio-based materials generation, establishing an emerging field of Biomolecular Systems Engineering, developing science-based solutions to mitigating the impact of micro- and nano-plastics on aquatic environments, and developing transformative technologies that can rapidly capture, sense, and identify viruses and predict new strains.
- In FY 2023, GCR will incubate the capacity of research teams to address emerging research challenges that are large in scope, innovative in character, originate outside of any particular NSF directorate, and require the application of ideas, approaches and perspectives from multiple science and engineering fields. GCR investments will support three to seven new research collaborations and the continuation of three to six projects begun in FY 2021.

Mid-scale Research Infrastructure (Mid-scale RI)

Mid-scale RI is 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.

- NSF made ten awards from the second Mid-scale RI-1 solicitation (NSF 21-505) on September 27, 2021[1], including construction of ocean-bottom seismographs; development of an observatory for on-line human and platform behavior; deployment of a network of sensors for measurement of atmospheric gases and aerosols; construction of a national silicon carbide fabrication facility; and support for the design of a new superconducting magnet and next generation astronomical radars. NSF made two additional awards from the first Mid-scale RI-2 solicitation (NSF 19-542): a network for advanced Nuclear Magnetic Resonance studies, in June 2021[2], and data infrastructure to enable transformative research by leveraging complex data about human behavior, society and the economy, in February 2022[3].
- In FY 2023, NSF will invest $126.25 million in Mid-scale RI, split between Mid-scale RI-1 ($50.0 million), funded through R&RA, and Mid-scale RI-2 ($76.25 million), funded through MREFC. NSF anticipates that Mid-scale RI-2 funding will provide continuing support to projects resulting from the first Mid-scale RI-2 competition that concluded in FY 2021 and will enable new awards to be made from proposals submitted to the second Mid-scale RI-2 solicitation (NSF 21-537). NSF plans to issue a new solicitation for Mid-scale RI-1 in FY 2023.

For more information on Mid-scale Research Infrastructure Track 1, see the IA narrative in the R&RA chapter. See the Mid-scale Research Infrastructure Track 2 narrative in the Research Infrastructure Theme chapter of NSF-wide Investments for more information on Track 2.

[1] www.nsf.gov/news/special_reports/announcements/092721.jsp
[2] www.nsf.gov/news/special_reports/announcements/061621.jsp
[3] www.nsf.gov/news/special_reports/announcements/020422.jsp

NSF CENTERS PROGRAMS

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 Centers Funding

(Dollars in Millions)

	Program Initiation	Number of Centers in FY 2021	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
AI Research Institutes	2020	14	$62.70	-	$70.31	$7.61	12.1%
Biology Integration Institutes	2020	10	19.95	-	49.50	29.55	148.1%
Centers for Analysis & Synthesis	1995	2	-	-	5.00	5.00	N/A
Centers for Chemical Innovation	1998	8	27.64	-	27.70	0.06	0.2%
Engineering Research Centers	1985	14	56.26	-	71.50	15.24	27.1%
Materials Centers	1994	23	50.08	-	56.80	6.72	13.4%
Quantum Leap Challenge Insts[1]	2020	5	32.05	-	32.00	-0.05	-0.2%
Regional Innovation Engines	2023	0	-	-	200.00	200.00	N/A
Science & Technology Centers	1987	18	61.03	-	77.60	16.57	27.2%
Spectrum Innovation Initiative Ctr	2021	1	7.79	-	5.00	-2.79	-35.8%
Total			**$317.50**	**-**	**$595.41**	**$277.91**	**87.5%**

[1] Since FY 2020, funding for the Quantum Leap Challenge Institutes has been a vital part of NSF's overall $50+ million investment in multidisciplinary centers for quantum research and education. Also see the Engineering Research Center narrative below and the MPS narrative for additional information on quantum center activities.

Description of Major Changes

Artificial Intelligence Research Institutes – multi-directorate

The FY 2023 Request of $70.31 million will support up to 21 National AI Research Institutes—five institutes launched in FY 2020, nine awarded in FY 2021, and up to seven additional institutes planned in FY 2023. In addition, two FY 2020 institutes and two FY 2021 institutes are wholly funded by the U.S. Department of Agriculture National Institute of Food and Agriculture (USDA NIFA).

The National AI Research Institutes program, a multisector collaboration among government, industry, and academia, supports multidisciplinary advances on challenges in both foundational and use-inspired AI research. Each funded institute has three missions: (1) to advance fundamental knowledge of AI; (2) to advance use-inspired work on using AI to solve real-world problems of importance to the U.S. economy; and (3) to grow the U.S. AI workforce and build pathways for students from diverse backgrounds. More specifically, the funded institutes provide sustained, large-scale support for academic research groups to work on real-world problems, while also creating national AI infrastructure in the form of living laboratories. They serve as nexus points for academic, government, and industry interaction, and integrate research with the development of the next-generation AI workforce. A key motivation for the program is to maintain and grow U.S. leadership and competitiveness in AI at a time when other nations are making massive investments in the field. The

National AI Research Institutes program is led by CISE and includes contributions from all NSF directorates along with external partners, including federal agencies and industry. Each year, the program solicits proposals that respond to one of a given set of themes. For institutes launched in FY 2020 and FY 2021, these themes included Foundations of Machine Learning; Trustworthy AI; AI-Driven Innovation in Agriculture and the Food System; AI-Augmented Learning; AI for Accelerating Molecular Synthesis and Manufacturing; Human-AI Interaction and Collaboration; AI and Advanced Cyberinfrastructure; Advances in AI and Computer and Network Systems; and others. Each institute is funded at up to $4.0 million per year for up to five years. The latest solicitation issued in summer 2021 for awards in FY 2023 continues the ongoing collaboration with USDA NIFA as well as new partnerships with the DOD Office of the Undersecretary of Defense for Research and Engineering, the National Institute of Standards and Technology, the Institute for Education Sciences, and IBM.

<u>Biology Integration Institutes – BIO</u>

The FY 2023 Request of $49.50 million is expected to support 20 Biology Integration Institutes (BII). This will include fifteen continuing BII awards and five new awards.

The BII program supports collaborative teams of researchers investigating frontier questions about life that span multiple disciplines within and beyond the biological sciences. The goal is to foster creative integration of diverse fields using innovative experimental, theoretical, and modeling approaches to discover underlying principles operating across multiple levels of life; from molecules to cells, organisms, species, and ecosystems. Each institute has unique research themes centered around a compelling biological question poised for breakthroughs by collaboration across biological disciplines. The themes address fundamental and use-inspired research that serve to advance discovery and understanding in the life sciences and expand capabilities in biotechnology to control and utilize living systems. Outcomes from BII awards will foster innovation and applications that benefit U.S. security and health, mitigate the impacts of climate change, and spur economic growth.

BII awards support team-science and training environments that are fully integrated with the research theme and conducive to addressing complex science challenges, leveraging new ideas, expertise and infrastructure, and exploration of new modes of collaboration, which will prepare the next generation of biological scientists to pursue multidisciplinary research throughout their careers. Typically, BII awards bring together multiple organizations to leverage interdisciplinary talent and infrastructure, and to broaden participation of undergraduate and graduate students from underrepresented groups in the life sciences. In this way, BII awards build a diverse and inclusive workforce that can address the challenges of climate change and emerging infectious diseases, and that fulfill the needs of an expanding U.S. bioeconomy.

<u>Centers for Analysis and Synthesis - BIO</u>

The FY 2023 Request of $5.0 million for Centers for Analysis and Synthesis is expected to provide continuing support ($3.0 million) for a new center in environmental science and eco-forecasting (award will be issued in FY 2022). The Center will develop the teams, concepts, resources, and expertise to enable inclusive, effective, and coordinated efforts to answer broad scientific questions that emerge at interfaces between biological and environmental sciences, including climate change, land use change, biodiversity loss, and ecosystem services. The center will leverage data being provided by the National Ecological Observatory Network (NEON), Long-Term Ecological Research (LTER) and other environmental observatories and databases to support community efforts in ecological modeling to develop a national capability for eco-forecasting. A new funding competition for BIO's first Center for Analysis and Synthesis in the area of molecular and cellular biosciences is being planned for completion in FY 2023 with an initial year funding of $2.0 million. Its goal is to achieve a comprehensive understanding of cell biology that relates molecular structure, function and interactions to cellular properties in ways that predict the emergent behavior of cells in a dynamic environment. The Center will aim to provide a catalytic role to advance the integrated knowledge of the workings of cells, metabolism, information processing, growth, senescence, proliferation and differentiation by analysis and synthesis of diverse molecular and cellular data.

<u>Centers for Chemical Innovation - MPS</u>
The FY 2023 Request of $27.70 million will fund up to seven Phase II Centers for Chemical Innovation (CCI). This includes up to six continuing centers and one new center. Each Phase II center is slated to be funded at $4.0 million per year (five-year awards with potential for renewal up to a total of ten years). An eighth center remains active and will sunset in FY 2023.

CCIs are developed through a two-phase process. Phase I CCIs conduct research, pilot broader impact activities, and complete key center development activities before submitting their Phase II proposal. There are currently nine Phase I awards supported by the Division of Chemistry.

CCIs focus on major, long-term fundamental chemical research challenges. CCIs are agile, collaborative entities that respond rapidly to emerging opportunities by integrating research with innovation, higher education, broadening participation, and informal science communication. The themes of the CCIs are varied and include Administration priorities such as clean energy technologies, climate solution, AI, QIS, biotechnology, advanced manufacturing, as well as sustainable chemistry, 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. Several CCIs are studying various aspects of sustainability and clean energy technologies: the Center for Sustainable Nanotechnology (CSN) is examining how technologically important nanoparticles found in batteries interact with biological systems and how those nanoparticles can be redesigned to be environmentally benign; the Center for Synthetic Organic Electrochemistry (CSOE) is developing new electrosynthesis reactions that are safer, more energy-efficient, and generate less waste; and the Center for Sustainable Polymers (CSP) works on the discovery and development of new sustainable, degradable, and chemically recyclable plastics with improved performance, providing alternative solutions to the growing global plastics crisis.

Each year, CCIs include more than 70 participating academic institutions, 70 non-academic partner institutions, 150 Senior Personnel, 110 Postdoctoral Associates, 250 Graduate Students, and 70 Undergraduate Students.

<u>Engineering Research Centers - ENG</u>
The FY 2023 request is $71.50 million to support 15 NSF Engineering Research Centers (ERC), which aim to advance clean energy and climate change mitigation, biotechnology, quantum technology, semiconductors and microelectronics, and other national priorities. The investment includes support for four Gen-4 ERCs, funded as part of the Class of 2022, that will conduct convergent engineering research to tackle high-impact challenges with the potential to benefit U.S. security, prosperity, health, and society. The Class of FY 2022 ERCs will implement strategies for effective team formation and engagement with stakeholder communities to maximize their impacts. Three centers from the Class of 2012 will receive their final year of NSF funding in FY 2022.

All NSF ERCs combine the intellectual curiosity of university research focused on discovery with real-world engineered systems and technology opportunities through partnerships with industry. Each ERC has interacting foundational components that go beyond the research project, including engineering workforce development at all participant stages, a culture of diversity and inclusion where all participants gain mutual benefit, and value creation within an innovation ecosystem that will outlast the lifetime of the ERC.

Since the program began in 1985, products of ERC innovation include more than 2,600 inventions disclosures, over 2,300 patent applications filed, more than 900 patents awarded, and 1,381 licenses, as well as more than 240 spinoff companies. ERCs also have a successful track record for educating a technology-enabled workforce with hands-on, real-world experience. On average, NSF ERCs graduate over 130 Bachelor's, 123 Master's, and 150 Doctoral degree students each year. Over that time, they have also impacted, on average over 2,500 K-12 teachers and students. NSF ERCs are also effective at broadening participation from underrepresented groups. For example, across currently active ERCs, women comprise approximately 36 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.

<u>Materials Centers - MPS</u>

The FY 2023 Request level of $56.80 million is expected to support up to 19 Materials Research Science and Engineering Centers (MRSEC). The triennial MRSEC competition that will begin in June of FY 2022 is expected to end at the end of FY 2023. Funding in FY 2023 will continue support of 11 new centers established in FY 2020 and up to 8 new centers from the FY 2023 competition.

MRSECs function as hubs for solving complex grand-challenge materials problems requiring broad multidisciplinary expertise within the physical sciences and engineering to understand materials phenomena, exploit materials properties, 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, materials science, and engineering. Through collaborative efforts involving academics, industry, national laboratories experts, and international and educational partners, MRSECs advance materials research and education in the United States, and in many cases are international leaders. MRSECs have served as partners with more than 50 MSIs and develop new pathways for underrepresented groups, aiming to educate and train a diverse materials workforce across the U.S.

MRSECs have six major coordinated components: (1) interdisciplinary research groups, (2) education and outreach, (3) industrial and international outreach/partnerships, (4) diversity and broadening participation – serving as a major partner with Minority-Serving Institutions in MPS/DMR Partnerships in Research and Education in Materials (PREM) program, (5) 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 (6) the seed program, which enables MRSECs to rapidly react to and move into new high-risk and potentially transformative areas not yet fully explored.

Each year, MRSECs produce over 180 Ph.Ds. in STEM fields, mentor nearly 400 Research Experiences for Undergraduate students and 60 Research Experiences for Teachers participants, and impact over one million students and their 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 approximately 180 startups and annually produces about 60 awarded patents and 35 patent licensures. MRSECs engage and assist more than 500 other individuals from industry, national laboratories, and international partners per year in advancing fundamental materials research that can be translated into the marketplace.

<u>Quantum Leap Challenge Institutes – MPS</u>
The FY 2023 Request level of $32.0 million will support the fourth year of the three Quantum Leap Challenge Institutes (QLCI) established in FY 2020 along with the third year of additional institutes that resulted from the second phase of the QLCI competition held in FY 2021. Each of the existing institutes is addressing a different key area of QIS research, one in sensing, one in computing, and one in networking. The FY 2021 competition expanded the areas covered to include quantum simulation and the potential applications in biology and bioengineering. Total award sizes for each institute are $25.0 million over five years. In FY 2023 NSF will continue the Expand QISE thrust begun in FY 2022, which focuses on enhancing the participation of academic institutions not currently participating in the national QISE initiative and promoting the inclusion of members of groups currently underrepresented in the field.

Quantum information science and engineering utilizes profound aspects of quantum physics such as superposition, interference, and entanglement to develop revolutionary approaches for information processing. Such approaches include quantum computation, quantum communication, quantum simulation and quantum sensing. These rapidly developing fields have been bolstered by recent discoveries and breakthroughs. However, several foundational and technological challenges must be overcome before the full potential of quantum information science and engineering can be realized. The QLCI's program goal is to support timely and bold research agendas aimed at making breakthroughs on one of these clearly identified and compelling challenges within a five-year period. QLCIs are expected to: engage an intellectually-diverse community in the pursuit of identified challenges; develop cohesive, collaborative and national-scale approaches to research in quantum information science and engineering; and enable the development of a well-trained workforce with strong cross-disciplinary skill sets needed for quantum information science and engineering.

The QLCI program, along with other NSF multidisciplinary centers related to quantum research and education, collectively address Section 302 of the 2018 National Quantum Initiative Act. In addition, as all of the institutes funded under the QLCI program address topics that have been identified by the NSTC Subcommittee on Quantum Information Science as being critical to the U.S. investment in QIS, the program exercises a key role in the NSF response to this need.

<u>Regional Innovation Engines – TIP</u>
The FY 2023 Request level of $200.0 million will support up to 10 NSF Regional Innovation Engines (NSF Engines) in FY 2023. The NSF Engines program constitutes a bold new initiative that aims to create regional-scale innovation ecosystems throughout the United States and spur economic growth by bringing together the science and technology research enterprise and regional-level resources to address societal and economic challenges and promote long-term national competitiveness. NSF is providing funding to support activities focused on use-inspired research, entrepreneurship, and workforce development to nurture and accelerate regional industries. The NSF Engines program specifically emphasizes the meaningful engagement of the consumers of research outcomes in research as well as in the subsequent prototyping and piloting of research-based solutions (i.e., co-

design and co-creation), along with the translation of research results to practice, entrepreneurship, and direct economic growth.

In particular, the NSF Engines will aim to advance use-inspired, solutions-oriented research and innovation in a range of emerging technologies (e.g., advanced manufacturing, advanced wireless, AI, biotechnology, QIS, semiconductors) as well as in a diverse set of national challenges (e.g., climate change and the bioeconomy). They will bring together multiple disciplines, institutions, and sectors. They will balance technical and geographic (i.e., local and regional challenges, capabilities, and perspectives) innovation as well as individual, organizational, and geographic diversity; incentivize partnerships between NSF, other federal agencies, academia, industry, nonprofits, state, local, and tribal governments, civil society, and communities of practice; and serve as hubs for NSF's broader portfolios of investment in their respective areas of focus.

The bold nature of this effort is reflected in the program's goals, as described above; the nature and types of partnerships expected; the outputs that are being tracked and assessed (notably an emphasis on technology and workforce capabilities); the level of post-award oversight; the budgets of the NSF Engines, which are an order of magnitude greater than traditional NSF center-scale awards; and the duration of NSF funding for the NSF Engines, i.e., a ten-year award lifetime, paired with an intentional focus on longer-term sustainability from day one. Notably, the NSF Engines are funded at levels ranging from $145 million to $160 million over eight to ten years, depending on the initial stage of a given NSF Engine at the time of its proposal.

Science and Technology Centers: Integrative Partnerships – multi-directorate
The FY 2023 Request level of $77.60 million will support at least 15 Science and Technology Centers (STC) and the administrative costs associated with program management and oversight. These include STCs from the FY 2016 and FY 2021 cohorts and new centers to be funded in FY 2023, which will replace the sunsetting cohort funded in FY 2013. Preliminary proposals for the Class of FY 2023 were received in February 2022. Currently, STC awards are for five years, with possible renewal for an additional five years, or ten 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 current STC competition requests proposals with budgets of up to $6 million per year.

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: improving agricultural production via programmable plants based on digital biology; new technologies and solutions to limit the need for phosphorus usage in agricultural practice while reducing its harmful environmental impacts by enabling phosphorus recovery from the environment; advancing the understanding of Earth's climate; realizing a new generation of optoelectronic materials and devices; creating atomic-scale devices and systems based on quantum materials; and elucidating the mechanisms and architecture of intelligence in the human brain.

STCs conduct world-class research through partnerships among institutions of higher education, national laboratories, industry, other public or private entities, and via international collaborations. STCs strengthen the caliber of the Nation's STEM workforce through intellectually challenging research experiences for students, postdoctoral fellows, researchers, and educators. One of the goals of STCs is to increase involvement of traditionally underrepresented groups and institutions in science and engineering, which they achieve through dedicated mentoring and partnerships, most notably with MSIs and emerging research institutions. Proposals describe institutional commitment to diversity and inclusion within the participating institutions. Additionally, STCs 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 policymakers, and disseminating knowledge across scientific disciplines. The STC program uses a network of evaluators working with the centers to share information and lessons learned about the most effective way to measure progress.

<u>Spectrum Innovation Initiative: National Center for Wireless Spectrum Research (SII-Center) – MPS</u>
The FY 2023 Request level of $5.0 million is to fund the continuing operations of the SII-Center program. In FY 2020, NSF began the process of standing up a National Center for Wireless Spectrum Research through the provision of 17 SII-Center planning grants and established one SII-Center in FY 2021.

The worldwide growth of wireless communication, navigation, and telemetry has provided immense societal benefits including mobile broadband data, Internet of Things (IoT), mobile healthcare, and intelligent transportation systems. These and other applications call for innovations that can circumvent the challenges of radio spectrum scarcity and interference, and foster the growth of ubiquitous, high speed, low latency connectivity. Commercial applications like the above must operate in harmony with scientific uses of spectrum (e.g., radio astronomy, Earth and atmospheric sciences, and polar research) and other nationally vital spectrum-dependent services (e.g., weather prediction). NSF continues to support wireless spectrum research and the scientific uses of the electromagnetic spectrum through multiple programs that enable fast, accurate, dynamic coordination and usage of the limited spectrum resource. These programs have created an opportune ground to build and create a large center-based ecosystem for spectrum research, which is the target of this SII-Center program. The goal of this program is to chart out a trajectory to ensure United States leadership in future wireless technologies, systems, and applications in science and engineering through the efficient use and sharing of the radio spectrum. A key expectation is establishing harmony between scientific uses of the electromagnetic spectrum and the forthcoming technological advances for high-speed, low latency, secure connectivity among pervasive devices, autonomous vehicles, and numerous other platforms. SII-Center will serve as a focal point for sustained research in the most challenging topics in spectrum. Research in these areas is expected to create advanced wireless technologies and systems that benefit society, of which 5G and future wireless broadband networks are an example. SII-Center is also expected to facilitate the education and development of an agile workforce needed to support emerging industries. These industries will rely heavily on wireless technologies and will require new advanced and automated spectrum management techniques. NSF's goal is to promote transformative use and management of the electromagnetic spectrum, resulting in profound benefits for science, engineering, industry, and other national interests.

NSF is working closely with the Federal Communications Commission and the National Telecommunications Information Administration to ensure that NSF SII investments in spectrum research and development are in alignment with national spectrum regulatory and policy objectives, principles, and strategies.[1]

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[1] www.fcc.gov/document/fcc-federal-partners-sign-spectrum-innovation-cooperation-agreement

Estimates for Centers Participation in 2021

	Number of Participating Institutions[1]	Number of Partners[2]	Total FY 2021 NSF Support ($ in millions)	Total Leveraged Support ($ in millions)[3]	Number of Participants[4]
AI Research Institutes	104	203	$62.70	$16.00	NA
Biology Integration Institutes	9	4	$19.95	N/A	270
Centers for Analysis & Synthesis	39	20	N/A	N/A	1,448
Centers for Chemical Innovation	72	73	$27.64	$6.13	628
Engineering Research Centers	793	263	$56.26	$71.93	3,470
Materials Centers	157	146	$50.08	$23.48	3,000
Quantum Leap Challenge Insts	26	51	$32.05	$0.00	183
Regional Innovation Engines[5]	N/A	N/A	N/A	N/A	N/A
Science & Technology Centers	177	222	$61.03	$55.00	2,031
Spectrum Innovation Initiative Ctr[6]	28	1	$7.79	$0	*TBD*

[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.

[5] New NSF Centers activity in FY 2022.

[6] New NSF Centers activity in FY 2020. Full estimates for Centers Participation are not available at this time.

Centers Supported by NSF in FY 2021

Center	Institution	State
Artificial Intelligence Research Institutes		
Artificial Intelligence for Environmental Sciences (AI2ES)	U of Oklahoma	OK
Institute for Foundations of Machine Learning	U of Texas at Austin	TX
Institute for Student-AI Teaming	U of Colorado at Boulder	CO
Molecule Maker Lab Institute (MMLI): An AI Institute for Molecular Discovery, Synthetic Strategy, and Mfg.	U of Illinois Urbana-Champaign	IL
AI Research Institute for Fundamental Interactions	MIT	MA
AI Institute for Collaborative Assistance and Responsive Interaction for Networked Groups (AI-CARING)	Georgia Tech Research Corp.	GA
AI Institute for Learning-enabled Optimization at Scale (TILOS)	U of California-San Diego	CA
AI Institute for Advances in Optimization	Georgia Tech Research Corp.	GA
AI Institute for Intelligent CyberInfrastructure with Computational Learning in the Environment (ICICLE)	Ohio State University	OH
AI Institute for Future Edge Networks and Distributed Intelligence (AI-EDGE)	Ohio State University	OH
AI Institute for Edge Computing Leveraging Next Generation Networks (Athena)	Duke University	NC
AI Institute in Dynamic Systems	University of Washington	WA
AI Institute for Engaged Learning	North Carolina State University	NC
AI Institute for Adult Learning and Online Education	Georgia Research Alliance	GA
Biology Integration Institutes		
Behavioral Plasticity Research Institute (BPRI)	Baylor College of Medicine	TX
Emergent Ecosystem Responses through Genes-to-Systems Institute (EMERGE)	Ohio State University	OH
Advancing Spectral biology in Changing Environments to understand Diversity (ASCEND)	University of Minnesota-Twin Cities	MN
Genomics and Eco-evolution of Multi-scale Symbioses Institute (GEMS)	University of Illinois at Urbana-Champaign	IL
Host-Virus Evolutionary Dynamics Institute (HVEDI)	University of Arkansas	AR
Mechanisms of Cellular Evolution	Arizona State University	AZ
New Roots for Restoration	Donald Danforth Plant Sci. Ctr.	MO
Uncovering mechanisms of amphibian resilience to global change from molecules to landscapes	University of Pittsburgh	PA
Emergent Mechanisms in Biology of Robustness, Integrations & Organization (EMBRIO)	Purdue University	IN
Regional OneHealth Aerobiome Discovery Network	Colorado State University	CO
Centers for Analysis and Synthesis[2]		
Nat'l Inst. for Mathematical & Biological Syn. NIMBios)	U of Tennessee	TN
Socio-Environmental Synthesis Center (SESYNC)	U of Maryland	MD

[2] NIMBioS and SESYNC are operating on no-cost extensions. No funds were obligated for the centers in FY 2021.

Centers for Chemical Innovation (Phase II awards only)[3]		
Center for Chemical Evolution (CCE)	Georgia Institute of Tech	GA
NSF Center for Sustainable Nanotechnology (CSN)	U of Wisconsin	WI
NSF Center for Sustainable Polymers (CSP)	U of Minnesota	MN
NSF Center for Aerosol Impacts on the Chemistry of the Environment (CAICE)	U of California-San Diego	CA
NSF Center for Selective C-H Functionalization (CCHF)	Emory	GA
NSF Center for Genomically Encoded Materials (CGEM)	U of California-Berkeley	CA
NSF Center for Synthetic Organic Electrochemistry (CSOE)	U of Utah	UT
NSF Center for the Chemistry of Molecularly Optimized Networks (MONET)	Duke University	NC
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
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
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 Nanoscale Precision (CELL-MET)	Boston College	MA
Nanotechnology Enabled-Water Treatment System	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
Translational Applications of Nanoscale Multiferroic Systems (TANMS)	U of California-Los Angeles	CA
NSF Engineering Center for Quantum Networks (CQN)	U of Arizona	AZ
NSF Engineering Research Center for the Internet of Things for Precision Agriculture (IoT4Ag)	U of Pennsylvania	PA
NSF Engineering Research Center for Advancing Sustainability Through Powered Infrastructure for Roadway Electrification (ASPIRE)	Utah State University	UT
NSF Engineering Research Center for Advanced Technologies For Preservation of Biological Systems (ATP-Bio)	U of Minnesota	MN
Materials Centers		
Brandeis Bioinspired Soft Materials Center	Brandeis	MA
Center for Complex and Active Materials	U of California-Irvine	CA
Center for Dynamics and Control of Materials	U of Texas at Austin	TX

[3] Smaller, developmental Phase I awards do not meet the criteria as formal NSF Centers and so are not captured here.

Center for Emergent Materials	Ohio State University	OH
Center for Hybrid, Active and Responsive Materials	U of Delaware	DE
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 U/C	IL
Laboratory for Research on the Structure of Matter	U of Pennsylvania	PA
Materials Research Science and Engineering Ctr at UCSB	U of California-Santa Barbara	CA
Materials Research Science and Engineering Center	U of California-San Diego	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
Quantum Leap Challenge Institutes		
Enhanced Sensing and Distribution Using Correlated Quantum States	U of Colorado Boulder	CO
Hybrid Quantum Architectures and Networks	U of Illinois-Urbana Champaign	IL
Present and Future Quantum Computing	U of California-Berkeley	CA
Quantum Sensing in Biophysics and Bioengineering	U of Chicago	IL
Robust Quantum Simulation	U of Maryland-College Park	MD
Nanoscale Science and Engineering Centers[4]		
Center for the Environmental Implications of Nanotechnology (CEINT)	Duke	NC
Predictive Toxicology Assessment & Safe Implementation of Nanotechnology in the Environment (CEIN)	U of California-Los Angeles	CA
Science and Technology Centers		
BEACON: An NSF Ctr. 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 Chemical Currencies of a Microbial Planet	Woods Hole Ocean. Inst	MA
Center for Dark Energy Biosphere Investigations	U of Southern California	CA
Center for Emergent Behaviors of Integrated Cellular Systems	Massachusetts Institute of Tech	MA

[4] CEINT and CEIN are operating on no-cost extensions. No funds were obligated for the centers in FY 2020.

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
Center for Integration of Modern Optoelectronic Materials on Demand	U of Washington	WA
Center for Learning the Earth with Artificial Intelligence and Physics	Columbia U	NY
Center for OLDest Ice Exploration	Oregon State U	OR
Center for Research On Programmable Plant Systems	Cornell	NY
Center for Science of Information	Purdue	IN
S&T Center on Real-Time Functional Imaging	University of Colorado	CO
S&T Technologies for Phosphorus Sustainability Center	North Carolina State U	NC
Spectrum Innovation Initiative		
Spectrum X – An NSF Spectrum Innovation Center	University of Notre Dame	IN

SECURE AND TRUSTWORTHY CYBERSPACE (SaTC)

SaTC Funding[1]
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request
CISE	$70.81	-	$75.81
EDU[2]	59.99	-	75.00
ENG	3.25	-	3.25
MPS	1.26	-	1.25
SBE	4.00	-	4.00
Total	**$139.31**	**-**	**$159.31**

[1] Funding displayed may have overlap with other topics and programs.
[2] Formerly known as Directorate for Education and Human Resources (EHR).

Overview

In today's increasingly networked, distributed, and asynchronous world, society is deeply reliant on 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 an interdisciplinary 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 and information science; engineering; mathematics; statistics; the social, behavioral, and economic sciences; and education research, but also the transition 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 cybersecurity 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). 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 and mitigations of 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 supports education research that leads to

[1] www.nitrd.gov/pubs/Federal-Cybersecurity-RD-Strategic-Plan-2019.pdf

the development of new instructional materials, degree programs, and educational pathways, for example from the undergraduate sector into the cybersecurity workforce. Ultimately, through SaTC, NSF funds a broad and deep interdisciplinary 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 these technologies may present. Similarly, NSF's support in this area will lead to the development of an American workforce and citizenry with an understanding of cybersecurity and privacy issues. As the goals of SaTC contribute to national security, NSF plans to continue investments in this area for the foreseeable future.

Goals

1. *Fundamental 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 promising 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 and privacy solutions and moving them into operational environments.
3. *Education and Preparation of Cybersecurity and Privacy 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 includes NSF's investment in the CyberCorps®: Scholarship for Service (SFS) program.

FY 2023 Investments

<u>Fundamental Research</u>

- NSF will issue a revised SaTC solicitation in FY 2023 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 and engineering of cybersecurity and privacy, with emphases on: security and privacy aspects of pandemic-related technologies including new threats in the virtual setting; security and reliability of 5G and Beyond wireless networks; methods of reliably detecting "deep fakes" and inferring provenance of such misinformation, especially in the context of images, audio, and video; radio-frequency (RF)/analog hardware electronics and supply chain security; implications of quantum computing for security, including post-quantum cryptography; developing new architectures, systems, and technologies for protecting cyberspace from new and increasingly sophisticated attacks including adversarial machine learning; and security of smart infrastructure including the Internet of Things (IoT) and advanced manufacturing.
- 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; mathematics; statistics; the social, behavioral, and economic sciences; 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 and privacy in the global software supply chain; in virtual, augmented, and extreme

reality; and in the next generation of wireless networks beyond 5G. Additionally, NSF anticipates one or more workshops examining security and privacy needs associated with sharing government data with researchers.

- In FY 2023, NSF will continue to explore the role of cybersecurity and privacy research in future pandemics through the Pandemic Research for Preparedness and Resilience (PREPARE) Virtual Organization (VO)[2] that was established in FY 2020 to engage researchers, industry, government, and other stakeholders. To encourage research collaborations, the PREPARE VO will continue to hold workshops to identify future research directions and run the Science Before the Storm podcast exploring the frontiers of pandemic research. The VO serves as a resource to the community by conducting an annual meeting of researchers working in pandemic related challenges, providing links to data sets and upcoming workshops of interest, and disseminating all information collected as a result of this project with the aim of generating a community-driven research roadmap that identifies key research challenges and directions to bolster resilience and prepare the community for the next pandemic.
- In May 2021 NSF held a workshop in collaboration with NIH on "Establishing the Roadmap for Security, Privacy, and Ethics in Health and Biomedical Research"[3] that brought together leading researchers and stakeholders from the computing and information as well as the health and biomedical research fields to establish the vision and create a roadmap for security, privacy, and ethics in the intersection of computing health/bio-medical research. NSF will consider activities or new funding initiatives based on the roadmap produced by this workshop.
- NSF is working with the White House Office of Science and Technology Policy (OSTP), and the National Institute of Standards and Technology (NIST) to lead an interagency initiative to jointly develop, with the United Kingdom, prize challenges in the area of privacy enhancing technologies (PETs).[4] These PETs present an important opportunity to harness the power of data in a manner that protects privacy and intellectual property and enables cross-border and cross-sector collaboration to accelerate work to overcome technical gaps and adoption challenges. This effort was also motivated by the discussion in the NSF-NIST workshop "To Develop a Roadmap for Greater Public Use of Privacy-Sensitive Government Data"[5] held in May 2021, which focused more broadly on impediments to broader use of government data.
- NSF issued a DCL in February 2022 that invites proposals related to information integrity including detecting, mitigating, and countering threats to accuracy of information, and understanding the interactions of people with information systems. In FY 2023 NSF will continue to invest in information integrity research to analyze, among other areas, the flow of information and to mitigate the impacts of manipulated information in online and other computer-mediated systems. This research includes analyzing factors that influence trust in communications and understanding the motivations and behaviors of actors creating and transmitting misinformation and disinformation. NSF will promote interdisciplinary research collaborations in information integrity that will enable enhancements to the integrity of U.S. information systems, for example, by helping to counter foreign and extremist influence on social media and to enhance the flow of accurate information to support public health and a thriving economy.

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[2] https://prepare-vo.org/events
[3] https://sites.rutgers.edu/idsla/spe-in-healthcare/
[4] www.whitehouse.gov/ostp/news-updates/2021/12/08/us-and-uk-to-partner-on-a-prize-challenges-to-advance-privacy-enhancing-technologies/
[5] https://may2021privacy.github.io/

Accelerating TTP

Through the SaTC program and in collaboration with TIP, 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 through support of TTP-designated projects. These projects must demonstrate how technology from prior successful research results will be deployed into an organization, system, or community. The outcome of a TTP-designated project should be demonstrable advancement in the technology's readiness, robustness, validation, or functionality. NSF will also continue to support research infrastructure in security and privacy in conjunction with the CISE Community Research Infrastructure program.

Education and Preparation of Cybersecurity Researchers and Professionals

- In support of the 2019 *Federal Cybersecurity Research and Development Strategic Plan*, NSF will continue its focus on cybersecurity education in FY 2023, with the aims of (a) building and sustaining an unrivaled cybersecurity workforce; (b) promoting the development and maintenance of inclusive learning settings to improve diversity in cybersecurity; and (c) raising cybersecurity awareness across the general population.
- In FY 2023 NSF will further expand or initiate new cybersecurity education programs), which improve education delivery methods for K-12 students, teachers, counselors, and post-secondary institutions and encourage students to pursue cybersecurity careers. NSF will provide education supplements to SaTC research projects, leveraging the original SaTC projects to rapidly transition advances in cybersecurity research to novel educational materials that can lead to new ways of teaching and learning cybersecurity concepts and principles and enable the co-evolution of cybersecurity curricula with the state-of-the-art in the cybersecurity body of knowledge. These supplements could focus on educational innovations at any level from K-12 to graduate school and are complementary to NSF's efforts to strengthen the national cybersecurity workforce pipeline via the CyberCorps®: SFS program highlighted below, and part of this program ($5.0 million) is also complementary to the Cyber Defense Education & Training program at the Cybersecurity and Infrastructure Security Agency.
- CyberCorps®: SFS will seek to increase investments in K-12 as well as post-secondary education) with the aim of growing interest in cybersecurity careers and their intersection with other key areas of national interest such as data science and AI. Such investments will promote learning of foundational cybersecurity principles and safe online behavior; develop curriculum materials and improve teaching methods to help K-12 teachers and college professors integrate cybersecurity and privacy into formal and informal learning settings; develop new knowledge on how people learn the concepts, practices, and ways of thinking in cybersecurity; and promote teacher recruitment in the field of cybersecurity. Part of this program ($5.0 million) is complementary to the Cyber Defense Education & Training program at the Cybersecurity and Infrastructure Security Agency.
- CyberCorps®: SFS will address a critical shortage of cybersecurity educators and researchers by preparing up to 10 percent of SFS scholars to fulfil their service obligation as cybersecurity faculty members; continuing support of collaborative efforts among the AI, cybersecurity, and education research communities to foster a robust workforce with integrated AI and cybersecurity competencies; and exploring new collaborations at the intersection of cybersecurity and privacy, and other priority areas such as quantum information science and engineering as well as next-generation wireless networks.

- With the aim of increasing the participation of populations traditionally underrepresented in the cybersecurity workforce, CyberCorps®: SFS will make investments to (a) understand barriers to diversity, equity, and inclusion at SFS institutions; and (b) implement best practices to address such barriers.

SPECTRUM INNOVATION INITIATIVE (SII)

SII Funding
(Dollars in Millions)

FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request
$17.00	**$17.00**	**$17.00**

Overview

The electromagnetic spectrum and its management play 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 communication devices. The SII is a multidisciplinary, cross-Directorate, NSF-wide program to promote dynamic and agile electromagnetic spectrum utilization, while ensuring innovation and security for all users: both active spectrum applications such as those in advanced wireless and spectrum for passive scientific purposes such as radio astronomy and geospace sciences. The SII promotes United States leadership through basic research, infrastructure development, new collaborations, public outreach, education, and workforce development.

Goals

NSF's goal is to promote transformative use and management of the electromagnetic spectrum, resulting in profound benefits for science and engineering, industry, and other national interests. As demands for spectrum availability have increased, the need to use this limited natural resource more efficiently and robustly to meet multiple goals has also increased. Increasing demand for spectrum from applications such as 5G-and-beyond networks, national defense systems, and cutting-edge tools and facilities utilized by scientific research for atmospheric sensing, astronomy, and other purposes are major sources of demand for spectrum availability. 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, coherent, 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 spectrum, and development of a technologically sophisticated workforce. Enhancing efficient spectrum utilization and access is vital to the national interest, including the scientific enterprise, national defense, and emerging industries. NSF is working closely with the Federal Communications Commission and the National Telecommunications and Information Administration to ensure that NSF SII investments in spectrum research and development are in alignment with national spectrum regulatory and policy objectives, principles, and strategies. [1]

The primary goals of the SII include the following:

1. Develop the concept and infrastructure for National Radio Dynamic Zones (NRDZ), which will be used for testing of next-generation, advanced dynamic spectrum utilization techniques within pilot test beds in unique geographic locations to minimize regulatory hurdles that slow innovation. The goal is improved spectrum efficiency/effectiveness through secure/autonomous spectrum decision making.

[1] www.fcc.gov/document/fcc-federal-partners-sign-spectrum-innovation-cooperation-agreement

2. Establish and sustain an interdisciplinary National Center for Wireless Spectrum Research (SII-Center) that will catalyze partnerships between government, industry, and academia, and bring teams of scientists, engineers, computer scientists, and social scientists together to innovate. The goal of the SII-Center is to develop new solutions that enable more efficient use of the electromagnetic spectrum.
3. Integrate NRDZ and the SII-Center with the frontier research currently being conducted through other NSF programs and facilities. Those programs include, for example, 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 which require access to the electromagnetic spectrum such as the Green Bank Observatory, the National Radio Astronomy Observatory, and the National Center for Atmospheric Research.
4. Promote opportunities and develop the workforce needed, as a key national resource, 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 tomorrow.
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 2023 Investments

Investments in FY 2023 include the following:

<u>National Radio Dynamic Zones ($9.0 million)</u>
This investment will continue work on spectrum sharing solutions, site studies and application studies for National Radio Dynamic Zones towards enhancement of active electromagnetic spectrum management efforts at NSF's major research facilities and platforms. The investment will also initiate work to understand social, behavioral, and economic issues that affect the deployment of radio dynamic zones.

<u>National Center for Wireless Spectrum Research ($5.0 million)</u>
This investment will sustain activities of the interdisciplinary SII-Center program, which brings together diverse groups of researchers to develop, innovate, and sustain new solutions that enable more efficient use of the electromagnetic spectrum.

<u>Integration Activities ($2.0 million)</u>
This investment will continue to integrate ongoing and increasing NSF activities, including SWIFT research, partnerships with EPSCoR to explore active radio frequency interference cancellation and build workforce capacity, and the support of national and international spectrum regulatory efforts, such as NSF's management of polar programs.

<u>Workforce Development and Public Outreach ($1.0 million)</u>
To promote national leadership in spectrum innovation and enhance opportunities on both national and local levels, including for underserved communities, the investment in workforce development will include fellowships associated with the above efforts and research funded through SWIFT, PAWR, and the SII-Center, 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.

NSF SELECTED CROSSCUTTING PROGRAMS

Many investments at NSF draw on interdisciplinary teams from across the Foundation. Other parts of this chapter, NSF-Wide Investments, provide narratives for selected NSF-wide investments. Additional cross-cutting programs are presented in the narrative below.

ADVANCE

In FY 2023, $20.50 million 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 to enhance gender equity for faculty and academic administrators. As such, ADVANCE is an integral part of 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. Further, ADVANCE contributes important research on successfully supporting women in STEM. EDU (formerly known as EHR) stewards funding for ADVANCE in FY 2023 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 2023 Request provides $360.10 million for the CAREER program, funding approximately 680 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. Funding for CAREER is provided by BIO, CISE, ENG, GEO, MPS, and SBE.

Industry-University Cooperative Research Centers (IUCRC)

The Industry–University Cooperative Research Centers (IUCRC) program accelerates the impact of basic research through close relationships between industry innovators, world-class academic teams, and government leaders. IUCRCs are designed to help corporate partners and government agencies connect directly and efficiently with university researchers to achieve three primary objectives. 1) Conduct high-impact research to meet shared industrial needs in companies of all sizes; 2) Enhance U.S. global leadership in driving innovative technology development; and 3) Identify, mentor, and develop a diverse high-tech, exceptionally skilled workforce. NSF created the IUCRC program in 1973 to foster long-term partnerships among industry, academe, and government. These partnerships support research programs of mutual interest, contribute to the nation's research infrastructure base, promote workforce development, and facilitate technology transfer. Every year, more than 2,000 students engage in industrially relevant research at Centers nationwide, giving them on the job training for a career in the private sector. About 30 percent of these student researchers are hired by the member companies.

The FY 2023 Request provides $21.86 million for the IUCRC program. Primary funding for IUCRC is provided by CISE and ENG, with additional contributions from other directorates.

Long-Term Ecological Research (LTER)

The FY 2023 Request provides $34.14 million for LTER. LTER 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 28 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 2023 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 40 years and conducting syntheses of long-term data using contemporary modeling methods. Funding for LTER is provided by BIO, GEO, and SBE.

The National Ecological Observatory Network (NEON) infrastructure is co-located at nine 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 some 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 Facilities chapter.

National Nanotechnology Coordinated Infrastructure (NNCI)

In FY 2023, $15.46 million is requested for the NNCI sites. This represents part of NSF's contribution to the National Nanotechnology Initiative (NNI), which is described in greater detail in the NNI section of NSF-Wide Investments. Funding for NNCI is provided by BIO, CISE, ENG, GEO, MPS, SBE, and OISE.

NSF Innovation Corps (I-Corps™)

In FY 2023, $40.0 million is requested for NSF Innovation Corps. The 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 by NSF in 2011, is to reduce the time and risk associated with translating promising ideas and technologies from the laboratory to the marketplace. 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 fundamental research into deep technology ventures. Its curriculum consists of experiential learning for customer and industry discovery, coupled with first-hand investigation of industrial processes, allowing teams to quickly assess the translational potential of inventions. Funding for I-Corps™ is provided by TIP.

Research Experiences for Undergraduates (REU)

In FY 2023, $84.14 million 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. Funding for REU is provided by BIO, CISE, ENG, GEO, MPS, and SBE.

Research in Undergraduate Institutions (RUI)

The FY 2023 Request for NSF's RUI program totals $34.99 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. Funding for RUI is provided by BIO, CISE, MPS, and SBE.

NATIONAL SCIENCE FOUNDATION
SELECTED CROSSCUTTING PROGRAMS
FY 2023 BUDGET REQUEST TO CONGRESS
(Dollars in Millions)

Selected Crosscutting Programs		FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	FY 2023 Request change over FY 2021 Actual	
					Amount	Percent
ADVANCE	R&RA	0.12	-	-	-0.12	-100.0%
	EDU	18.00	-	20.50	2.50	13.9%
	Total, NSF	**$18.12**	**-**	**$20.50**	**$2.38**	**13.1%**
Faculty Early Career Development - CAREER	R&RA	473.86	-	354.10	-119.76	-25.3%
	EDU[1]	-	-	6.00	6.00	N/A
	Total, NSF	**$473.86**	**-**	**$360.10**	**-$113.76**	**-24.0%**
Industry/University Cooperative Research Centers - I/UCRC	R&RA	21.79	-	21.86	0.07	0.3%
	EDU	-	-	-	-	N/A
	Total, NSF	**$21.79**	**-**	**$21.86**	**$0.07**	**0.3%**
Long-Term Ecological Research Sites - LTERs	R&RA	32.21	-	34.14	1.93	6.0%
	EDU	-	-	-	-	N/A
	Total, NSF	**$32.21**	**-**	**$34.14**	**$1.93**	**6.0%**
National Nanotechnology Coordinated Infrastructure - NNCI	R&RA	15.70	-	15.46	-0.24	-1.5%
	EDU	-	-	-	-	N/A
	Total, NSF	**$15.70**	**-**	**$15.46**	**-$0.24**	**-1.5%**
NSF Innovation Corps - I-Corps™	R&RA	39.02	-	40.00	0.98	2.5%
	EDU	-	-	-	-	N/A
	Total, NSF	**$39.02**	**-**	**$40.00**	**$0.98**	**2.5%**
Research Experiences for Undergraduates - REU - Sites Only	R&RA	62.96	-	66.82	3.86	6.1%
	EDU	-	-	-	-	N/A
	Total, NSF	**$62.96**	**-**	**$66.82**	**$3.86**	**6.1%**
Research Experiences for Undergraduates - REU - Supps Only	R&RA	22.49	-	17.32	-5.17	-23.0%
	EDU	-	-	-	-	N/A
	Total, NSF	**$22.49**	**-**	**$17.32**	**-$5.17**	**-23.0%**
Research in Undergraduate Institutions - RUI	R&RA	45.36	-	34.99	-10.37	-22.9%
	EDU	-	-	-	-	N/A
	Total, NSF	**$45.36**	**-**	**$34.99**	**-$10.37**	**-22.9%**

[1] EDU did not report CAREER funding in prior years.

IMPROVING UNDERGRADUATE STEM EDUCATION (IUSE)

IUSE Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request
BIO	$5.00	-	$5.00
CISE	-	-	3.00
EDU[1]	90.00	-	95.50
ENG	-	-	5.15
GEO	4.25	-	-
Total	**$99.26**	**-**	**$108.65**

[1] Formerly known as EHR.

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 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 systemic efforts. In addition, IUSE supports innovative undergraduate STEM education to prepare the STEM workforce in interdisciplinary areas, such as computational and data-enabled science and engineering. It also supports education in emerging fields such as AI and QIS. All IUSE projects include 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. 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, institutional and community transformation, increasing access to undergraduate research experiences, and developing courses and instructional materials utilizing emerging technologies. This flexibility enables IUSE to respond rapidly to support emerging areas and Administration priorities. For example, in FY 2021, IUSE contributed to the Data Science Corps (DSC) program within the HDR Big Idea. HDR-DSC supports projects that engage a diverse cadre of students in solving data science challenges faced by communities, organizations, and governmental agencies. Thus, DSC leverages undergraduate data

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[1] National Science Board (2018). Our Nation's Future Competitiveness Relies on Building a STEM-Capable U. S. Workforce. Retrieved from: 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

science education in service to science and society, contributing to a strong national data science infrastructure and workforce. In FY 2021 IUSE launched a new initiative through the release of a program description, *Advancing Innovation and Impact in Undergraduate STEM Education at Two-Year Institutions of Higher Education*[4], which also seeks to support systemic approaches to advance inclusive and equitable STEM education practices at two-year colleges. With more than 1,000 two-year colleges enrolling over 11 million students, these institutions provide STEM education to a large population of students entering the STEM workforce and are critical to our STEM competitiveness. Among U.S. students who earned Science & Engineering bachelor's degrees between 2010 and 2017, about half (47 percent) had done some coursework at a community college and nearly a fifth (18 percent) earned associate degrees.

IUSE was initiated as a multi-year, NSF-wide priority investment area, originally 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 to ensure the United States' undergraduate STEM education enterprise remains current with advances in STEM and STEM education. However, NSF anticipates that IUSE will continue as the principal component of its undergraduate education strategies for the long term.

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 Environments:* Investments will build 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 build the knowledge base for how to do so.
3. *Build the STEM Workforce for Emerging Industries:* Investments will advance the preparation of undergraduate students to be productive members of the future STEM and STEM-capable workforce.

FY 2023 Investments

As part of its mission to advance STEM, NSF plans to invest $108.65 million in IUSE in FY 2023. The IUSE initiative's anchor investment is made by IUSE/EDU, a program solicitation within EDU's Division of Undergraduate Education. IUSE/EDU supports research and development activities such as studying 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/EDU is complemented by five additional IUSE core programs, which share the three common IUSE goals listed in the previous section but have more specific funding goals than IUSE/EDU:

- EDU – *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 40 awards.

[4] https://beta.nsf.gov/funding/opportunities/advancing-innovation-and-impact-undergraduate-stem-education-two-year

- EDU – *IUSE: Two Year Colleges (IUSE: TYC):* Supports STEM education initiatives which enhance STEM teaching and learning at two-year colleges; approximately 20 awards.
- BIO – *IUSE: Research Coordination Networks/Undergraduate Biology Education (RCN-UBE)*: Supports collaborative networks to improve undergraduate biology education; approximately 15 awards.
- ENG – *IUSE/Professional Formation of Engineers: Revolutionizing Engineering Departments (IUSE/PFE:RED)*: Supports organizational change strategies to transform undergraduate engineering education; approximately five to ten awards.
- CISE – *IUSE: Computing in Undergraduate Education (IUSE:CUE)*: Supports collaborative partnerships to re-envision the role of computing in undergraduate education, leading to a larger, more diverse population of students with the computational skills necessary for careers in a broad range of fields; approximately six awards.

IUSE funding focuses on advancing the Nation's vision of an undergraduate STEM education enterprise in which every undergraduate becomes STEM-knowledgeable and all students who desire to pursue a STEM education that maximizes their full potential for a STEM career can do so.

MAJOR INVESTMENTS IN SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS (STEM) GRADUATE STUDENTS AND GRADUATE EDUCATION

Overview

The progress of science and engineering (S&E) requires a U.S. workforce that has a significant segment with graduate-level preparation in STEM research and innovation, or in professional fields such as cybersecurity and STEM teaching. Today, S&E research increasingly demands collaborations that span institutions, disciplines, and national boundaries; requires the use of sophisticated data infrastructure and instruments; and rests on professionals who are adept at working in teams and communicating about their work. Moreover, computationally intensive and data-enabled investigations not only in specialized areas such as AI and QIS, but increasingly, in all areas of science, are 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 highly capable scientists and engineers who not only meet the needs of the STEM enterprise, but who also have the knowledge, skills, and preparation to lead STEM innovation in academia and the private and public sectors.

Aligned with Administration and Congressional priorities, NSF invests substantial resources through inclusive processes to support the next generation of discoverers. Such support helps to create a diverse and talented pool of future STEM research leaders and professionals in leading-edge scientific areas that touch many sectors of the economy. Towards this end, NSF makes a significant investment in the education of graduate students via research assistantships funded through research awards across the agency. The Division of Graduate Education (DGE) also supports both individual graduate students through mechanisms such as traineeships, scholarships, and fellowships, and, importantly, innovation in graduate education to best prepare future research leaders.

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 lead and innovate in STEM-intensive careers. This goal is based on an NSF strategic framework[1] that outlines the following specific aims:

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.

[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.

FY 2023 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). EDU's DGE leads management for both programs, with the benefit of input from NSF-wide working groups. Both programs support actions recommended in major national reports[2] as ways to better prepare graduates for a broad range of careers. 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 that supports 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 by providing them with stipend support as well as a contribution towards the costs of their education. Both NRT and GRFP 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 improving the understanding of STEM professional workforce development.

Several other NSF programs focus on developing sectors of the STEM workforce and supporting students in testing new models and approaches to graduate education. For example, the CyberCorps®: Scholarship for Service (SFS) program 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 from there 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 the NRT Program are to support highly effective training of STEM graduate students in convergent research areas of national priority, as well as to create, promote, and disseminate innovative, effective, and scalable models for STEM graduate student training. In FY 2023, NRT will focus particularly on traineeships that prepare students to lead in emerging industries.

NRT addresses interdisciplinary graduate education through two approaches: traineeships and fundamental research into graduate education. Traineeships emphasize comprehensive training

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[2] National Academy of Sciences, Engineering, and Medicine. 2018. Graduate STEM Education in the 21st Century. Washington, 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 www.acd.od.nih.gov/documents/reports/bmw_report.pdf

models that are innovative, evidence-based, and aligned with changing workforce and research needs. Such models aim to prepare STEM graduate students to contribute to high-priority interdisciplinary research areas. The training includes development of technical and professional skills for both research and research-related careers within and outside academia. NRT training components are made available to both NRT-funded students and other graduate students who may want to take advantage of these opportunities. NRT also seeks to support projects in diverse institution types. Fundamental education research is addressed through the IGE component of NRT, which focuses on test-bed projects aimed at piloting, testing, and validating innovative and potentially transformative approaches to graduate education of students pursuing academic master's, professional science master's, and doctoral degrees. These approaches include activities such as career preparation, mentoring, partnerships, and internships. IGE will also support broader access to these advances for the graduate education community, including graduate faculty, staff, and graduate school administrators. NSF expects to fund 16-19 traineeships and invest up to $4.0 million in fundamental research on graduate education.

NRT Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request
BIO	$0.05	-	-
EDU	58.00	-	62.50
Total	**$58.05**	**-**	**$62.50**

Graduate Research Fellowship Program

The goal of GRFP is to identify and nurture the STEM human capital necessary to ensure the Nation's leadership in advancing innovations in S&E, with an emphasis on broadening participation. GRFP selects, recognizes, and financially supports graduate students with demonstrated high potential for excellence in STEM careers. Applications are welcome from students in all disciplines supported by NSF, including STEM, STEM education, or STEM interdisciplinary areas. In FY 2023, GRFP will be funded entirely within EDU at a total of $355.51 million. This funding will support a total of 2,750 new fellows with a cost of education allowance of $12,000 and a stipend of $37,000, an increase of $3,000 from the previous amount. The GRFP program will continue to welcome proposals from all S&E fields and also align awards with NSF and Administration research priorities.

GRFP Funding by Account
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request
STEM Education	$284.51	-	$355.51
Research and Related Activities[1]	*[142.19]*	-	-
Total	**$284.51**	-	**$355.51**
Number of New Fellows	2,005	-	2,750
Projected Fellows on Tenure[2]	5,842	-	6,837

[1] In FY 2022, funding will be consolidated in the Directorate for STEM Education. Prior year funding is restated for comparability across fiscal years.

[2] 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.

<u>CyberCorps®: Scholarship for Service</u>

The SFS program addresses cybersecurity education and workforce development by providing funding to institutions to support development of cybersecurity educational projects and related activities such as cyber camps, cohort building and mentoring, and to allow the award of scholarships to undergraduate and graduate students enrolled in these educational programs. In return for their scholarships, tuition, fees, health insurance, travel, and book allowances, recipients must complete a government-based internship and work after graduation for a Federal, state, local, or tribal government organization in a cybersecurity-related position for a period equal to the length of the scholarship. The SFS program also supports research and development to improve cybersecurity education and workforce training, particularly in emerging areas such as the nexus between cybersecurity and AI, through the Secure and Trustworthy Cyberspace: Education program (SaTC-EDU).

SFS Funding

(Dollars in Millions)

FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request
$59.99	**-**	**$75.00**

<u>Additional Programs and Activities Supporting STEM Graduate Education and Workforce Development</u>

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 individuals from populations historically underrepresented 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 groups such as those above. The LSAMP-BD is a targeted activity through which established alliances provide post-baccalaureate fellowships to support transition into and success of students in STEM master's and/or doctoral programs, thus increasing their entry into the STEM workforce. In FY 2023, LSAMP expects to direct about $13.50 million toward the LSAMP-BD program.

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 reflected the national need to increase the number of American scientists and engineers. The S-STEM program provides institutions with funds for student scholarships to support low-income, academically talented U.S. students with demonstrable financial need. These scholarships, together with additional supports such as mentoring and internships, help these students earn an associate, baccalaureate, or graduate degree in STEM fields. These graduates will be highly prepared to enter and contribute to the STEM workforce. The S-STEM program emphasizes the importance of recruiting students to pursue 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 for up to four years, depending on cost of attendance and unmet financial need. S-STEM expects to offer support for up to 250 Masters or PhD students in FY 2023. In addition to providing scholarship support, S-STEM projects also contribute to the knowledge base about effective STEM education by carrying out research on effective practices to recruit STEM students and support them to earn STEM degrees. S-STEM is funded through H-1B Nonimmigrant Petitioner Account receipts. In FY 2023, S-STEM expects to invest approximately $10.0 million in awards to support scholarships for graduate students.

Robert Noyce Teacher Scholarship (Noyce)

The Noyce responds to the increasing need for highly effective K-12 STEM teachers and teacher leaders. Noyce supports institutions of higher education to develop and sustain comprehensive programs of study that encourage and support undergraduate STEM majors and STEM professionals to become effective K-12 STEM teachers in high-need school districts. It also supports experienced, exemplary K-12 STEM teachers to become teacher leaders in high-need school districts and to engage their colleagues in communities of practice focused on continued professional development. Furthermore, the Noyce program funds research on the effectiveness and retention of K-12 STEM teachers in high-need school districts.

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 2023.

Additional Programs Supporting STEM Graduate Education and Funding Workforce Development

(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request
LSAMP-BD	-	-	$13.50
S-STEM	14.50	-	10.00
Noyce Teaching and Master Teaching Fellows (10A)	16.80	-	20.00
Total	**$31.30**	**-**	**$43.50**

RESEARCH AND RELATED ACTIVITIES (R&RA) $8,425,990,000

+$1,522,780,000 / 22.1%

The FY 2023 Budget Request for the Research and Related Activities account is $8,425.99 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 accelerate progress in basic science and engineering research as well as support the private sector.

NSF is the only federal agency dedicated to funding basic research across all areas of non-biomedical science and engineering. In FY 2023, NSF will continue its longstanding commitment to investing in learning and discovery that will promote the innovations that help fuel the Nation's future prosperity.

R&RA Funding
(Dollars in Millions)

	FY 2021 Actual[1,2]	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Percent
Biological Sciences	$817.41	-	$970.23	$152.82	18.7%
Computer & Information Science & Engineering	1,007.13	-	1,150.78	143.65	14.3%
Engineering	764.43	-	940.28	175.85	23.0%
Geosciences	1,004.27	-	1,239.05	234.78	23.4%
Mathematical & Physical Sciences	1,593.31	-	1,746.85	153.54	9.6%
Social, Behavioral & Economic Sciences	282.11	-	330.21	48.10	17.1%
Technology, Innovation, & Partnerships	369.01	-	879.87	510.86	138.4%
Office of International Science & Engineering	51.29	-	74.04	22.75	44.4%
Office of Polar Programs	484.04	-	547.10	63.06	13.0%
Integrative Activities	528.61	-	545.86	17.25	3.3%
U.S. Arctic Research Commission	1.60	-	1.72	0.12	7.5%
Total	**$6,903.21**	**-**	**$8,425.99**	**$1,522.78**	**22.1%**

[1] Funding in FY 2021 is re-stated for comparability across fiscal years to reflect the creation of TIP in FY 2022.

[2] Funding in FY 2021 is re-stated for comparability across fiscal years to reflect the movement of the Graduate Research Fellowship Program from IA to the Directorate for STEM Education in the EDU Account, expected in FY 2022.

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; ~~$8,139,710,000~~$8,425,987,000, to remain available until September 30, ~~2023~~2024, of which not to exceed ~~$544,000,000~~$640,000,000 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 2023 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 2021 Appropriation	$7,376.68	$10.27	-$280.82	$22.24	-$29.29	$7,099.08
FY 2022 Annualized CR	6,909.77	280.82				7,190.59
FY 2023 Request	8,425.99					8,425.99
$ Change from FY 2022 Annualized CR						$1,235.40
% Change from FY 2022 Annualized CR						17.2%

Totals exclude reimbursable amounts.

Explanation of Carryover

<u>Research and Related Activities (R&RA)</u>
Within the R&RA account, $280.82 million (including $271.46 million in American Rescue Plan Funding) was carried over into FY 2022.

Integrative Activities Research Investment Communications
- Amount: $299,000
- Purpose: Funds will be used for NSF multimedia contract awards that were not ready for obligation in FY 2021. Funding will be used on four procurement actions in process that will be completed in time for award this fiscal year.
- Obligation: FY 2022 Quarter 2.

Integrative Activities for Program Planning and Policy Development
- Amount: $840,000
- Purpose: These funds will support activities associated with NSF's merit review process including survey, studies, and committee of visitors data maintenance. Additionally, NSF funded an award supporting the core activities of the National Academies' Committee on Science, Engineering, Medicine, and Public Policy.
- Obligation: Anticipated FY 2022 Quarter 4.

Integrative Activities for Evaluation and Assessment Capabilities program

- Amount: $251,000
- Purpose: These carryover funds will be used for Evaluation and Assessment Program Services contract to support NSF's implementation of Evidence Act requirements, notably those identified in NSF's draft Learning Agenda and Capacity Assessment.
- Obligation: Anticipated FY 2022 Quarter 3.

Integrative Activities for Historically Black Colleges and Universities – Excellence in Research

- Amount: $993,000
- Purpose: Funds will provide supplemental support to postdoctoral researchers, graduate students, and undergraduate students disproportionately impacted by the COVID-19 pandemic.
- Obligation: Anticipated FY 2022 Quarter 3.

National Coordination Office for Networking and Information Technology Research and Development

- Amount: $60,276
- Purpose: Funding to continue government procurements and operational expenses (i.e., credit card purchases, government travel, mailroom operations, etc.).
- Obligation: Anticipated FY 2022 Quarter 4.

National Nanotechnology Coordination Office

- Amount: $214,130
- Purpose: Funding for the National Nanotechnology Coordination Office (NNCO) for NNCO operational expenses.
- Obligation: Anticipated FY 2022 Quarter 4.

American Rescue Plan (R&RA)

- Amount: $271.46 million
- Purpose: Funds will be used for awards that were not ready for obligation in FY 2021.
- Obligation: FY 2022 Quarter 1–2 and remaining amounts to be obligated in Quarter 3

The remaining $6.70 million within discretionary R&RA consists of funds from throughout the Foundation for projects not funded in FY 2021.

DIRECTORATE FOR BIOLOGICAL SCIENCES (BIO) $970,230,000
+$152,490,000 / 18.6%

BIO Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2021 ARP Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Biological Infrastructure (DBI)	$167.01	-	-	$221.28	$54.27	32.5%
Environmental Biology (DEB)	178.78	-	-	186.15	7.37	4.1%
Integrative Organismal Systems (IOS)	206.89	-	-	214.81	7.92	3.8%
Molecular and Cellular Biosciences (MCB)	155.55	-	-	162.47	6.92	4.4%
Emerging Frontiers (EF)	109.51	9.18	-	185.52	76.01	69.4%
Total	**$817.74**	**$9.18**	**-**	**$970.23**	**$152.49**	**18.6%**

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 simultaneously sensing processes at multiple biological scales, and new computational and AI approaches in bioinformatics and modeling that 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. The progress that will drive the Nation's bioeconomy comes from discovering and harnessing life's evolutionary innovations. BIO's support for foundational and translational research promotes economic prosperity, health, security, and well-being by addressing existing and future global challenges.

BIO's scientific investments align directly with Administration priorities, including biotechnology to promote the bioeconomy, forecasting, and mitigating the impacts of global warming on essential ecosystem services, and predicting and preventing the emergence of infectious diseases. BIO investments in genomics; cellular, organismal, and developmental biology; and bioinformatics spur further development of capabilities in synthetic biology and enhance biotechnology beyond current state-of-the-art technologies. 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.

Biotechnology advancements also support development of a circular bioeconomy that reduces carbon emissions and creates new sources of clean energy. To further support the development of dynamic, eco-forecasting models to predict climate change impacts at local, national, and global scales, BIO invests in research that covers the topics of ecology, evolution, and biodiversity, and includes support for the National Ecological Observatory Network (NEON). Similarly, BIO support for investigations into life's natural innovation will focus on understanding the adaptive potential of species and ecosystems to respond to climate change stressors such as ocean acidification, sea level rise, droughts, flooding, and other extreme events. Together, these investments are responsive to the national need to understand and develop solutions for the climate emergency. BIO will also increase investments in research on infectious disease emergence and transmission, contribute to a goal of preventing future pandemics, and fill knowledge gaps concerning the spread and evolution of biothreats.

Biological questions often drive convergence research across multiple fields of science and technology and stimulate applications that enhance economic and national security, and societal well-being. Pursuits in the biological sciences to quantify living systems at all scales have propelled the frontiers of research in statistical, 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 in biomaterial and other bio-inspired products, biological computing, and semiconductors, which exploit the extraordinary information density in genetic polymers, and neuro-technologies that power 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.

Tackling bold questions in biology increasingly requires an integrated approach that leverages advances from multiple subdisciplines and incorporates cutting-edge methods, tools, and concepts. Such research is critical to inform solutions to societal challenges, including natural resource management, resilience to environmental change, and global food security. BIO investments in Integrative Biology (IntBIO) and in Biology Integration Institutes (BII) represent major funding opportunities to encourage this type of synergistic research seeking a holistic understanding of how living systems function. BIO will increase support for these two programs to accelerate discovery of underlying principles operating across all hierarchical levels of life, from cells to organisms to ecosystems. BII provides institute-scale funding to address integration within biology itself, integration of research across scales of living systems, and cultural integration across the traditional sub-disciplines of biology that will propel significant advances in the life sciences. BII and IntBIO awards promote this integrative biology through highly collaborative, team science endeavors, which also fosters diversity and inclusion in science. This complements BIO's other investments in workforce development, including postdoctoral fellowships, which will also be expanded to promote advanced training and integrative research on genomes, environment, and phenotypes.

BIO will place greater emphasis on racial equity and inclusion in the biological sciences with the goal of broadening participation of biologists across the nation through a comprehensive and integrated portfolio of programs. The portfolio implements three evidence-based strategies to support BIO's goals: targeting critical career transition points, investing in under-resourced institutions, and addressing the culture of science and its critical role in diversity, equity, and inclusion. In recognizing the importance of targeting critical career transition points, BIO is investing in new efforts to support full-time research, mentoring, networking, and training for recent college graduates through the Research and Mentoring for Postbaccalaureate in Biological Sciences program, with an emphasis on engaging underrepresented groups. BIO is also investing in new opportunities for mid-career scientists and researchers from groups underrepresented in STEM through the Mid-Career Advancement and Transitions to Excellence in Molecular and Cellular Biosciences (Transitions) programs, as well as its existing Postdoctoral Research Fellowships in Biology program to support a diversity of young researchers, with an increased focus on broadening participation. For the strategy to invest in under-resourced institutions, BIO continues to invest in HBCU-EiR as well as a new program, Building Research Capacity of New Faculty in Biology, to enhance the research capacity and broaden the participation of new faculty of biology at predominantly undergraduate minority-serving institutions, as well as other universities and colleges that are not among the nation's most research-intensive institutions. For the strategy to address the culture of science and its crucial role in broadening participation, BIO will continue to leverage the unique ability of professional societies to create culture change in the biological sciences through the Professional Societies program as well as continue to invest in the cross-agency INCLUDES program. Finally, BIO will continue investments in the Research Experiences for Teachers Sites in Biological Sciences program to provide new opportunities to engage teachers and their classrooms in STEM and support early engagement and the creation of inclusive learning environments.

BIO promotes other opportunities for convergence research and training through active participation and foundational investments in several Big Ideas. BIO participates in the NNA Big Idea through investments in environmental research and observational infrastructure in the Arctic, the Long-Term Ecological Research program (LTER), and NEON. BIO also participates in QIS-related activities, 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 structure and function of tens of thousands of molecules in cells, to collecting and analyzing data from environmental observatories such as NEON, which provide open data on environmental and land use change for the entire United States. BIO's investments in data and informatics include CyVerse for omics data, Protein Data Bank for structural biology, and iDigBio for biodiversity collections. BIO also provides support for the Environmental Data Initiative and will continue to support a new Center for Open Environmental Data Synthesis to advance modeling and forecasting capability for climate change impacts established in FY 2022.

As the lead directorate, BIO is the steward of funds designated for NSF-wide investments for the URoL. For more information about the Big Ideas, see the narrative in the Cross Theme Topics section of the NSF-Wide Investments chapter.

BIO provides 65 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 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Advanced Manufacturing	$7.16	-	$17.16	$10.00	139.7%
Artificial Intelligence	20.00	-	20.00	-	-
Biotechnology	110.00	-	130.00	20.00	18.2%
Climate: Clean Energy Technology	45.00	-	59.28	14.28	31.7%
Climate: USGCRP[3]	155.00	-	237.15	82.15	53.0%
Improving Undergraduate STEM Education	5.00	-	5.00	-	-
Postdoctoral Research Fellowships in Biology[4]	22.79	-	26.90	4.11	18.0%
Quantum Information Science	3.28	-	3.28	-	-
Understanding the Rules of Life	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] Funding includes resources for agency-wide initiatives.

[4] $10.50 million will support the Broadening Participation track.

- 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. BIO will support an AI Institute to advance the use of AI methods such as machine learning, natural language processing, computer vision, and genetic algorithms in biological research. AI contributes to solving 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.
- Biotechnology: BIO will increase investments in support of the bioeconomy through research funding programs in synthetic biology, genomics, bioinformatics, biotechnology, and training fellowships to help build the U.S. workforce in this area. BIO will support research to advance the ability to build cells and cell-like systems, explore novel concepts and enabling technologies to develop next-generation information storage and computing systems driven by biological principles, foundational research, and tool development in the growing field of plant synthetic biology, and interdisciplinary research to develop novel biological platforms that are capable of sensing and responding to infectious agents and other biothreats. These investments will be coordinated with programs established in the Directorate for Technology, Innovation, and Partnerships (TIP) to translate knowledge and tools into applications that promote the U.S. bioeconomy in public health, agriculture, energy, climate change, and security.
- Clean Energy: BIO supports research to advance clean energy biotechnologies and practices

through fundamental research in areas such as systems and synthetic biology, plant genomics, and ecosystem sciences. This research seeks to streamline and scale the metabolic, energetic, and physiological potential of living organisms to produce non-petroleum sources of important chemicals/materials, plant biomass, feed stocks, and biofuels. Bioinspired design of complex biomaterials that can transform light into energy will also be supported. Investigations to assess the impact of fuel and/or bio-renewable chemical production on genome stability and phenotype of the production organisms are of interest, as are studies to assess environmental impacts of these technologies.

- Climate Change: With a broad set of complementary and interacting funding programs, BIO will increase its support for research to understand the critical feedbacks between Earth's biota and the climate system, and to advance predictive models for how climate warming will impact critical U.S. ecosystems, including agricultural systems, forests, grasslands, freshwater, coastal and arctic systems, human communities in both urban and rural regions, and Tribal Nations. In addition, BIO will increase support for research to understand the adaptive potential of species, ecosystems, and human society to respond to a warming climate and how this scales to impact regional ecosystems. Results will inform efforts to improve natural and human system resilience to climate change. BIO's support for this urgent challenge includes operations of NEON, the Nation's premier ecological observatory, and research programs such as LTER, Macrosystem Biology, and Dynamics of Integrated Socio-Environmental Systems. These provide the foundational knowledge to advance eco-forecasting capability and guide efforts to mitigate the impact of climate warming on human health, and sectors of the bioeconomy such as agriculture, fisheries, and forestry.
- Improving Undergraduate STEM Education (IUSE): BIO is committed to continuing investments to enhance and improve education in the nation. BIO supports the creation of networks of scientists, educators, and other stakeholders to advance and transform biology education. In pursuit of this goal, BIO will continue to support undergraduate biology education activities through Research Collaboration Networks in Undergraduate Biology Education to stay current with challenges, new technology, and trends. BIO places a high value on virtual learning, including virtual tutoring systems and virtual laboratories. For more information regarding IUSE, see the Cross Theme Topics section of the NSF-Wide Investments chapter.
- Postdoctoral Research Fellowships in Biology: BIO will continue to support this program with an increased emphasis on broadening the participation of groups underrepresented in biology. BIO's investments will prepare biologists from underrepresented groups and others who share NSF's diversity goals at the postdoctoral level for scientific leadership positions in academia, industry, and government.
- 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 the NSF URoL Big Idea, which 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. URoL science advances biological theory that explains the complexity, diversity, and adaptability of living systems. BIO also will continue foundational investments that support the goals of URoL through its institute-scale program, Biology Integration Institutes, and its Integrative Biology program, which promotes ambitious, high-risk/high-reward collaborative research. A priority within these funding programs is discovery of rules of life and advancing understanding of functional genomics, especially plant genomics, that can inform applications in agriculture, energy, and climate change mitigation.

BIO Funding for Centers Programs and Major Facilities

BIO Funding for Centers Programs
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Biology Integration Institutes	$19.95	-	$49.50	$29.55	148.1%
Centers for Analysis & Synthesis	-	-	5.00	5.00	N/A
STC: Biology with X-ray Lasers	4.15	-	-	-4.15	-100.0%
STC: Center for Cellular Construction	5.20	-	5.00	-0.20	-3.8%
STC: Center for Research on Programmable Plant System	-	-	5.00	5.00	N/A
Total	**$29.30**	**-**	**$64.50**	**$35.20**	**120.1%**

BIO supports investment in core research and education as well as research infrastructure. In FY 2023, BIO will invest $64.50 million in research centers, accounting for 6.8 percent of the BIO budget, funding twenty BIIs, two Centers for Analysis and Synthesis, and two Science and Technology Centers. O&M funding for BIO-supported facilities is 7.4 percent of BIO's FY 2023 Request.

For detailed information on individual centers programs, please see the Cross Theme Topics section of the NSF-Wide Investments chapter.

BIO Funding for Major Facilities
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
National Ecological Observatory Network (DBI)	$65.00	-	$70.00	$5.00	7.7%

For detailed information on individual facilities, please see the Research Infrastructure section of the NSF-Wide Investments chapter.

Funding Profile

BIO Funding Profile

	FY 2021 Actual Estimate	FY 2022 (TBD)	FY 2023 Estimate
Statistics for Competitive Awards:			
Number of Proposals	3,960	-	4,000
Number of New Awards	1,175	-	1,200
Regular Appropriation	1,175		1,200
ARP			
Funding Rate	30%	-	30%
Statistics for Research Grants:			
Number of Research Grant Proposals	3,355	-	3,400
Number of Research Grants	934	-	1,000
Regular Appropriation	934		1,000
ARP			
Funding Rate	28%	-	29%
Median Annualized Award Size	$222,366	-	$230,000
Average Annualized Award Size	$260,029	-	$270,000
Average Award Duration, in years	3.5	-	3.5

People Involved in BIO Activities

Number of People Involved in BIO Activities

	FY 2021 Actual Estimate	FY 2021 ARP Actual Estimate	FY 2022 (TBD)	FY 2023 Estimate
Senior Researchers	4,474	-	-	5,000
Other Professionals	1,402	-	-	1,600
Postdoctoral Associates	1,638	135	-	1,700
Graduate Students	2,926	-	-	3,800
Undergraduate Students	4,225	-	-	4,700
K-12 Teachers	-	-	-	-
K-12 Students	-	-	-	-
Total Number of People	**14,665**	**135**	**-**	**16,800**

DIVISION OF BIOLOGICAL INFRASTRUCTURE (DBI) $221,280,000

+$54,270,000 / 32.5%

DBI Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	FY 2021 Actual Amount	FY 2021 Actual Percent
Total	**$167.01**	**-**	**$221.28**	**$54.27**	**32.5%**
Research	**28.98**	**-**	**77.17**	**48.19**	**166.3%**
Centers Funding (total)	9.15	-	50.00	40.85	446.4%
Biology Integration Institutes	-	-	37.00	37.00	N/A
Centers for Analysis & Synthesis	-	-	3.00	3.00	N/A
STC: Biology with X-ray Lasers (BioXFEL)	4.15	-	-	-4.15	-100.0%
STC: Center for Cellular Construction (CCC)	5.00	-	5.00	-	-
STC: Center for Res. on Program. Plant Sys. (CROPPS)	-	-	5.00	5.00	N/A
Education	**20.89**	**-**	**31.00**	**10.11**	**48.4%**
Infrastructure	**117.14**	**-**	**113.11**	**-4.03**	**-3.4%**
MSRIAP	0.50	-	-	-0.50	-100.0%
NEON	65.00	-	70.00	5.00	7.7%
NNCI	0.35	-	0.35	-	-
Research Resources	51.29	-	42.76	-8.53	-16.6%

About DBI

DBI empowers biological discovery by investing in the innovation and capacity-building of cutting-edge research infrastructure for fundamental biological science, which includes human capital, technologies, institutes and centers, and mid-to-large scale infrastructure. DBI supports the development of, and improvements to, research infrastructure, including cyberinfrastructure; bioinformatics; biotechnology; 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 at the undergraduate level by participating in the NSF-wide IUSE program, and the Research Experiences for Undergraduate Sites program. DBI also offers a multi-track postdoctoral research fellowships program with special emphasis on interdisciplinary research training, and on broadening participation in the biological sciences.

In calendar year 2021, BIO launched several new programs that have a strong emphasis on broadening participation at the individual or institutional level and are managed through the Human Resources cluster of DBI. DBI also provides sustained support for key facilities and other resources that enable researchers across the full breadth of biology to address targeted but deep questions. DBI supports the operation and maintenance of NEON, which is enabling study of the biosphere and its response to environmental change at a continental scale. NEON goals have major societal impact, particularly with respect to ecological forecasting. Additional infrastructure support will focus on developing the 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 ENVIRONMENTAL BIOLOGY (DEB) $186,150,000
+$7,370,000 / 4.1%

DEB Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	FY 2021 Actual Amount	Percent
Total	**$178.78**	**-**	**$186.15**	**$7.37**	**4.1%**
Research	174.87	-	183.65	8.78	5.0%
Education	3.91	-	2.50	-1.41	-36.1%

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 living systems, including its history and patterns of speciation and extinction. DEB also supports research that advances understanding of the important role biodiversity plays in regulating ecological and ecosystem processes over both short- and long-temporal scales and varying spatial scales. The discoveries from this research can inform strategies to develop, utilize, and sustain biological resources, including natural, agricultural, and other managed ecosystems, and to forecast changes in species populations and ecosystems responding to climate change and other anthropogenic disturbances.

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 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, about 75 percent of the DEB portfolio is available for new research grants, and 25 percent is available for continuing grants.

DIVISION OF INTEGRATIVE ORGANISMAL SYSTEMS (IOS) $214,810,000
+$7,920,000 / 3.8%

IOS Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$206.89**	**-**	**$214.81**	**$7.92**	**3.8%**
Research	**187.73**	**-**	**199.01**	**11.28**	**6.0%**
Education	**7.74**	**-**	**4.80**	**-2.94**	**-38.0%**
Infrastructure	**11.42**	**-**	**11.00**	**-0.42**	**-3.7%**
Research Resources	11.42	-	11.00	-0.42	-3.7%

About IOS

IOS supports fundamental research and training focused on mechanistic analyses of the functional phenotypic characteristics of diverse organisms. IOS prioritizes integrative research linking biological molecules to complex populations through understanding the processes that build and maintain diverse organisms in the contexts in which they function. Spanning the gamut of biological diversity, including viruses and other microbes, fungi, and wild and domesticated plants and animals, IOS-funded research reveals the mechanisms underlying multi-scale emergent properties of organisms that allow them to function as they do in a variety of developmental, social, physiological, and environmental contexts. Specifically, IOS-funded research uncovers how the nervous system, organismal growth and development, behavioral, genetic, genomic, biochemical, biophysical, and physiological processes are integrated and result in the stability and flexibility of organisms living in dynamic environments. Such analyses are essential to understanding the principles that produce the vast diversity of life on Earth and the mechanisms that allow for biological resilience and adaptation to change.

IOS encourages interdisciplinary science, and the development of new approaches, to solve basic and applied problems through the Enabling Discovery through Genomics and Organismal Response to Climate Change Programs. IOS continues to leverage its activities across the spectrum of NSF basic science, together with agricultural research supported by the U.S. Department of Agriculture's National Institutes of Food and Agriculture, by supporting research on plant biotic interactions, genomics, and innovative tools for high-throughput analysis of agriculturally important plants. IOS prioritizes investments in computational biology in neuroscience and support for the NSF-Simons Research Centers for Mathematics of Complex Biological Systems.

Results of IOS-supported research contribute to the URoL and other NSF Big Ideas. IOS-supported science is highly relevant to the bioeconomy and societal needs for pandemic preparedness, food security and sustainability, understanding the healthy brain, and understanding how organisms respond, withstand, and adapt to multi-dimensional stressors, including those associated with life in a changing world.

In general, about 66 percent of the IOS portfolio is available for new research grants, and 34 percent is available for continuing grants.

DIVISION OF MOLECULAR AND CELLULAR BIOSCIENCES (MCB) $162,470,000
+$6,920,000 / 4.4%

MCB Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$155.55**	**-**	**$162.47**	**$6.92**	**4.4%**
Research	**153.36**	**-**	**159.47**	**6.11**	**4.0%**
STC: Center for Cellular Construction (CCC)	0.20	-	-	-0.20	-100.0%
Education	**0.94**	**-**	**2.00**	**1.06**	**112.8%**
Infrastructure	**1.25**	**-**	**1.00**	**-0.25**	**-20.0%**
Facilities Design Stage Activities (total)	1.25	-	1.00	-0.25	-20.0%
Center for High Energy X-ray Sciences (CHEXS)	1.25	-	1.00	-0.25	-20.0%

About MCB

MCB supports fundamental interdisciplinary research to uncover the basic principles that describe cellular function at the molecular level, including (a) how information content in cells is maintained and transmitted to the next generation and guides expression of cellular characteristics; (b) how material and energy are absorbed, transformed, and flow through biological systems; and (c) how biological molecules assemble into complex structures and compartments with varied functions. MCB also supports research that uses molecular biophysics, systems biology, and synthetic biology to probe fundamental biological questions that address the essential processes required for life. Due to its interdisciplinary nature, MCB research contributes to NSF's Big Ideas, URoL, and QIS-related activities.

Additionally, MCB supports convergence research at both 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, while also advancing 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 fundamental research not only enable the development of design rules for engineering molecules and cells, but also directly contribute to biological innovations that advance emerging industries and the U.S. bioeconomy, medicine, agriculture, environmental sustainability, and biomanufacturing sectors. MCB research has the potential to address future challenges by providing biotechnology solutions to mitigate the impact of climate change; predicting, detecting, and preventing future pandemics; and ensuring food production on a changing plant.

In general, about 80 percent of the MCB portfolio is available to support new research grants, and 20 percent is available for continuing grants.

DIVISION OF EMERGING FRONTIERS (EF) $185,520,000

+$76,010,000 / 69.4%

EF Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over Amount	Percent
Total	**$109.51**	**-**	**$185.52**	**$76.01**	**69.4%**
Research	**105.65**	**-**	**117.52**	**11.87**	**11.2%**
Centers Funding (total)	19.95	-	14.50	-5.45	-27.3%
Biology Integration Institutes	19.95	-	12.50	-7.45	-37.3%
Centers for Analysis & Synthesis	-	-	2.00	2.00	N/A
Education	**3.68**	**-**	**68.00**	**64.32**	**1747.8%**
Infrastructure	**0.18**	**-**	**-**	**-0.18**	**-100.0%**
Research Resources	0.18	-	-	-0.18	-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 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, about 50 percent of the EF portfolio is available for new research grants. The remaining 50 percent supports research grants made in prior years and research infrastructure needed by the biological sciences community.

DIRECTORATE FOR COMPUTER AND INFORMATION SCIENCE AND ENGINEERING (CISE) $1,150,780,000 +$143,650,000 / 14.3%

CISE Funding
(Dollars in Millions)

	FY 2021[1] Actual	FY 2021 ARP Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Office of Advanced Cyberinfrastructure (OAC)	$230.44	$6.59	-	$252.25	$21.81	9.5%
Computing and Communication Foundations (CCF)	200.95	1.75	-	218.57	$17.62	8.8%
Computer and Network Systems (CNS)	238.02	4.87	-	266.06	$28.04	11.8%
Information and Intelligent Systems (IIS)	217.78	1.75	-	248.16	30.38	14.0%
Information Technology Research (ITR)	119.94	20.75	-	165.74	45.80	38.2%
Total	**$1,007.13**	**$35.72**	**-**	**$1,150.78**	**$143.65**	**14.3%**

[1] Funding for FY 2021 is adjusted for comparability to reflect the movement of I-Corps™ to TIP in FY 2022.

About CISE

Advances in information technology (IT) over recent decades have proven to be key drivers of the U.S. economy. Essentially all practical applications of today's IT are based on ideas and concepts that emerged from investments in fundamental computing and information research, many of them funded by CISE.[1] Fundamental ideas and concepts advanced through computing and information research have enabled innovative products and applications that now benefit many aspects of daily life, including personal communication, clean energy, intelligent 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 investments will accelerate climate and clean energy research, advance equity in science, engineering, and society, and bolster U.S. leadership in critical and emerging technologies.

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 cyberinfrastructure (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 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 and information professionals; and more broadly, informs the preparation of a U.S. workforce with computing, computational, and information competencies essential for success in an increasingly competitive global and digital market. CISE investments foster and support research and teaching environments that promote equity. CISE executes its mission through its Divisions of Computing and Communication Foundations (CCF), Computer and Network Systems (CNS), Information and Intelligent Systems (IIS), and Information Technology Research (ITR), and through the Office of Advanced Cyberinfrastructure

[1] www.nap.edu/catalog/25961/information-technology-innovation-resurgence-confluence-and-continuing-impact

(OAC), 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, private industry and foundations, and international funders.

In FY 2023, CISE will continue to support Nation's priorities through investments in AI, advanced computing systems and services including high-performance computing (HPC), QIS, advanced communications technologies, advanced manufacturing, semiconductors and microelectronics, biotechnology, cybersecurity, and disaster response and resilience. CISE's investments in these areas contribute significantly to national security, economic competitiveness, sustainability, and the broad advancement of all fields of science and engineering. Advances in these areas will provide opportunities for major scientific breakthroughs and will positively transform U.S. lives and industry for years to come. As part of these investments, CISE will advance democracy-affirming technologies, including privacy-preserving technologies.

CISE's FY 2023 Budget Request is also shaped by the directorate's continued support for NSF's Big Ideas, including co-leadership of HDR and FW-HTF, and participation in NNA and URoL. Further, as part of HDR, and in partnership with the other research directorates and offices, CISE will invest, through its ITR division, in convergent activities that transcend the traditional disciplinary boundaries of individual NSF units. CISE, as the steward for HDR and in partnership with the other directorates, 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. CISE's FY 2023 Budget Request comprises support for other ongoing NSF-wide priorities as well, including microelectronics and semiconductor research and SaTC.

CISE, through OAC, will provide NSF's co-leadership of the National Science and Technology Council's Future Advanced Computing Ecosystem (FACE) subcommittee.[2] As part of its support for FACE, CISE investments will support the full breadth of NSF-funded S&E, including research furthering our understanding of climate science and clean-energy technologies, by (i) advancing future computing paradigms, devices, architectures, and platforms; and (ii) furthering 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. These investments will enable shared resources and improved capabilities across a range of disciplines, a diverse set of users within a large number of academic institutions, and a wide range of science and engineering advances. In FY 2023, CISE will invest, through its ITR division, in the development of a National Discovery Cloud (NDC) for Climate. This resource will federate advanced compute, data, software and networking resources, democratizing access to a cyberinfrastructure ecosystem that is increasingly necessary to further climate-related S&E. The NDC for Climate will serve as a pilot for future efforts to enable equitable access to an NDC across all fields of S&E.

Given the increasingly influential societal role of computing research, it is critical to ensure the Nation offers broad access to and education on this topic. As a part of an agency-wide emphasis, CISE will continue to invest in a broad suite of activities to support broadening participation in research and education in CISE fields and STEM more generally. For example, in alignment with NSF INCLUDES, the Broadening Participation in Computing Alliances (BPC-A) will serve as broad coalitions of institutions

[2] www.nitrd.gov/pubs/Future-Advanced-Computing-Ecosystem-Strategic-Plan-Nov-2020.pdf

of higher education, K-12 schools, government, industry, professional societies, and other not-for-profit organizations that design and carry out comprehensive programs addressing underrepresentation in the computing and information science disciplines. Additionally, the CISE Minority-Serving Institutions Research Expansion (CISE-MSI) program will continue to broaden participation by increasing the number of CISE-funded research projects from MSIs, which are central to inclusive excellence. CISE's investments in Computer Science for All (CSforAll) and CISE Graduate Fellowships (CSGrad4US) also will emphasize education and training of more U.S.-based students from diverse backgrounds.

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. In addition, CISE co-chairs the National Artificial Intelligence Research Resource (NAIRR) Task Force, which is charged with developing a roadmap and implementation plan for a shared computing and data infrastructure. The envisioned NAIRR aligns with the NDC for Climate described above.

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 translation of research innovations to practice, and enhance workforce development. CISE will coordinate closely with other directorates as well as with the Strategic Partnerships Office within the TIP directorate.

CISE provides about 79 percent of the federal funding for fundamental computer science research at U.S. academic institutions.

Major Investments

CISE Major Investments

(Dollars in Millions)

				Change over FY 2021 Actual	
Area of Investment[1,2]	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Amount	Percent
Advanced Manufacturing	$44.40	-	$42.22	-$2.18	-4.9%
Advanced Wireless Research	87.45	-	93.26	5.81	6.6%
Artificial Intelligence	344.00	-	369.80	25.80	7.5%
Biotechnology	6.92	-	6.00	-0.92	-13.3%
CISE Graduate Fellowships	-	-	20.70	20.70	N/A
Climate: Clean Energy Technology	24.22	-	31.12	6.90	28.5%
Climate: USGCRP[3]	-	-	40.00	40.00	N/A
Microelectronics and Semiconductors	17.95	-	23.46	5.51	30.7%
Quantum Information Science	20.70	-	24.28	3.58	17.3%
Secure & Trustworthy Cyberspace[4]	70.81	-	75.81	5.00	7.1%

[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] Funding includes resources for agency-wide initiatives.

[4] FY 2023 Request funding includes $5.0 million to strengthen the national cybersecurity workforce pipeline, which is complementary to the Cyber Defense Education & Training program at the Cybersecurity and Infrastructure Security Agency. An additional $5.0 million for this program is budgeted within EDU.

- 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: 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 specifically enable further exploration of additional spectrum bands, efficient spectrum sharing, spectrum monitoring, and development of novel applications that leverage advanced wireless communication networks. In partnership with the private sector and other federal agencies, CISE will accelerate research in areas with potential significant impact on emerging Next-Generation (NextG) wireless and mobile communications, networking, sensing, and computing systems, with a focus on greatly improving the resiliency and intelligence of such networked systems, through the Resilient & Intelligent NextG Systems (RINGS) program and other related investments. CISE investments in at-scale research testing platforms through the Platforms for Advanced Wireless Research program will also expand engagement in important advanced wireless areas, including affordable rural broadband and autonomous aerial vehicles. These investments enable broad researcher access to large-scale research resources and accelerate the translation of innovative research outcomes in academic and government labs to societal benefits and to successful commercial products and services.

- AI: CISE, together with other NSF directorates/offices, other federal agencies, and the private sector, will increase support for AI research and development. A key focal point will be support for the National AI Research Institutes. These center-scale projects advance foundational research; conduct use-inspired research; build the next generation of talent, including at emerging research institutions; mobilize multidisciplinary groups of scientists, engineers, and educators; comprise multiple organizations working together to create significant new research capabilities; and serve as a nexus point for multisector collaborative efforts. The National AI Research Institutes will fill a major 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]
- Climate: Clean Energy Technology: CISE will support research and education projects on all sustainability topics in which advances in computing and information management are indispensable, including the areas of advanced sensing techniques; large-scale data management and analytics; optimization, modeling, simulation, prediction, and inference; intelligent systems and decision making; infrastructure design, control, and management; and human-computer interaction and social computing. Additionally, the widespread, intensive use of computing technologies introduces further sustainability challenges and motivates new approaches across the lifecycle of technology design, use, and decommission.
- Climate: USGCRP: Through its ITR division, CISE will invest funds in the NDC for Climate to federate access to advanced compute, data, software, and networking resources from multiple sources, including NSF-funded advanced computing resources, edge resources located at NSF major facilities, and capabilities deployed at other compute- and data-intensive NSF research facilities, as well as commercial cloud computing resources. The NDC for Climate will incorporate systems to curate, federate, and provide access to data from multiple sources. These approaches will advance our understanding of the Earth's climate by supporting the broad examination and reexamination of collected data, and by supporting scientific analysis of combinations of data from different sources, be they NSF-funded large facilities, resources provided by other organizations, or the data contributions of individual researchers. The NDC for Climate will further NSF's commitment to equity by democratizing access to research resources, along with the necessary support services, including outreach, on-ramping, and access to the resources made available through the NDC for Climate.
- CSGrad4US: CISE will select, recognize, and financially support early-career individuals with the demonstrated potential to be high-achieving CISE researchers and innovators, with the goal of developing the national workforce necessary to ensure the Nation's continued leadership in advancing CISE research and innovation. Through this investment, CISE aims to increase the number and diversity of domestic graduate students pursuing graduate degrees and research and innovation careers in the CISE fields—computer science, computer engineering, and/or information science—and broaden participation among groups underrepresented in these areas, including women, African Americans, Hispanics, American Indians, Alaska Natives, Native Hawaiians, Native Pacific Islanders, and persons with disabilities.
- Microelectronics and Semiconductors: CISE 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

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

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.

- 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. Part of CISE's investments in QIS will be continuing to grow 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 EDU, 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, information integrity, and critical infrastructure security. CISE SaTC investments will also nurture the next generation of American cybersecurity and privacy researchers and practitioners. CISE will fund programs that strengthen the national cybersecurity workforce pipeline through education, K-12 programs, and funding to universities and colleges. This funding is intended to further expand and initiate cybersecurity education programs, which improve education delivery methods for K-12 students, teachers, counselors, and post-secondary institutions and encourage students to pursue cybersecurity careers.

CISE Funding for Centers Programs

CISE Funding for Centers Programs
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Percent
Artificial Intelligence Research Institutes (Multiple)[1]	$40.55	-	$30.50	-$10.05	-24.8%
STC: Center for Brains, Minds & Machines: The Science & the Tech. of Intelligence (CCF, IIS, ITR)	4.15	-	-	-4.15	-100.0%
STC: Center for Learning the Earth with Artificial Intelligence and Physics (IIS)	1.50	-	-	-1.50	-100.0%
Total	**$46.20**	**-**	**$30.50**	**-$15.70**	**-34.0%**

[1] In FY 2021, CISE increased investments in AI Institutes by $15.5 million over the $25.5 million originally planned. The FY 2023 Request reflects an increase of $5.0 million over the FY 2021 Current Plan.

For detailed information on individual centers programs, please see the Cross Theme Topics section of the NSF-Wide Investments chapter.

Funding Profile

CISE Funding Profile

	FY 2021 Actual Estimate	FY 2022 (TBD)	FY 2023 Estimate
Statistics for Competitive Awards:			
Number of Proposals	7,247	-	8,500
Number of New Awards	1,739	-	2,300
Regular Appropriation	1,694		2,300
ARP	45		
Funding Rate	24%	-	27%
Statistics for Research Grants:			
Number of Research Grant Proposals	7,054	-	8,300
Number of Research Grants	1,625	-	2,150
Regular Appropriation	1,582		2,150
ARP	43		
Funding Rate	23%	-	26%
Median Annualized Award Size	$166,549	-	$166,000
Average Annualized Award Size	$224,030	-	$225,000
Average Award Duration, in years	3.1	-	3.0

In FY 2023, the number of research grant proposals is expected to increase as compared to the FY 2021 Actual Estimate, and correspondingly the number of research grant awards is anticipated to increase to 2,150. The funding rate for research grants is expected to be 27 percent in FY 2023, an increase over the FY 2021 Actual Estimate. Average annualized award size and average award duration are expected to remain about the same between the FY 2021 Actual Estimate and the FY 2023 Estimate.

People Involved in CISE Activities

Number of People Involved in CISE Activities

	FY 2021 Actual Estimate	FY 2021 ARP Actual Estimate	FY 2022 (TBD)	FY 2023 Estimate
Senior Researchers	8,110	235	-	9,300
Other Professionals	1,438	63	-	1,600
Postdoctoral Associates	522	72	-	600
Graduate Students	6,150	69	-	7,000
Undergraduate Students	2,933	50	-	3,400
Total Number of People	**19,153**	**489**	**-**	**21,900**

OFFICE OF ADVANCED CYBERINFRASTRUCTURE (OAC) $252,250,000 +$21,810,000 / 9.5%

OAC Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$230.44**	**-**	**$252.25**	**$21.81**	**9.5%**
Research	**97.29**	**-**	**97.65**	**0.36**	**0.4%**
Centers Funding (total)	12.00	-	4.00	-8.00	-66.7%
Artificial Intelligence Research Institutes	12.00	-	4.00	-8.00	-66.7%
Education	**9.18**	**-**	**10.35**	**1.17**	**12.7%**
Infrastructure	**123.97**	**-**	**144.25**	**20.28**	**16.4%**
Networking and Computational Resources	121.48	-	144.25	22.77	18.7%
Mid-scale Research Infrastructure	2.49	-	-	-2.49	-100.0%

About OAC

OAC supports 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 supporting the national response to the COVID-19 pandemic, and enabling innovations in AI, QIS, and advanced wireless, which are critical to the Nation's economy and future jobs. OAC investments also further understanding of climate science and clean-energy technologies by enabling data science, artificial intelligence and machine learning, and predictive and high-end computational modeling and simulation. 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, encouraging a rich and vibrant ecosystem that blends translational computer science, 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. OAC enables 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, international research funders, and the private sector.

OAC will continue to co-chair on behalf of NSF, the National Science and Technology Council's (NSTC) Subcommittee on the Future Advanced Computing Ecosystem (FACE). The FACE Subcommittee has developed a strategic plan describing priority areas that spur 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 advanced computing ecosystem including software, data, and expertise; and forge and expand partnerships. The FACE Subcommittee has also developed the National Strategic Computing Reserve (NSCR), a vision for sustaining the highly successful COVID-19 High-Performance Computing Consortium in the longer term.

OAC also co-chairs the National Artificial Intelligence Research Resource Task Force, which is charged by Congress with developing a roadmap and implementation plan for a shared computing and data infrastructure that would provide a diverse set of researchers and students across the broad spectrum of AI research and development with access to a holistic ecosystem of resources to fuel AI discovery and innovation.

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

DIVISION OF COMPUTING AND COMMUNICATION FOUNDATIONS (CCF) $218,570,000 +$17,620,000 / 8.8%

CCF Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$200.95**	**-**	**$218.57**	**$17.62**	**8.8%**
Research	**188.75**	**-**	**203.17**	**14.42**	**7.6%**
Centers Funding (total)	4.99	-	3.00	-1.99	-39.9%
Artificial Intelligence Research Institutes	2.50	-	3.00	0.50	20.0%
STC: Center for Brains, Minds and Machines: The Science and the Technology of Intelligence (CCF, IIS, ITR)	2.49	-	-	-2.49	-100.0%
Education	**10.35**	**-**	**13.80**	**3.45**	**33.3%**
Infrastructure	**1.85**	**-**	**1.60**	**-0.25**	**-13.5%**
National Nanotechnology Coordinated Infrastructure (NNCI)	0.60	-	0.60	-	-
Research Resources	1.25	-	1.00	-0.25	-20.0%

About CCF

CCF supports research and education activities involving the mathematical, scientific, and technological 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 efficiency, fairness, correctness, and robustness of systems including 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 various facets of computation, communication, and information that are of relevance to key priorities such as climate change and the economy.

In general, about 68 percent of the CCF portfolio is available to support new grants. The remaining 32 percent supports grants made in prior years.

DIVISION OF COMPUTER AND NETWORK SYSTEMS (CNS) $266,060,000
+$28,040,000 / 11.8%

CNS Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$238.02**	**-**	**$266.06**	**$28.04**	**11.8%**
Research	**192.25**	**-**	**226.96**	**34.71**	**18.1%**
Centers Funding (total)	9.00	-	3.50	-5.50	-61.1%
Artificial Intelligence Research Institutes	9.00	-	3.50	-5.50	-61.1%
Education	**13.36**	**-**	**16.10**	**2.74**	**20.5%**
Infrastructure	**32.41**	**-**	**23.00**	**-9.41**	**-29.0%**
Research Resources	31.41	-	23.00	-8.41	-26.8%
Mid-scale Research Infrastructure	1.00	-	-	-1.00	-100.0%

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, as well as innovations in climate and clean energy technology. CNS-enabled systems include, but are not limited to, cyber-physical, embedded, distributed, centralized, virtualized, cloud, wireless, mobile systems, and information integrity. 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. CNS has fostered and continues to expand partnerships with many high-tech companies and government funding agencies to enhance support for research and education programs. CNS also supports research-based pilot projects that have the potential for scalable, sustainable, and transferable impact on communities, from small to large, and rural to urban – across the US.

In general, about 73 percent of the CNS portfolio is available to support new grants. The remaining 27 percent supports grants made in prior years.

DIVISION OF INFORMATION AND INTELLIGENT SYSTEMS (IIS) — $248,160,000 +$30,380,000 / 14.0%

IIS Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$217.78**	**-**	**$248.16**	**$30.38**	**14.0%**
Research	**202.00**	**-**	**231.96**	**29.96**	**14.8%**
Centers Funding (total)	11.38	-	10.00	-1.38	-12.1%
Artificial Intelligence Research Institutes	9.05	-	10.00	0.95	10.5%
STC: Center for Brains, Minds and Machines: The Science and the Technology of Intelligence (CCF, IIS, ITR)	0.83	-	-	-0.83	-100.0%
STC: Center for Learning the Earth with Artificial Intelligence and Physics	1.50	-	-	-1.50	-100.0%
Education	**10.71**	**-**	**14.20**	**3.49**	**32.5%**
Infrastructure	**5.06**	**-**	**2.00**	**-3.06**	**-60.5%**
Research Resources	2.06	-	2.00	-0.06	-3.0%
Mid-scale Research Infrastructure	3.00	-	-	-3.00	-100.0%

About IIS

IIS supports research and education activities that advance our knowledge of AI, data science, and human-computer interaction. The range of research topics within these areas is broad: AI includes work on knowledge representation and reasoning, machine learning, human language technologies, and computer vision; data science includes data collection and management, data integration, data mining and analytics, and informatics; and human-computer interaction includes useability, interfaces, assistive technology, and the social impacts of computing. The work supported by IIS lays the foundations for building more intelligent, human-compatible computing systems capable of advancing all sectors of the economy and society. IIS partners with other divisions, directorates, and agencies to advance diverse areas of foundational AI, data science, and human-computer interaction research across almost all areas of science, engineering, and society, including climate change and racial equity.

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

DIVISION OF INFORMATION TECHNOLOGY RESEARCH (ITR) $165,740,000 +$45,800,000 / 38.2%

ITR Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual: Amount	Change over FY 2021 Actual: Percent
Total	**$119.94**	**-**	**$165.74**	**$45.80**	**38.2%**
Research	**90.87**	**-**	**150.95**	**60.08**	**66.1%**
Centers Funding (total)	8.83	-	10.00	1.17	13.3%
Artificial Intelligence Research Institutes	8.00	-	10.00	2.00	25.0%
STC: Center for Brains, Minds and Machines: The Science and the Technology of Intelligence (CCF, IIS, ITR)	0.83	-	-	-0.83	-100.0%
Education	**6.86**	**-**	**3.55**	**-3.31**	**-48.2%**
Infrastructure	**22.22**	**-**	**11.24**	**-10.98**	**-49.4%**
Research Resources	17.22	-	11.24	-5.98	-34.7%
Mid-scale Research Infrastructure	5.00	-	-	-5.00	-100.0%

About ITR

ITR provides support for transformative explorations in computer and information science and engineering research, infrastructure, and education, which are foundational for a wide range of emerging industries. These investments support emerging and high-priority areas that cut across traditional disciplinary boundaries and promise to accelerate discovery at the frontiers of the field. This includes support for foundational research on AI, QIS, particularly quantum computation and communication, and advanced wireless as well as the development of world-class research infrastructure. ITR further catalyzes research through innovative partnerships and collaborations between academia and industry. ITR will also support the development of a National Discovery Cloud (NDC) for climate that will offer large-scale democratized and equitable access to advanced compute, data, and software resources. ITR investments, often in partnership with all CISE divisions as well as NSF directorates, agencies, and industry, further research that address climate, clean energy, and equity, as well as grow our economy and jobs.

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. 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 38 percent of the ITR portfolio is available to support new grants. The remaining 62 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 2021 Actual	FY 2022 (TBD)	FY 2023 Request
Leadership Class Computing	$19.50	-	$0.50
Advanced/Innovative Computing Systems and Services	68.56	-	82.77
Coordination and Support Services	1.52	-	14.80
Total	**$89.58**	**-**	**$98.07**

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 (S&E) research. Going forward, 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 its co-leadership of the all-of-government National Science and Technology Council (NSTC) Future Advanced Computing Ecosystem (FACE) Subcommittee efforts. Within the broad goals set for the FACE[4,5] and as further elaborated by the NSTC FACE Subcommittee, key NSF foci include fundamental and translational research to support future generations of the advanced computing ecosystem; research cyberinfrastructure (CI) including software and data services to promote cohesive platforms and interoperability for large-scale data analytics as well as modeling and simulation applications across all of S&E; and the CI expertise necessary for advancing the frontiers of CI as well as enabling S&E discovery and innovation using CI. These foci include an emphasis on a holistic approach to America's computational and data infrastructure for S&E research, spanning both human and technical dimensions, and involve forging and expanding partnerships that ensure American leadership in science, technology, and innovation. For example, during the novel coronavirus disease 2019 (COVID-19) pandemic, NSF's suite of complementary advanced computing systems and coordination services were mobilized as key contributors to the COVID-19 High-Performance Computing (HPC) Consortium, a public-private partnership that NSF helped co-found to support cutting-edge scientific research in epidemiology, virology, and microbiology, among other topics.[6]

The overall NSF advanced computing strategy and program portfolio receives guidance and input from the Advisory Committee on Cyberinfrastructure (ACCI); the Assistant Directors (AD) Council, which includes ADs and office heads from the NSF research and education directorates and offices; the Cyberinfrastructure Strategy Group, which includes senior leadership from the NSF research and education directorates and offices, and directly from the research community through multiple sources including principal investigator meetings, workshops, sessions at professional conferences,[7] community blue-ribbon studies, and Requests for Information (RFIs). In 2019, NSF funded a conference focused on the *National Cyberinfrastructure Coordination Service Conference*, which

[4] www.nitrd.gov/news/2020/Future-Advanced-Computing-Ecosystem-Strategic-Plan-Nov-2020.aspx
[5] www.nsf.gov/cise/nsci/
[6] covid19-hpc-consortium.org/
[7] See, for example, https://sc20.supercomputing.org/proceedings/bof/bof_pages/bof143.html

examined the configuration of services intrinsic to a national CI.[8] Later in the year, NSF issued a RFI asking for input on "specific data-intensive S&E research questions and challenges and the essential data-related CI services and capabilities needed to publish, discover, transport, manage and process data in secure, performant and scalable ways to enable data-intensive research."[9] Although focused primarily on data and software CI, the responses to this RFI[10] have implications for the architectures of future advanced computing systems and the services associated with maintaining and operating them. In August and September 2020, NSF sponsored the CI Workforce Development Workshop[11] focused on issues related to building and enhancing the cyberinfrastructure professional workforce. Additionally, international 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 that the U.S. maintains its global leadership role in S&E.

In response to rapid advances in technology, changes in the capabilities and services offered by commercial interests (e.g., cloud services), and the rapid evolution of S&E research requirements, in FY 2019, NSF released a forward-looking computational ecosystem blueprint[12] and invested in three broad and complementary advanced computing areas in order to meet continually evolving needs in an agile yet predictable way. These investment areas 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 S&E research frontiers not otherwise possible;
- **Advanced/Innovative Computing Systems and Services**, which aims to provide a technically diverse, connected, 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 S&E 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.

In FY 2023, NSF-funded advanced computing systems and services will support the full breadth of NSF-funded S&E, including research furthering our understanding of climate science and clean-energy technologies, notably (i) data-driven approaches to assimilate heterogeneous data sets about climatology; (ii) large-scale modeling of Earth systems; and (iii) high-end simulations of renewable and alternative energy approaches, and novel materials supporting energy efficiency and sustainability.

[8] www.rti.org/publication/national-cyberinfrastructure-coordination-service-conference
[9] www.nsf.gov/pubs/2020/nsf20015/nsf20015.jsp
[10] www.nsf.gov/cise/oac/datacirfi/rfi_responses.jsp
[11] www.rcac.purdue.edu/ciworkforce2020
[12] www.nsf.gov/cise/oac/vision/blueprint-2019/nsf-aci-blueprint-v10-508.pdf

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 an U.S. academic campus. The system began accepting early S&E 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 S&E applications than ever before, within and across disciplines as diverse as biology, astronomy, engineering, materials science, and the geosciences. The Frontera system offers the highest scale, throughput, and data analysis capabilities ever deployed on a U.S. university campus. In addition, Frontera's graphics processing unit (GPU) accelerates discoveries in important research areas such as deep learning and molecular dynamics.

Current Status

At its July 2018 meeting, the NSB authorized the Director 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 first acquisition in a two-phased process. The NSB, at its May 2019 meeting, authorized the Director to make an award to TACC for the operations and maintenance (O&M) of Frontera in an amount not to exceed $60 million over a period of five years. Frontera has been in operation since September 2019 and is being actively used by the S&E research and education community across NSF and other agencies.

The July 2018 NSB resolution also authorized, pending appropriate approval associated with MREFC policies, supplemental funding to advance the design of a Phase 2 leadership-class computing facility (LCCF). In July 2019, TACC started the design and planning process for the LCCF. As noted in solicitation NSF 17-558[13] and as reported to Congress in response to the recommendations set forth in *Future Directions for NSF Advanced Computing Infrastructure to Support U.S. Science and Engineering in 2017-2020*, the LCCF planning will lead to the design of a major new facility that will host a new system with a ten-fold or more time-to-solution performance improvement over the Frontera system. The Frontera system is providing S&E evaluation to inform the design of the future facility. LCCF planning will be managed and overseen according to the NSF MREFC process. The project is therefore subject to MREFC policies regarding entry and approval into the required design stages as laid out in the NSF Research Infrastructure Guide.[14] LCCF planning will continue in FY 2023 with the start of construction of the future facility anticipated in FY 2024, pending successful reviews and approvals pursuant to the NSF MREFC process.

S&E 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 2020, NSF issued a Dear Colleague Letter[15] describing a new innovative pilot mechanism for the Nation's researchers to request access to Frontera to enable scientific and engineering research that would

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[13] www.nsf.gov/pubs/2017/nsf17558/nsf17558.htm
[14] www.nsf.gov/pubs/2021/nsf21107/nsf21107.pdf
[15] www.nsf.gov/pubs/2020/nsf20018/nsf20018.jsp

not otherwise be possible without access to a leadership-class computing resource. To date, this effort has resulted in over 100 allocation awards to research teams across the country. Examples of research that were enabled by the Frontera allocation awards include the full-scale modeling of the entire hippocampus in the brain to understand neurological disorders; simulations of supermassive black hole mergers to enable future gravitational wave detection; some of the largest simulation in the world to understand the physics and conditions that cause the formation of severe tornados; and high-resolution seismic hazard modeling to improve the health and safety of the Nation's earthquake prone regions.

In addition, Frontera continues to provide important compute cycles in the all-of-nation effort in response to the COVID-19 pandemic, including as a key contributor to the COVID-19 HPC Consortium. For example, the system provided significant computing capabilities to researchers seeking to understand the fundamental infection vectors through large-scale, all-atom simulations of the SARS-CoV-2 virus, as well as tracking the epidemiology of the virus to devise better intervention strategies for preventing disease spread.

NSF-funded leadership-class computing education and outreach activities consist of projects targeting students at pre-college, undergraduate, graduate, and post-graduate levels; workshops, conferences, summer schools, and seminars; as well as industry partnership activities. These 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 (EPSCoR) jurisdictions. An example of one of these activities is the Frontera Computational Science Fellowship program,[16] which provides a year-long opportunity for talented graduate students to compute on Frontera and collaborate with experts at TACC; this program awarded four fellowships in FY 2021.

<u>Management and Oversight</u>
The Frontera project is 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 LCCF system is coordinated with the Large Facilities Office and the Division of Acquisition and Cooperative Support in BFA 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

<u>Description</u>
NSF funds the acquisition and operation of nationally available Advanced/Innovative Computing Systems and Services that, in aggregate, are forward-looking, connected, 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

[16] frontera-portal.tacc.utexas.edu/fellowship/

(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 O&M following deployment. When an award is made, the awardee institution issues subawards to vendors and/or other organizations for acquisitions and services, as necessary. Expenditures are contingent on successful completion of deployment milestones. These systems are also accessible via the Partnership to Advance Throughput Computing (PATh) project.[17]

Current Status

In FY 2016, NSF awarded *Stampede 2: The Next Generation of Petascale Computing for Science and Engineering* to TACC, enabling the acquisition and deployment of Stampede 2. Stampede 2 serves as the primary national resource for approximately 7,000 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 June 2023. This includes a technical upgrade awarded in FY 2021 to extend operations, partially upgrade the processor architecture, and explore pilot high throughput computing allocations via the PATh project.[18]

In addition, beginning in FY 2019, NSF made a series of investments in advanced/innovative computing systems and services to foster an integrated CI ecosystem that addresses the growing scale and diversity of the S&E community, the changing nature of S&E 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 S&E domains. Specifically, NSF issued the *Advanced Computing Systems and Services (ACSS): Adapting to the Rapid Evolution of Science and Engineering Research* solicitation[19] in FY 2019, with the first cohort of three awards running from FY 2019 to FY 2024,[20] followed by a second cohort of five awards running from FY 2020 to FY 2025,[21] and a third cohort of 2 awards running from FY 2021 to FY 2026.[22]

The ACSS solicitation called 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 S&E research; and
- 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 S&E discoveries.

In the FY 2019 ACSS competition, two Category I awards were made to the Pittsburgh Supercomputing Center (PSC), and the San Diego Supercomputer Center (SDSC) at UCSD; and one Category II award was made to the State University of New York (SUNY) at Stony Brook. In the FY 2020 ACSS competition, three Category I awards were made to Indiana University, Purdue University, and University of Illinois at Urbana-Champaign (UIUC); and two Category II awards were made to SDSC and PSC. In the FY 2021

[17] www.nsf.gov/awardsearch/showAward?AWD_ID=2030508
[18] www.nsf.gov/awardsearch/showAward?AWD_ID=2030508
[19] nsf.gov/funding/pgm_summ.jsp?pims_id=503148
[20] www.nsf.gov/pubs/2019/nsf19534/nsf19534.htm
[21] www.nsf.gov/pubs/2019/nsf19587/nsf19587.htm
[22] www.nsf.gov/pubs/2020/nsf20606/nsf20606.htm

ACSS competition, two Category II awards were made to the San Diego Supercomputer Center (SDSC) at UCSD and Texas A&M University. Given interruptions to supply chains resulting from the COVID-19 pandemic, some scheduled deployments were slightly delayed, but disruptions to the relevant S&E research communities have been minimal. When fully deployed, the suite of Category I systems will include the following:

- *Expanse*: Located at SDSC this system will be operational from FY 2021 through FY 2024. Expanse is a large-capacity, data-focused system supporting increasingly diverse, complex, and expanding research across multiple S&E disciplines within the "long tail" of science.
- *Bridges 2*: Located at PSC this system will be operational from FY 2021 through FY 2024. Bridges 2 integrates AI-based analytics capabilities with the technical capacity to execute data- and computationally-intensive research in broad, cross-cutting manners, enabling advances across a range of S&E research and education.
- *Anvil*: Located at Purdue University, a new service provider within the NSF ecosystem of advanced computing systems, Anvil will be operational from FY 2022 through FY 2025. Anvil will be a composable system with an expansive portfolio of S&E-focused interfaces, programming environments, and advanced capabilities to support research and education.
- *Delta*: Located at the UIUC, Delta is expected to be operational from FY 2022 through FY 2025. Delta will be a large-capacity, balanced computational resource supporting traditional computational methods combined with rapidly evolving and expanding AI-based techniques and advanced data science methods to advance S&E research and education. Transition to production operations for Delta following a successful acceptance review is expected in 2022.
- *Jetstream 2*: Located at Indiana University Jetstream 2 is expected to be operational from FY 2022 through FY 2025. Jetstream 2 will provide a nationally distributed, large-capacity, cloud-enabled computational resource supporting diverse S&E-focused "on-demand" access modes and utilization models to be available across research and education. Jetstream 2 is expected to transition to production operations following a successful acceptance review in 2022.

In addition, the Category II, or Testbed-Prototype Systems, comprise:

- *Ookami*: Located at SUNY at Stony Brook, this prototype will be operational through FY 2024. NSF will evaluate the utility of the system and determine whether it can be integrated into the suite of production services. Ookami incorporates processors originally developed to lead Japanese national efforts[23] towards future computing to advance U.S.-based S&E research and education.
- *Neocortex*: Located at PSC, this prototype will be operational through May 2025. NSF will evaluate the utility of the system and determine whether it can be integrated into the suite of production services. Neocortex will deploy a novel AI-focused processor architecture in a high-performing system design supporting very high-scale, complex analytics challenges across S&E research and education.
- *Voyager*: Located at SDSC, this prototype will be operational through May 2025. NSF will evaluate the utility of the system and determine whether it can be integrated into the suite of production services. Voyager will integrate AI/ML/deep learning-focused components to advance S&E research and education.
- *National Research Platform (NRP):* Located at SDSC, with partners at University of Nebraska, Lincoln (UNL) and the Massachusetts Green High Performance Computing Center (MGHPCC), this prototype will be operational through May 2026. The prototype NRP will deploy a distributed testbed architecture including a high-performance subsystem at SDSC; two Graphics Processing

[23] www.r-ccs.riken.jp/en/fugaku/project

Unity (GPU) subsystems at UNL and MGHPCC; and low latency high bandwidth research and education networking.
- *Accelerating Computing for Emerging Sciences (ACES)*: Located at Texas A&M University, this prototype system will be operational through September 2026. ACES will deploy a novel composable system architecture with the flexibility to aggregate various components on an as-needed basis to solve problems previously not addressable by researchers.

NSF will evaluate the utility of the above listed Category II, or Testbed-Prototype Systems and determine whether they can be integrated into the suite of production services.

<u>S&E 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 S&E research, in the integration of research and education, and in broadening participation in S&E 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 expertise, interfaces, consulting support, and training necessary to facilitate use of the systems and services. This activity is central to America 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 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 that are a part of the periodic NSF external reviews conducted by an external panel of experts is to revisit and reassess the risk and make recommendations as deemed necessary. In the case of projects that involve an acquisition, project risks are generally substantially reduced after 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

Description

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 to and expertise for 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.

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 provisioning 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 S&E 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.

For researchers requiring high-throughput computing – computing that can be characterized by executing large numbers of tasks over a long period of time - The Partnership to Advance Throughput Computing (PATh) makes Distributed High Throughput Computing (dHTC) capacity available to researchers through a fabric of services. These services enable the federation of resources into an effective source of computing capacity for a wide spectrum of science applications. PATh supports single-PIs and collaborative science groups across science and engineering disciplines to join the cohort of international physical science collaborations who have leveraged the dHTC paradigm for decades.

Current Status

Two awards are currently active within the XD program: the eXtreme Science and Engineering Discovery Environment (XSEDE) and the XD Metrics Service (XMS). An upcoming suite of six independent, yet highly coordinated, awards planned for FY 2022 will replace XSEDE and XMS by establishing the next generation of Advanced Cyberinfrastructure Coordination Ecosystem: Services and Support (ACCESS) (described below). Continued operation of XSEDE and XMS awards during a 6-month overlap period with ACCESS is intended to provide a smooth transition to services with a new organizational structure with minimal disruption to the community.

The current XSEDE award to UIUC was renewed in September 2016, continuing the prior XSEDE award for another five-year period. This five-year award has been extended for a sixth year, based on a very successful site review. 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 (PSC), UT Austin (TACC), UCSD (SDSC), 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, University of Georgia, Oklahoma University, University of Southern California, University of Arkansas, Notre Dame, and Internet 2.

The current XMS award was made in FY 2015 to SUNY at Buffalo. This award provides metrics services allowing measurement and monitoring of key operational data from XSEDE services and the advanced computing/innovative systems and services portfolio. 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.

The main award, "Partnership to Advance Throughput Computing (PATh)", is a five-year award to the University of Wisconsin-Madison. Within the award, six partners are engaged through sub-awards: Indiana University, Information Sciences Institute (USC), Morgridge Institute for Research, University of California San Diego, University of Chicago, and University of Nebraska-Lincoln. The award is now in its 2nd year.

NSF has outlined plans for a fabric of national CI coordination services in a blueprint document released in FY 2020.[24] This blueprint is based on findings from the NSTC FACE Subcommittee, guidance from ACCI and advisors, responses to an RFI, and feedback from engagement with the community about the structure and composition of future coordination efforts. Following the blueprint, NSF issued the *Advanced Cyberinfrastructure Coordination Ecosystem: Services & Support (ACCESS)* and *ACCESS - Coordination Office (ACCESS-ACO)* solicitations[25-26] in early FY 2021. Awards for ACCESS services and the ACCESS-ACO will be made during FY22.

S&E Research and Education Activities Enabled by Coordination and Support Services

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

Coordinated access to advanced/innovative computing systems and services enables researchers to efficiently manipulate, analyze, visualize, and share extremely large amounts of distributed digital information from simulations, sensors, and experiments. The ACCESS awards will enable the cyberinfrastructure ecosystem resources and CI professionals to innovate and evolve in sync with S&E research and education needs and opportunities. External communication, outreach, and community-building efforts by the ACCESS awardees will broaden the participation of individuals and communities that have been underserved by the national CI ecosystem.

The fabric of coordination and support services for the advanced CI ecosystem deliver tools and

[24] www.nsf.gov/cise/oac/vision/blueprint-2019/nsf-aci-blueprint-services.pdf
[25] www.nsf.gov/pubs/2021/nsf21555/nsf21555.htm
[26] www.nsf.gov/pubs/2021/nsf21556/nsf21556.htm?org=NSF

democratized access for researchers seeking resources, such as those described above, but also enable scientific collaborations for geographically distributed teams. In doing so, these services facilitate dynamic access to digital resources and experimental testbeds within and across university campuses, as well as government laboratories. These services also support the integration research software and data with CI resources. Human-in-the-loop expert services and widely available training materials reduce barriers to the use of advanced digital systems by the research and education communities, thereby promoting enhanced productivity. For example, the XSEDE platform has provided the basis for coordination and resource allocation among the more than 40 members of the COVID-19 HPC Consortium, and the team continues to provide essential services to support end users.

Monitoring and measurement services collect multi-dimensional data on advanced CI ecosystem usage statistics, users, and the computing resources' performance. They have also deployed CI measurement and optimization tools, namely XDMoD (XD Metrics on Demand) and its open-source counterpart, Open XDMoD, which are in use worldwide for advanced CI monitoring and reporting in academia and industry. Ongoing investments in these tools will enable the exploration of novel usage modes for advanced/testbed computing systems, integration with data repositories, instrumentation, and network performance. The immediate users of these methods and tools are the providers of NSF-supported advanced computing systems and services. However, both the tools and data are publicly available and used by researchers, academic research computing center administrators, federal agencies, and industry seeking to optimize performance and forecast capacity demand.

Management and Oversight

OAC's program directors oversee the advanced CI ecosystem services and support projects. Project management is supported by guidance from an external advisory board, service provider councils, and ongoing formal and informal engagement with stakeholder communities. OAC's oversight of projects includes participation in weekly teleconferences with senior personnel of awardee teams, quarterly briefings, and regularly scheduled planning sessions such as the allocation requests review meetings. Formal reporting consists of quarterly and annual reports, which are reviewed by the program directors. Projects participate annually in site reviews or virtual reviews conducted by external panels of expert reviewers and managed by OAC program directors. Each award is managed under a cooperative agreement with tailored terms and conditions, including an approved Project Execution Plan detailing management structure, milestones, deliverables, risk management, 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.

The PATh award is actively managed through monthly project meetings, monthly reports, monthly updates on goals and milestones, quarterly reports, annual reports, and a Project Execution Plan that is updated at least once per year.

DIRECTORATE FOR ENGINEERING (ENG) $940,280,000

+$175,850,000 / 23.0%

ENG Funding[1]
(Dollars in Millions)

	FY 2021 Actual	FY 2021 ARP Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Chemical, Bioengineering, Environmental and Transport Systems (CBET)	$199.87	-	-	$226.17	$26.30	13.2%
Civil, Mechanical, and Manufacturing Innovation (CMMI)	241.58	3.00	-	265.86	24.28	10.1%
Electrical, Communications, and Cyber Systems (ECCS)	124.00	-	-	137.20	13.20	10.6%
Engineering Education and Centers (EEC)	127.23	-	-	144.46	17.23	13.5%
Emerging Frontiers and Multidisciplinary Activities (EFMA)	71.76	-	-	166.59	94.83	132.1%
Total	**$764.44**	**$3.00**	**-**	**$940.28**	**$175.84**	**23.0%**

[1] The Division of Industrial Innovation and Partnerships (IIP) was dissolved in FY 2022, with the bulk of its programs moving to the new Directorate for Technology, Innovation, and Partnerships (TIP) and the remainder to EEC.

About ENG

In FY 2023, 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 and in key Administration and NSF-wide research priorities. Substantial directorate investments—in cross NSF priority areas as well as the fourth generation of NSF Engineering Research Centers (ERCs)—will emphasize convergence research approaches to help address grand challenges and achieve societal impact. In addition, to advance U.S. global competitiveness, strategic ENG support will strengthen the engineering workforce and accelerate the translation of technological innovations.

To accelerate the translation of research results towards economic and societal benefits, ENG will build on its long tradition of partnerships with industry and other government agencies and laboratories, including both direct and indirect partnerships (e.g., ERC, Industry–University Cooperative Research Centers (IUCRC), Grant Opportunities for Academic Liaison with Industry (GOALI)). Working with the new TIP directorate, ENG will spur the engineering research community to follow existing well-established pathways towards technology translation, including I-Corps™, Partnerships for Innovation (PFI), and Small Business Innovation Research and Small Business Technology Transfer (SBIR/STTR). In addition, ENG will work closely with TIP to develop new translation pathways, building on and enhancing existing successes in our center programs (ERC and IUCRC). Research results coming out of mid-size ENG research awards create new opportunities that are ripe for translational impact.

ENG funding in FY 2023 will help protect Americans through the continuation of its long-term support for engineering research to improve resilience to hurricanes, earthquakes, and other disasters, including the Natural Hazards Engineering Research Infrastructure (NHERI). ENG will help secure and advance communications, computing, and sensing through investments in QIS-related programs for quantum technologies and systems. Other ENG-funded research will investigate methods and technologies for protecting the electric grid, understanding online influence and misinformation, detecting biological threats, and disrupting illicit supply networks.

ENG FY 2023 investments will build future prosperity through essential contributions to research on advanced manufacturing and supply chains, new materials and semiconductor technologies, and clean energy and climate change adaptation and mitigation. The directorate will support advances in robotics, AI, and smart and autonomous systems, and will continue stewardship of the FW-HTF Big Idea. ENG will also invest in disruptive technologies in support of HDR, energy-efficient microelectronics and computing and spectrum-efficient advanced wireless systems. Funding for NNA and other programs across ENG will help ensure sustainable and reliable infrastructure systems through, for example, sensor systems to understand soil dynamics, complex models of food-energy-water systems, and eco-friendly building materials and designs.

ENG support will advance health technologies and systems through investment in fundamental research to observe nanoscale cellular processes and changes, engineering biology to reverse disease and produce therapies, and synthetic biology to advance URoL and a wide array of biotechnologies. The directorate also will support research on the transport of contaminants and pathogens (bacteria, viruses, or other microbes) in natural and built environments, methods to detect and monitor their presence, and the prevention and understanding of their impacts on the community and ecology. Engineering investments will continue advances in prosthetic and assistive technologies for veterans, senior citizens, and people with disabilities.

ENG will also emphasize support for racial equity efforts. ENG, together with other NSF directorates and offices, will invest in research, education, and workforce development that remove barriers, build capacity, and foster partnerships. ENG will increase investment in the Broadening Participation in Engineering program, grow mentoring and professional development activities, support collaborations with MSIs, and promote systemic changes that enhance diversity, equity, and inclusion in engineering.

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 engineering education, broadening participation, equity, and inclusion in engineering, as well as in student experiences with industry. ENG will maintain its commitment to talented students and faculty through programs supporting transitions between career stages, and opportunities for mid-size, interdisciplinary team research. ENG investments in academic partnerships and professional development opportunities with industry will help bring new ideas from lab to market and fortify the Nation’s innovation ecosystem.

ENG provides 42 percent of 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 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Advanced Manufacturing	$123.65	-	$174.37	$50.72	41.0%
Advanced Wireless Research	25.83	-	27.75	1.92	7.4%
Artificial Intelligence	85.86	-	95.80	9.94	11.6%
Biotechnology	86.77	-	101.50	14.73	17.0%
Climate: Clean Energy Technology[3]	143.38	-	223.57	80.19	55.9%
Improving Undergraduate STEM Education	-	-	5.15	5.15	N/A
Microelectronics/Semiconductors	43.07	-	46.00	2.93	6.8%
Postdoctoral Fellows	-	-	15.00	15.00	N/A
Quantum Information Science	21.31	-	32.89	11.58	54.3%
Secure & Trustworthy Cyberspace	3.25	-	3.25	-	-

[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] Funding includes resources for agency-wide initiatives.

- 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 2023 Request includes $24.0 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.

- Biotechnology: 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 biotechnology include synthetic biology, engineering biology, engineered living systems, 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.
- Clean Energy Technology: ENG, together with other NSF directorates and offices, will invest in fundamental research to advance clean energy technologies that are sustainable, reduce or mitigate the impacts of climate change, and improve human and community resiliency. ENG supports research on renewable and alternative energy sources, manufacturing, storage, distribution, and management, including smart grids, transmission and conversion systems, grid-scale energy storage, and carbon capture. ENG also supports the development of energy materials, use and efficiency, including low-power and green electronics, energy-intelligent and sustainable computing and communication systems, eco-manufacturing of materials and chemicals, and the remediation and reduction of legacy pollution, as well as societal and environmental aspects of clean energy.
- 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. 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 U.S. capabilities, capacity, and workforce 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.
- Postdoctoral Fellowships: The Engineering Postdoctoral Fellowships Program (eFellows) places early-career PhDs in engineering fields in university research postdoctoral fellowships. In addition to hands-on academic research with a faculty advisor, each fellowship cohort will participate in professional development and mentoring activities designed to prepare them for future research careers. The eFellows program will focus support on postdoctoral Fellows who will broaden the participation of groups that are underrepresented in ENG fields in the U.S. including women,

Blacks or African Americans, Hispanics, Latinos, Native Americans, Alaska Natives, Native Hawaiians, and other Native Pacific Islanders as future leaders in ENG fields.

- 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. QIS activities will also address education and workforce development needs.
- 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.

ENG Funding for Centers Programs

ENG Funding for Centers Programs
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual: Amount	Change over FY 2021 Actual: Percent
National Artificial Intelligence Research Institutes (Multiple)	$8.18	-	$9.20	$1.02	12.5%
Engineering Research Centers (ERC)	56.26	-	71.50	15.24	27.1%
STC: Emergent Behaviors for Integrated Cellular Systems (CBET)	-	-	5.00	5.00	N/A
STC: Engineering Mechano-Biology (CMMI)	2.74	-	5.00	2.26	82.7%

For detailed information on individual centers programs, please see the Cross Theme Topics section of the NSF-Wide Investments chapter.

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

Funding Profile

ENG Funding Profile

	FY 2021 Actual Estimate	FY 2022 (TBD)	FY 2023 Estimate
Statistics for Competitive Awards:			
Number of Proposals	7,270	-	8,100
Number of New Awards	1,471	-	1,750
Regular Appropriation	1,466	-	1,750
ARP	5		
Funding Rate	20%	-	22%
Statistics for Research Grants:			
Number of Research Grant Proposals	6,877	-	7,500
Number of Research Grants	1,337	-	1,600
Regular Appropriation	1,332	-	1,600
ARP	5		
Funding Rate	19%	-	21%
Median Annualized Award Size	$127,582	-	$130,000
Average Annualized Award Size	$161,514	-	$165,000
Average Award Duration, in years	3.4	-	3.4

ENG investments support fundamental engineering research, engineering education, and innovation, as well as research infrastructure such as facilities. In FY 2023, funding for centers accounts for over nine percent of ENG's Request.

People Involved in ENG Activities

Number of People Involved in ENG Activities

	FY 2021 Actual Estimate	FY 2021 ARP Actual Estimate	FY 2022 (TBD)	FY 2023 Estimate
Senior Researchers	7,274	15	-	8,500
Other Professionals	739	-	-	850
Postdoctoral Associates	371	-	-	430
Graduate Students	7,376	24	-	8,850
Undergraduate Students	4,507	12	-	5,400
Total Number of People	**20,267**	**51**	**-**	**24,030**

DIVISION OF CHEMICAL, BIOENGINEERING, ENVIRONMENTAL, AND TRANSPORT SYSTEMS (CBET) $226,170,000 +$26,310,000 / 13.2%

CBET Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over Amount	Percent
Total	**$199.87**	**-**	**$226.17**	**$26.30**	**13.2%**
Research	**194.91**	**-**	**220.98**	**26.07**	**13.4%**
CAREER	43.59	-	45.60	2.01	4.6%
Centers Funding (total)	2.73	-	7.00	4.27	156.8%
Artificial Intelligence Research Institutes	2.73	-	2.00	-0.73	-26.6%
STC: Emergent Behaviors for Integrated Cellular Systems	-	-	5.00	5.00	N/A
Education	**1.12**	**-**	**1.50**	**0.38**	**33.4%**
Infrastructure	**3.83**	**-**	**3.69**	**-0.14**	**-3.7%**
National Nanotechnology Coordinated Infrastructure (NNCI)	3.68	-	3.69	0.01	0.3%

About CBET

CBET supports research and education to enhance and protect U.S. national health, energy, food, water, environment, process manufacturing, and security, by investing in areas that involve the transformation and/or transport of matter and energy by chemical, thermal, or mechanical means. Through CBET, the physical, chemical, and biological sciences are integrated in engineering research and education, resulting in advances in the rapidly evolving fields of biotechnology, bioengineering, biomanufacturing, advanced materials, environmental engineering, climate adaptation and mitigation, and sustainable clean energy. 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, materials for advanced manufacturing, natural gas and petroleum production, food, textiles, utilities, and microelectronics.

CBET investments support research in three priority areas:

- Climate change-related research increases understanding of climate change impacts and accelerates the creation and use of mitigation and adaptation strategies. Understanding the impacts of climate change includes wildfire, agricultural resilience, urban heat, and water sustainability research. Mitigating climate change includes research on reducing greenhouse gas emissions in the chemical, environmental and energy sectors, as well as carbon capture, utilization, storage, and conversion to useful products. Engineering adaptation to climate change includes research on catalytic remediation of emission process streams, the water-energy nexus, and sustainable systems.
- Clean energy research advances understanding of new energy options (such as hydrogen production, photovoltaics, wind/ocean energy harvesting), methods to decarbonize fuels, energy storage and electricity systems, and sustainability of critical mineral extraction and use.
- Biomanufacturing and biotechnology research supports new understanding and emerging technologies for microphysiological systems, biomaterials, tissue engineering, neuro-engineering, biosensors, and bio-photonic systems.

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.

CBET also contributes to the directorate's annual operations support of NSF facilities such as NNCI.

In general, 83 percent of the CBET portfolio is available to support new research grants. The remaining 17 percent supports research grants made in prior years.

DIVISION OF CIVIL, MECHANICAL, AND MANUFACTURING INNOVATION (CMMI) $265,860,000 +$24,280,000 / 10.1%

CMMI Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$241.58**	**-**	**$265.86**	**$24.28**	**10.1%**
Research	**221.78**	**-**	**246.16**	**24.38**	**11.0%**
CAREER	60.52	-	33.60	-26.92	-44.5%
Centers Funding (total)	5.74	-	8.00	2.26	39.4%
Artificial Intelligence Research Institutes	3.00	-	3.00	-	-
STC: Engineering Mechano-Biology	2.74	-	5.00	2.26	82.7%
Education	**3.26**	**-**	**2.40**	**-0.86**	**-26.4%**
Infrastructure	**16.54**	**-**	**17.30**	**0.76**	**4.6%**
Natural Hazards Engineering Research Infrastructure (NHERI)	13.71	-	14.60	0.89	6.5%
Center for High Energy X-ray Science (CHEXS)	0.93	-	0.80	-0.13	-13.5%
National Nanotechnology Coordinated Infrastructure(NNCI)	1.90	-	1.90	-	-

About CMMI

CMMI funds fundamental research and education that advances civil, design, 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 on the built environment and in the context of a socio-technical system. CMMI encourages discoveries enabled by cross-cutting technologies such as adaptive systems, artificial intelligence, robotics, 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, clean manufacturing technology that does not exist today (such as future manufacturing); enable the design and analysis of complex engineered systems; enhance the sustainability, security, and resilience of U.S. infrastructure (for example, buildings, transportation, and communication networks); help protect the Nation from extreme natural disasters and human-induced events; and apply engineering principles to improve the Nation’s service and manufacturing enterprise systems, such as healthcare. CMMI also funds research that builds transparency and access to data and data infrastructure to build a robust and accessible cyberinfrastructure for engineering communities.

CMMI invests in the diverse human capital to ensure that high-risk/high-reward research is submitted, recognized, funded, and performed by a research community that reflects the diversity of the Nation. Important division support for this effort includes formal development opportunities for merit review panelists to learn about cognitive biases that affect appreciation for diverse scientific approaches, and special opportunities for researchers to pursue new directions for transformative and equitable advances in engineering.

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

In general, 82 percent of the CMMI portfolio is comprised of new research grants and 12 percent supports continuing grants.

DIVISION OF ELECTRICAL, COMMUNICATIONS, AND CYBER SYSTEMS (ECCS) $137,200,000 +$13,200,000 / 10.6%

ECCS Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$124.00**	**-**	**$137.20**	**$13.20**	**10.6%**
Research	**117.62**	**-**	**130.94**	**13.32**	**11.3%**
CAREER	31.27	-	18.60	-12.67	-40.5%
Centers Funding (total)	1.70	-	2.70	1.00	58.8%
Artificial Intelligence Research Institutes	1.70	-	2.70	1.00	58.8%
Education	**0.88**	**-**	**0.92**	**0.04**	**4.3%**
Infrastructure	**5.49**	**-**	**5.34**	**-0.15**	**-2.8%**
Center for High Energy X-ray Science (CHEXS)	0.10	-	0.10	-	-
National Nanotechnology Coordinated Infrastructure	5.39	-	5.24	-0.15	-2.8%

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, including energy-efficient and secure semiconductor technologies, 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 quantum, cyber and communications technologies (such as advanced wireless networks, spectrum efficiency and security), sensing, energy and power, healthcare, transportation, robotics, advanced manufacturing, and other systems-related areas.

ECCS's investments include three priority areas:

- Sustainable microelectronics research will advance semiconductors for recyclable, green, and secure micro-electronics, quantum engineering, novel photonics, electronic materials and fabrication at the device, chip, wafer, and system levels. Applications include future computing, AI, power electronics, sensing, and communications.
- Secure and resilient power systems research will enable a clean energy future with autonomous, continuous, and secure electric power grids using new advancements in power electronics technologies, machine learning, optimization, and control. It will enable the seamless integration of renewables and electric vehicles with the grid and the use of fair, accountable, and ethical AI for energy-efficient smart homes, smart buildings, and smart transportation.
- Advanced wireless research for 6G communications and beyond will enable high-speed, ubiquitous wireless communications with fundamental research in semiconductor devices, radio-frequency circuits, millimeter wave and terahertz communications, advanced signal processing, and quantum communication. Applications include the internet of things, augmented and virtual reality, smart and connected communities, and smart health.

The division also provides funding, in partnership with other NSF directorates, and management of the NNCI and contributes to the directorate's annual operations support of the CHEXS facility.

In general, 79 percent of the ECCS portfolio is comprised of new research grants and 21 percent supports continuing grants.

DIVISION OF ENGINEERING EDUCATION AND CENTERS (EEC) $144,460,000 +$17,230,000 / 13.5%

EEC Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$127.23**	**-**	**$144.46**	**$17.23**	**13.5%**
Research	**110.35**	**-**	**125.26**	**14.91**	**13.5%**
CAREER	0.62	-	-	-0.62	-100.0%
Centers Funding (total)	57.01	-	73.00	15.99	28.0%
Artificial Intelligence Research Institutes	0.75	-	1.50	0.75	100.0%
Engineering Research Centers (ERC)	56.26	-	71.50	15.24	27.1%
Education	**16.89**	**-**	**19.20**	**2.31**	**13.7%**

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 engineering and involves the physical, life, and social and behavioral sciences. Applications range across a wide spectrum, such as energy and the environment; health and biotechnology; communications, quantum, and computer systems; nano- and microelectronics; manufacturing; civil infrastructure; and others.

The complex, integrative role of EEC requires a comprehensive set of programs for centers, networks, and people. EEC funds formal scholarly studies in the professional formation of engineers, which can lead to innovations in engineering education and career development, and in broadening participation in engineering. Creative and effective approaches to developing a diverse and inclusive engineering workforce are vital, as a lack of properly prepared engineers is a critical barrier to a robust U.S. economy. EEC invests in faculty, graduate and undergraduate students, post-doctoral scholars, and K–12 teachers. As nontraditional students 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 managed within four clusters: (1) Centers and Networks; (2) Engineering Education Research; (3) Engineering Workforce Development; and (4) Broadening Participation in Engineering. The Centers and Networks cluster includes the signature Engineering Research Centers (ERC) and IUCRC programs.

The ERC program provides a framework for interdisciplinary research and education, development, and technology transfer in partnership with academia, industry, and government. The FY 2023 funding level supports 15 centers. The total includes funding to support up to five additional 4th-generation (Gen-4) ERCs that advance convergence engineering research to tackle high-impact challenges that have the potential to benefit U.S. security, prosperity, health, and society. Gen-4 ERCs implement strategies for effective team formation, diversity and inclusion, and engagement with stakeholder communities to maximize their impacts. The IUCRC program develops long-term partnerships among industry, academe, and government. IUCRCs are catalyzed by NSF investment and are primarily supported by membership fees from industry and government labs, with NSF taking a supporting role in the development of the Center. Each Center conducts fundamental research that is of interest to both the members and the Center faculty. IUCRCs contribute to the Nation's research infrastructure base and enhance the intellectual capacity of the engineering and science workforce through the integration of research and education. EEC's increased investment in center-based research will enhance center research outcomes, expand the engineering community, and grow its tremendous societal impact.

Engineering Education programs advance new productive engineering pedagogy and learning strategies in traditional and non-traditional environments. This cluster also includes EEC's participation in the NSF-wide activity, IUSE, which integrates the agency's investments in undergraduate education; EEC participates in IUSE and advances the professional development of engineers through the Revolutionizing Engineering Departments program.

Engineering Workforce Development includes programs such as Research Experiences for Undergraduates (REU) and Research Experiences for Teachers (RET), as well as support for GOALI/Non-Academic Research Internships for Graduate Students (INTERN), which stimulate university partnerships with non-academic organizations, including small and large companies, other government agencies, and non-profit organizations, and enable professional development.

The Broadening Participation in Engineering program supports research and activities that enhance opportunities for underrepresented groups by addressing structural inequalities and biases within educational and workforce systems. This cluster also includes EEC's engagement with NSF INCLUDES, which integrates the agency's investments to build on and scale up what works in broadening participation programs.

EEC will engage the groups traditionally underrepresented in the field across the country by increasing investment in equity and broadening participation and supporting initiatives that find, recruit, educate, retain, and graduate a larger, more-diverse engineering population. EEC will take an integrated approach—with innovative efforts that expand engineering education to pre-college and informal settings and with partnerships that develop a diverse and inclusive engineering workforce—to enable engineering careers and advances in emerging technologies.

In general, 24 percent of the EEC portfolio is comprised of new research grants. The remaining 76 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.

OFFICE OF EMERGING FRONTIERS AND MULTIDISCIPLINARY ACTIVITIES (EFMA)

$166,590,000
+$94,830,000 / 132.1%

EFMA Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$71.76**	**-**	**$166.59**	**$94.83**	**132.1%**
Research	**71.44**	**-**	**166.37**	**94.93**	**132.9%**
Education	**0.10**	**-**	**0.12**	**0.02**	**15.4%**
Infrastructure	**0.22**	**-**	**0.10**	**-0.12**	**-55.1%**
Center for High Energy X-ray Science (CHEXS)	0.23	-	0.10	-0.13	-55.6%

About EFMA

EFMA strategically pursues and supports projects in important emerging areas. The office has the necessary flexibility to target long-term challenges and to adapt as new challenges arise.

A central activity of 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.

In FY 2020 and FY 2021, EFMA invested in two EFRI topics: Distributed Chemical Manufacturing (DCheM) to enable the development of modular process plants that take advantage of distributed feedstocks and product delivery needs or address environmental remediation problems at the source; and Engineering the Elimination of End-of-Life Plastics (E3P) to create a scientific foundation for viable solutions to the capture, management, and elimination of end-of-use plastics. In FY 2022 and FY 2023, EFMA will invest in two new EFRI topics:

- Brain-Inspired Dynamics for Engineering Energy-Efficient Circuits and Artificial Intelligence (BRAID) will build on recent advances in neuroscience to stimulate and transform innovations in AI and engineered learning systems.
- Engineered Living Systems (ELiS) will foster research to advance the design, fabrication, manufacturing, and modeling of engineered systems that incorporate living materials in order to address societal needs, with a focus on sustainable engineering.

EFMA invests in 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. The GERMINATION program supports development of innovative pedagogical approaches to scientific problem formulation, including fostering convergence. REM and REU supplements underwrite capacity-building toward an expanded and diverse STEM workforce.

In the area of Clean Energy Technology, EFMA will invest $45.0 million specifically related to convergent approaches across scale, with attention to workforce training and foundational climate and clean energy research that emphasizes innovation, sustainability, resilience, equity and social justice, and engagement of local communities in formulating problems and translating promising research. This is in addition to other important clean energy investments across ENG.

The EFMA office also supports special activities such as the Engineering Research Visioning Alliance (ERVA), which convenes the engineering community to identify important engineering research challenges and opportunities. ERVA provides a mechanism for the engineering research community to coalesce around research priorities and speak with a unified voice. EFMA also contributes to the directorate's annual operations support of NSF facilities such as CHEXS.

Funding for the FW-HTF Big Idea supports convergence activities that transcend the traditional disciplinary boundaries of individual NSF directorates and offices. Financial stewardship for this NSF investment is the responsibility of ENG and is managed by EFMA. The convergence activities are overseen and managed collaboratively by the multi-directorate/office FW-HTF leadership team. These ongoing activities are designed to 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.

In general, 85 percent of the EFMA portfolio is comprised of new research grants, and about 15 percent supports continuing increments for grants made in previous years.

DIRECTORATE FOR GEOSCIENCES (GEO) $1,239,050,000
+$234,790,000 / 23.4%

GEO Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2021 ARP Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Atmospheric and Geospace Sciences (AGS)	$283.35	$17.29	-	$301.37	$18.02	6.4%
Earth Sciences (EAR)	201.65	16.74	-	206.36	4.71	2.3%
Research, Innovation, Synergies, and Education (RISE)[1]	116.27	15.00	-	299.54	183.27	157.6%
Ocean Sciences (OCE)	402.99	22.01	-	431.78	28.79	7.1%
Total	**$1,004.26**	**$71.04**	**-**	**$1,239.05**	**$234.79**	**23.4%**

[1] The Division of Integrative and Collaborative Education and Research (ICER) has been renamed the Division of Resarch, Innovation, Synergies, and Education (RISE).

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 coordination and administrative oversight to OPP, 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. 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 prioritizes support for interdisciplinary studies that contribute directly to national research priorities including climate change, racial equity, and recovery from the COVID pandemic.

Support for climate change research and USGCRP is a particular emphasis. Investments will focus on predictability and resilience of the Earth system, the role of the oceans in climate change, terrestrial-climate interactions, and water sustainability including drought and floods. There is special emphasis on social equity which utilizes the integrating theme of climate change as the foundation for building diverse and inclusive research ecosystems that also focus on institutional transformation towards inclusivity.

As the lead directorate, GEO is the steward of funds designated for the NSF-wide Big Idea: Navigating the New Arctic (NNA). For more information about the Big Ideas, see the narrative in the Cross Theme section of the NSF-Wide Investments chapter.

GEO provides 56 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 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Artificial Intelligence	$1.00	-	$5.00	$4.00	400.0%
Biotechnology	10.00	-	10.00	-	-
Climate: USGCRP[3]	329.00	-	515.37	186.37	56.6%
Coastlines and People[4]	29.59	-	23.00	-6.59	-22.3%
Navigating the New Arctic	32.82	-	30.00	-2.82	-8.6%
Postdoctoral Fellowships	5.34	-	13.34	8.00	149.8%

[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] Funding includes resources for agency-wide initiatives.

[4] FY 2021 Actual investment in the Coastlines and People program includes $14.57 million previously planned for FY 2020.

- AI: GEO, in partnership with CISE and other NSF directorates and offices, federal agencies, and the private sector, will support AI research and development. A key focal point in GEO is 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.
- Biotechnology: GEO, together with other NSF directorates and offices, will invest in fundamental research, infrastructure, and education that advances foundational knowledge needed to understand and harness biological processes for societal benefit.
- Climate: USGCRP: GEO leads NSF efforts to support the goals of the USGCRP. Investments will focus on predictability and resilience of the Earth system, the role of the oceans in climate change, terrestrial-climate interactions, and water sustainability including drought and floods.
- Coastlines and People (CoPe): CoPe was established in FY 2019 and received broad community interest. Through this program, GEO supports projects to build capacity and better 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
- Postdoctoral Fellowships: GEO is increasing support for programs that provide fellowships to postdoctoral researchers. These programs support fundamental research in important priority areas such as USGCRP, while also serving broader goals related to inclusivity in the science workforce.

GEO Funding for Centers Programs and Major Facilities

GEO Funding for Centers Programs
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
STC: Cntr for Learning the Earth w/ AI and Physics (AGS)	$3.50	-	$5.00	$1.50	42.9%
STC: Cntr for Chemicial Curriencies of a Microbial Planet	-	-	5.00	5.00	N/A
Total	**$3.50**	**-**	**$10.00**	**$6.50**	**185.7%**

For detailed information on individual centers programs, please see the Cross Theme Topics section of the NSF-Wide Investments chapter.

GEO Funding for Major Facilities
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Academic Research Fleet (ARF)	$99.54	-	$119.11	$19.57	19.7%
Arecibo Observatory (AO)	10.04	-	3.00	-$7.04	-70.1%
Geodetic Facility for the Advancement of Geoscience (GAGE)	13.13	-	13.25	$0.12	0.9%
International Ocean Discovery Program (IODP)	48.00	-	50.40	$2.40	5.0%
National Center for Atmospheric Research (NCAR)	104.10	-	116.20	$12.10	11.6%
Ocean Observatories Initiative (OOI)	45.30	-	51.00	$5.70	12.6%
Seismological Facility for the Advancement of Geoscience	21.36	-	22.50	$1.14	5.3%
Total	**$341.47**	**-**	**$375.46**	**$33.99**	**10.0%**

For detailed information on individual facilities, please see the Research Infrastructure section of the NSF-Wide Investments chapter.

Funding Profile

GEO Funding Profile

	FY 2021 Actual Estimate	FY 2022 (TBD)	FY 2023 Estimate
Statistics for Competitive Awards:			
Number of Proposals	3,293	-	4,100
Number of New Awards	1,441	-	1,500
Regular Appropriation	1,229		1,500
ARP	212		
Funding Rate	44%	-	37%
Statistics for Research Grants:			
Number of Research Grant Proposals	2,944	-	3,700
Number of Research Grants	1,216	-	1,300
Regular Appropriation	1,055		1,300
ARP	161		
Funding Rate	41%	-	35%
Median Annualized Award Size	$166,665	-	$175,000
Average Annualized Award Size	$219,659	-	$240,000
Average Award Duration, in years	3.0	-	3.2

The number of research grant proposals is expected to increase by about 750 compared to the FY 2021 Actual, and GEO expects to award about 100 more research grants as grant competitions related to climate change are anticipated to increase. Average annual award size and duration are expected to increase.

People Involved in GEO Activities

Number of People Involved in GEO Activities

	FY 2021 Actual Estimate	FY 2021 ARP Actual Estimate	FY 2022 (TBD)	FY 2023 Estimate
Senior Researchers	5,265	818	-	6,500
Other Professionals	3,238	116	-	4,000
Postdoctoral Associates	709	64	-	900
Graduate Students	2,570	315	-	3,200
Undergraduate Students	2,423	349	-	3,000
Total Number of People	**14,205**	**1,662**	**-**	**17,600**

DIVISION OF ATMOSPHERIC AND GEOSPACE SCIENCES (AGS) $301,370,000 +$18,020,000 / 6.4%

AGS Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$283.35**	**-**	**$301.37**	**$18.02**	**6.4%**
Research	**119.21**	**-**	**144.25**	**25.04**	**21.0%**
CAREER	9.73	-	10.00	0.27	2.8%
Centers Funding (total)	0.50	-	5.00	4.50	900.0%
STC: Cntr for Learning the Earth w/ AI and	0.50	-	5.00	4.50	900.0%
Education	**2.43**	**-**	**4.68**	**2.25**	**92.6%**
Infrastructure	**161.71**	**-**	**152.44**	**-9.27**	**-5.7%**
Arecibo Observatory (AO)	10.04	-	3.00	-7.04	-70.1%
National Center for Atmospheric Research (NCAR)	104.10	-	116.20	12.10	11.6%
Research Resources	47.57	-	33.24	-14.33	-30.1%

About AGS

AGS supports fundamental research that leads to improved understanding of the physics, chemistry, and dynamics of the Earth's atmosphere, weather, and climate, and how the sun interacts with the Earth's atmosphere and how the atmosphere interacts with other components of the Earth's integrated systems. Improved understanding drives state-of-the-science model development and predictability of weather, climate, and space weather events. AGS provides support for: (1) basic science projects and (2) the infrastructure, facilities, and services that enable and support modern-day atmospheric and geospace research activities.

Research supported by AGS directly impacts and improves the lives of Americans. Advances in understanding severe weather events leads to the development and enhancement of the sophisticated computer models that simulate and predict high-impact events e.g., tornados, hurricanes, and drought, which helps protect life, property, natural resources, and contributes to the establishment of a weather-ready nation. AGS also funds related education activities, 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.

AGS supports the research of individual scientists at academic institutions, groups of researchers, and research activities at the National Center for Atmospheric Research (NCAR). Often in partnership with complementary activities at other agencies, including the National Oceanic and Atmospheric Administration and the National Aeronautics and Space Administration, research is conducted using world-class facilities provided by NCAR and other groups across the U.S. AGS supports a neutron monitoring network, providing early warning should there be a large Earth-directed solar flare. AGS-supported scientists lead innovations ranging from development of research instruments, 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 and understanding of our climate and space environment.

AGS activities directly support the USGCRP. Enhanced process understanding, both through observational and modeling studies, builds our knowledge base related to climate change. This knowledge is translated into predictive models of future climate scenarios to help inform national and international climate policy. This knowledge has direct applications to society in terms of decision-making and forms the underpinnings of a robust development of the national policy for adaptation and mitigation of climate change.

In general, about 39 percent of the AGS portfolio is available for new research grants. The remaining 61 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.

DIVISION OF EARTH SCIENCES (EAR) $206,360,000

+$4,710,000 / 2.3%

EAR Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$201.65**	**-**	**$206.36**	**$4.71**	**2.3%**
Research	**134.58**	**-**	**134.59**	**0.01**	**0.0%**
CAREER	14.11	-	14.11	-	-
Education	**7.92**	**-**	**9.20**	**1.28**	**16.2%**
Infrastructure	**59.15**	**-**	**62.57**	**3.42**	**5.8%**
Geodetic Facility for the Advancement of Geoscience (GAGE)	13.13	-	13.25	0.12	0.9%
National Nanoscale Coordinated Infrastructure (NNCI)	0.40	-	0.30	-0.10	-25.0%
Seismic Facility for the Advancement of Geoscience (SAGE)	21.36	-	22.50	1.14	5.3%
Research Resources	24.25	-	26.52	2.27	9.4%

About EAR

EAR supports fundamental research into the structure and composition of the Earth and the processes that govern it. Research spans the Earth from its surface to its center, and includes its evolution and history, and the life it has sustained over its four and a half billion years. This research, as articulated by the National Academies of Science, Engineering and Medicine decadal *Earth in Time* report, is critical for understanding Earth's environment and its impact on society, including its climate (past, present, future), the distribution of its natural resources (mineral, water, biota, and energy), and the fundamental drivers of geologic hazards. EAR research provides predictive and quantitative understanding of earthquakes, volcanic eruptions, floods, landslides, changing climate, natural resources, and the overall Earth System. EAR education and human resources engages a wide range of audiences in Earth Science research efforts and fosters a just, equitable, diverse, and inclusive culture across the geosciences.

EAR's research programs support state-of-the-art science using observational, experimental, theoretical, and computational approaches to address topics ranging in scope from the Earth's surface to its deep interior. In addition to these fundamental research programs, EAR supports large-scale community and global efforts, including seismic and geodetic facilities, geohazards centers, and cyberinfrastructure focused on Earth science applications and reducing the risk of geologic hazards. EAR also supports community-based, shared-use facilities, and the acquisition and development of instrumentation by investigators. Integrated research that crosses disciplinary boundaries is supported through division programs as well as partnership with other GEO divisions and directorates. Education and human resource development activities support postdoctoral and other early career scientists, as well as projects and programs to attract students and young investigators to the field of Earth science.

EAR supports research aligned with USCGRP priorities. Programs support multi-disciplinary, fundamental research on the impacts and feedbacks between climate change and the water cycle, the Earth's surface, and biota, as well as the impacts of climate change on geohealth and extreme events, such as droughts, wildfires, and floods. Research on paleobiology and paleoclimate further the understanding of what the Earth's past reveals about the dynamics of climate change. Research on tectonics, geophysics, and geodesy advance understanding of how solid Earth processes impact soil moisture, landslides, subsidence, ice sheet mass balance, and sea level rise. The division also supports multidisciplinary research on the "critical zone", which extends from the top of the vegetation canopy to the base of the weathered rock zone, including woodland ecosystems. These components of the Earth's life-support system interact through connected processes that influence and are affected by climate, lithology, anthropogenic activity, and water and nutrient cycles. This research is vital to understanding the Earth System and how it has responded, and will respond, to climate change. Contributions to cross-disciplinary Earth observation efforts include continental drilling infrastructure that forms the basis of collection of records of past climate, providing critical data for predicting modern climate change; integration of atmospheric and Earth surface observations with seismic and geodetic capabilities; and cyberinfrastructure to enable analysis and modeling of terrestrial Earth responses to climate change. Through its community facilities, EAR supports collection of data critical for understanding past, present, and future climate; and the development and dissemination of integrated climate models related to Earth surface processes and the hydrologic cycle. These facilities and models serve the research community at large and further the understanding of the interactions between water, Earth, society, and changing climate.

In general, about 46 percent of the EAR portfolio is available for new research grants. The remaining 54 percent supports research grants made in prior years and the research infrastructure needed by this community.

DIVISION OF RESEARCH, INNOVATION, SYNERGIES, AND EDUCATION (RISE) $299,540,000 +$183,270,000 / 157.6%

RISE[1] Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$116.27**	**-**	**$299.54**	**$183.27**	**157.6%**
Research	**109.20**	**-**	**294.54**	**185.34**	**169.7%**
CAREER	0.54	-	-	-0.54	-100.0%
Centers Funding (total)	3.00	-	-	-3.00	-100.0%
STC: Cntr for Learning the Earth w/ AI and Physics	3.00	-	-	-3.00	-100.0%
Education	**6.16**	**-**	**5.00**	**-1.16**	**-18.8%**
Infrastructure	**0.91**	**-**	**-**	**-0.91**	**-100.0%**
Research Resources	0.91	-	-	-0.91	-100.0%

[1] The Division of Integrative and Collaborative Education and Research (ICER) has been renamed the Division of Resarch, Innovation, Synergies, and Education (RISE).

About RISE

RISE 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. RISE'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, RISE 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. The division makes strategic investments in multidisciplinary research areas, international activities, education, diversity, and human resource development. The results of RISE investments will assist in ensuring that the United States has a well-educated and diverse workforce in the geosciences and in related technical fields such as resource exploration.

Numerous RISE activities directly support goals the of the USGCRP. The NNA Big Idea focuses on the impacts of Arctic change and the NSF-wide CoPe program, which is primarily supported in RISE, examines the impacts of climate on coastal regions to improve human and community resilience to climate change. In addition, RISE supports international collaborative activities which focus on climate change.

New innovative activities are initiated in FY 2023 within RISE that will blur disciplinary boundaries to catalyze critical research efforts of strategic importance, RISE is home to several new crosscutting investments in FY 2023 in addition to increased investments in existing priority areas. Key incremental investments in new activities include:

- $80.0 million for large-scale interdisciplinary work on climate change. Building on the strong foundation of fundamental research supported across GEO, this investment will transcend

disciplinary boundaries and focus on topics of direct national importance at resolutions and scales needed by decisionmakers such as forecasting drought and water availability on timescales of months to years at local and regional scales.
- $33.67 million for agency-wide initiatives in climate, with a focus on multidisciplinary research.
- $20.0 million for computation and cyberinfrastructure development. Initial investment will focus on revolutionizing data structures and architectures used across the geosciences through an Open Science Initiative. This initiative will develop the data infrastructure necessary to address critical geosciences questions on climate and its impacts, support the AI and machine learning research that would use this open science framework, and support a scientific community and workforce trained to use these resources.
- $17.50 million for education, equity, and workforce development, emphasizing climate equity and the inclusion of all Americans in the growing green economy and geoscience research enterprise.

In general, about 63 percent of the RISE portfolio is available for new research grants with the remaining 37 percent supporting grants made in prior years.

In FY 2023, the former Division of Integrative and Collaborative Education and Research (ICER) has been renamed the Division of Research, Innovation, Synergies, and Education to better reflect the themes of synergy and entrepreneurial investment fostered by the division. All programs formerly supported in the ICER division including CoPe and NNA continue in the renamed organization.

DIVISION OF OCEAN SCIENCES (OCE) $431,780,000

+$28,790,000 / 7.1%

OCE Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$402.99**	**-**	**$431.78**	**$28.79**	**7.1%**
Research	**188.24**	**-**	**190.01**	**1.77**	**0.9%**
CAREER	6.20	-	6.20	-	-
Centers Funding (total)	-	-	5.00	5.00	N/A
STC: Cntr for Chemicial Curriencies of a Microbial	-	-	5.00	5.00	N/A
Education	**6.91**	**-**	**10.96**	**4.05**	**58.6%**
Infrastructure	**207.84**	**-**	**230.81**	**22.97**	**11.1%**
Academic Research Fleet (ARF)	99.54	-	119.11	19.57	19.7%
International Ocean Discovery Program (IODP)	48.00	-	50.40	2.40	5.0%
Ocean Observatories Initiative (OOI)	45.30	-	51.00	5.70	12.6%
Research Resources	13.23	-	10.30	-2.93	-22.1%

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 supports basic research, 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, harmful algal blooms, 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. Examples include the Ocean Observatories Initiative (OOI) network, the Global Ocean Biogeochemistry Array (GO-BGC) Project, and the Academic Research Fleet (ARF), including the Regional Class Research Vessels (RCRV). OCE-funded research, education, and infrastructure addresses the oceans' central role in a changing Earth and as a national strategic resource, as recognized in reviews by external bodies (e.g., the National Academies Decadal Survey Sea Change[1]). OCE is participating in the United Nations Decade of Ocean Science (2021-2030), through the U.S. National Committee for the Decade, to help ensure sustainable use of ocean resources and long-term ocean health.

[1] www.nap.edu/catalog/21655/sea-change-2015-2025-decadal-survey-of-ocean-sciences

OCE supports USGCRP with investments in science and infrastructure programs that focus on observing today's changing ocean and facilitating discoveries of past climate changes to inform future climate change. In addition to OOI, examples include the International Ocean Discovery Program (IODP), Long-Term Ecological Research (LTER), Hawaii Ocean Time-series (HOT), Bermuda Atlantic Time-series Study (BATS), Overturning in the Subpolar North Atlantic Program (O-SNAP), and the Paleo Perspectives on Climate Change (P2C2) Program. OCE has strong representation on the USGCRP Observations Interagency Working Group and the reinvigorated Coasts Focus Area.

In general, about 33 percent of the OCE portfolio is available for new research grants, with the remaining 67 percent supporting grants made in prior years and the research infrastructure needed by this community.

DIRECTORATE FOR MATHEMATICAL AND PHYSICAL SCIENCES (MPS) $1,746,847,000

+$153,540,000 / 9.6%

MPS Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2021 ARP Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual	
					Amount	Percent
Astronomical Sciences (AST)[1]	$289.27	-	-	$294.05	$4.78	1.7%
Chemistry (CHE)	259.60	-	-	284.14	24.54	9.5%
Materials Research (DMR)	330.07	-	-	349.92	19.85	6.0%
Mathematical Sciences (DMS)	243.66	-	-	259.47	15.81	6.5%
Physics (PHY)	304.42	-	-	316.59	12.17	4.0%
Office of Multidiscplinary Activities (OMA)	166.29	20.33	-	242.677	76.39	45.9%
Total	**$1,593.31**	**$20.33**	**-**	**$1,746.847**	**$153.54**	**9.6%**

[1] AST FY 2021 Actual funding includes $12.30 million from FY 2020 Appropriations.

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 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, enabling collaborations such as with the TIP Directorate, and help 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 ranging from fundamental 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 important to the advancement of these disciplines. Large scale research infrastructure is also highly important and provides opportunities for partnerships with international entities, other federal agencies, and private foundations, as is evidenced by facilities such as the Atacama Large Millimeter/submillimeter Array, the Gemini Observatory, the Large Hadron Collider (LHC), and the National High Magnetic Field Laboratory. Construction activities began in April 2020 to upgrade the two primary LHC detectors, A Toroidal LHC Apparatus and the Compact Muon Solenoid, in preparation for high luminosity operation of the LHC. The Vera C. Rubin Observatory Project is advancing the physical infrastructure on the summit of Cerro Pachón in Chile as well as a state-of-the-art data management system and the largest digital camera ever constructed. The construction of Daniel K.

Inouye Solar Telescope, the world's most powerful solar observatory, was completed and entered operations near the end of 2021, atop Haleakalā on Maui, Hawaii. Since its first detection of gravitational waves in 2015, the Laser Interferometer Gravitational-Wave Observatory (LIGO) has been reporting event alerts on a regular basis, including a neutron star-neutron star merger and a collision of heavy and light black holes. LIGO researchers are working to further enhance the sensitivity of the apparatus in preparation for a planned fourth observational run that is expected to begin as early as the Fall of 2022.

MPS' FY 2023 Request builds on past efforts and aligns with NSF's priorities articulated for FY 2023. 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 driven by the following key priorities: (a) sustaining core research programs, (b) supporting the highest priority centers, institutes, and facilities, (c) supporting early-career investigators, (d) providing funding for targeted basic research in NSF-wide investments including the NSF Big Ideas, (e) advancing support for Emerging Industries, such as QIS, advanced manufacturing, biotechnology, microelectronics, the spectrum innovation initiative (SII), and AI, (f) increasing support for clean energy and climate research, and (g) increasing support to promote equity and broadening participation in STEM research.

Climate change and its impacts clearly represents one of the greatest challenges facing civilization today. MPS will support research in providing scientific modeling tools needed to advance our understanding of the physical basis of climate change and develop mitigation and adaptation solutions. MPS-supported research will also significantly contribute to innovation in clean and sustainable energy resources, addressing problems that require fundamentally new ideas.

MPS will continue to explore ways to identify and address barriers to equity and broaden participation after the successful launch of several programs in FY 2021 and FY 2022, including those enhancing the support of early-career researchers from less resourceful institutions and postdoctoral fellows who will broaden the participation of groups that are underrepresented in MPS fields.

As the lead directorate, MPS is the steward of funds for the Big Idea, WoU. For more information about the Big Ideas, see the narrative in the Cross Theme Topic section of the NSF-Wide Investments chapter.

MPS provides 44 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 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Advanced Manufacturing	$193.42	-	$123.13	-$70.29	-36.3%
Advanced Wireless Research	17.00	-	17.00	-	-
Artificial Intelligence	110.63	-	71.67	-38.96	-35.2%
Biotechnology	91.88	-	62.20	-29.68	-32.3%
Climate: Clean Energy Technology[3]	132.07	-	128.56	-3.51	-2.7%
Climate: USGCRP[3]	9.83	-	34.63	24.80	252.3%
Microelectronics/Semiconductors	57.31	-	26.00	-31.31	-54.6%
MPS Postdoctoral Fellowships	20.21	-	40.55	20.34	100.6%
Quantum Information Science	154.03	-	156.13	2.10	1.4%
Secure & Trustworthy Cyberspace	1.26	-	1.25	-0.01	-0.8%

[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] Funding includes resources for agency-wide initiatives.

- 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—SII: 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 funding will primarily continue the support of three cross-cutting initiatives: (1) the most innovative approaches to dynamic spectrum sharing in specialized geographic regions - “National Radio Dynamic Zones”; (2) the national center for wireless SII-Center; and (3) education and workforce development specifically related to spectrum research.
- AI: Together with other NSF directorates/offices, MPS will continue its support for AI research, with a focus on supporting basic research in machine learning and deep learning and development of tools and techniques driven by the physical sciences.
- Biotechnology: 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.
- Climate Research and Clean Energy Technology: MPS, together with other NSF directorates/offices, will increase investment in activities that focus on research in developing mitigation and adaptation solutions for climate change and innovation in clean and sustainable energy resources.
- Equity and Broadening participation: MPS will enhance the support of Mathematical and Physical Sciences Ascending Postdoctoral Research Fellowship (MPS-Ascend) program with an additional

$10 million and continue its investment in early career researchers from less resourceful institutions.

- 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. This research is critical to future advances and security in information technology, communications, sensing, smart electric grid, transportation, health, advanced manufacturing, and other areas.
- MPS Postdoctoral Fellowships: Postdoctoral research is a critical stage in preparation for professional careers. The MPS-Ascend, the Mathematical Sciences Postdoctoral Research Fellowships, and the Astronomy and Astrophysics Postdoctoral Fellowship programs will significantly increase their investment to support an additional 80 fellows.
- QIS: As the steward for QIS, MPS will work together with other NSF directorates and offices to continue support for QIS research and development. These investments align with the National Quantum Initiative 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. MPS will increase the investment in QIS workforce development and in the newly launched Expanding Capacity in Quantum Information Science and Engineering program.
- SaTC: MPS will continue to invest in fundamental research in cybersecurity.
- 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. Through WoU investments, NSF will also grow the workforce not only for multi-messenger astrophysics but also for engineering and data science. For more information about the Big Ideas, see the narrative in the Cross Theme Topics section of the NSF-Wide Investments chapter.

MPS Funding for Centers Programs and Major Facilities

MPS Funding for Centers Programs
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Artificial Intelligence Research Institutes (AST, CHE, PHY)	$4.36	-	$5.00	$0.64	14.7%
Centers for Chemical Innovation (CHE)	27.64	-	27.70	0.06	0.2%
Materials Centers (DMR)	50.08	-	56.80	6.72	13.4%
Quantum Leap Challenge Institutes (OMA)[1]	32.05	-	32.00	-0.05	-0.2%
STC: Center for Integrated Quantum Materials (DMR)[2]	4.15	-	-	-4.15	-100.0%
STC: STC on Real-Time Functional Imaging (DMR)	5.00	-	5.00	-	-
STC: Center for Integration of Modern Optoelectronic Materials on Demand (DMR)[3]	-	-	5.00	5.00	N/A
STC: Center for Bright Beams (PHY)	4.84	-	5.00	0.16	3.3%
Spectrum Innovation Initiative Center (DIV or Multiple)	7.79	-	5.00	-2.79	-35.8%
Total	**$135.91**	**-**	**$141.50**	**$5.59**	**4.1%**

[1] Since FY 2020, Quantum Leap Challenge Institutes (QLCI) funding has been a vital part of NSF's overall $50 million investment in multidiscplinary centers for quantum research and education.

[2] All Class of 2013 STCs were sunsetted in FY2021.

[3] The IMOD STC was selected as part of the new STC Class of 2021.

For detailed information on individual centers programs, please see the Cross Theme Topics section of the NSF-Wide Investments chapter.

MPS Funding for Major Facilities

(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Arecibo Observatory[1]	$38.18	-	$3.00	-$35.18	-92.1%
Green Bank Observatory[2]	8.90	-	10.83	1.93	21.7%
IceCube Neutrino Observatory (IceCube)	3.53	-	3.83	0.30	8.5%
Large Hadron Collider (LHC)	20.00	-	20.50	0.50	2.5%
Laser Interferometer Gravitional-Wave Observatory (LIGO)	45.00	-	45.00	0.00	-
National High Magnetic Field Laboratory (NHMFL)[3]	26.13	-	40.49	14.36	55.0%
National Radio Astronomy Observatory (NRAO)	98.21	-	98.11	-0.10	-0.1%
NRAO O&M[4]	*49.53*	-	*44.45*	*-5.08*	*-10.3%*
Atacama Large Millimeter Array (ALMA) O&M[5]	*48.68*	-	*53.66*	*4.98*	*10.2%*
National Solar Observatory (NSO)	24.19	-	27.74	3.55	14.7%
NSO O&M[6]	*4.65*	-	*7.06*	*2.41*	*51.8%*
Daniel K. Inouye Solar Telescope (DKIST) O&M[7]	*19.54*	-	*20.68*	*1.14*	*5.8%*
National Superconducting Cyclotron Laboratory (NSCL)[8]	15.50	-	-	-15.50	-100.0%
NSF's National Optical-Infrared Astronomy Research Laboratory (NOIRLab)	60.32	-	70.90	10.58	17.5%
NOIRLab O&M (Mid-Scale Observatories & Community Science and Data Center)[9]	*29.95*	-	*25.99*	*-3.96*	*-13.2%*
Gemini Observatory O&M[10]	*24.27*	-	*24.61*	*0.34*	*1.4%*
Vera C. Rubin Observatory O&M	*6.09*	-	*20.30*	*14.21*	*233.4%*
Total	**$339.96**	**-**	**$320.40**	**-$19.56**	**-5.8%**

[1] FY 2021 Actual includes $34.92 million for emergency cleanup of the Arecibo site following the collapse of the platform above the 305-meter telescope in December 2020. FY 2021 Actual excludes $0.53 million of O&M funding obligated in FY 2020.

[2] FY 2023 Request contains $1.71 million for research infrastructure and O&M costs, including additional costs for repairs and maintenance.

[3] FY 2021 Actual excludes $12.00 million obligated in FY 2020 for FY 2021 operations. FY 2023 Request contains $2.21 million for additional research infrastructure and O&M costs, including costs for repairs and maintenance.

[4] FY 2021 Actual includes funding for the ngVLA program office. FY 2023 Request contains $3.92 million in additional research infrastructure and O&M costs, including additional costs for repairs and maintenance.

[5] FY 2023 Request includes $3.03 million in additional research infrastructure and O&M costs, including additional costs for repairs and maintenance.

[6] FY 2023 Request includes $1.18 million in additional research infrastructure funding for transition activities at Sacramento Peak Observatory.

[7] FY 2023 Request includes $1.10 million in research infrastructure to optimize community access.

[8] FY 2021 was the final year of NSF stewardship of NSCL, after which NSCL transitioned into the Department of Energy's Facility for Rare Isotope Bean

[9] FY 2021 Actual includes special projects funding of $9.44 million. FY 2023 Request contains $4.86 million in additional research infrastructure and O&M costs, including additional costs for repairs and maintenance.

[10] FY 2023 Request contains $1.63 million for additional research infrastructure and O&M, including costs for repairs and maintenance.

For detailed information on individual facilities, please see the Research Infrastructure section of the NSF-Wide Investments chapter.

Funding Profile

MPS Funding Profile

	FY 2021 Actual Estimate	FY 2022 (TBD)	FY 2023 Estimate
Statistics for Competitive Awards:			
Number of Proposals	8,114	-	9,500
Number of New Awards	2,422	-	3,000
Regular Appropriation	2,366		3,000
ARP	56		
Funding Rate	30%	-	32%
Statistics for Research Grants:			
Number of Research Grant Proposals	7,258	-	8,350
Number of Research Grants	2,117	-	2,400
Regular Appropriation	2,065		2,400
ARP	52		
Funding Rate	29%	-	29%
Median Annualized Award Size	$136,964	-	$135,000
Average Annualized Award Size	$164,267	-	$169,000
Average Award Duration, in years	3.2	-	3.1

In FY 2023, the number of research grant proposals is expected to increase by 1,400 compared to the FY 2021 Actual, and MPS expects to award about 3,000 research grants. Average annual award size and duration are not expected to materially fluctuate in FY 2021 through FY 2023. O&M funding for MPS-supported user facilities comprises 23 percent of MPS' FY 2023 Request.

People Involved in MPS Activities

Number of People Involved in MPS Activities

	FY 2021 Actual Estimate	FY 2021 ARP Actual Estimate	FY 2022 (TBD)	FY 2023 Estimate
Senior Researchers	9,651	227	-	10,200
Other Professionals	2,569	8	-	2,500
Postdoctoral Associates	2,478	29	-	2,200
Graduate Students	9,867	136	-	10,300
Undergraduate Students	5,044	171	-	7,000
Total Number of People	**29,609**	**571**	**-**	**32,200**

DIVISION OF ASTRONOMICAL SCIENCES (AST) $294,050,000
+$4,780,000 / 1.7%

AST Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$289.27**	**-**	**$294.05**	**$4.78**	**1.7%**
Research	**52.61**	**-**	**73.74**	**21.13**	**40.2%**
CAREER	3.60	-	4.81	1.21	33.6%
Centers Funding (total)	0.30	-	0.30	-	-
Artificial Intelligence Research Institutes	0.30	-	0.30	-	-
Education	**3.54**	**-**	**6.10**	**2.56**	**72.3%**
Infrastructure	**233.12**	**-**	**214.21**	**-18.91**	**-8.1%**
Arecibo Observatory[1]	13.83	-	3.00	-10.83	-78.3%
Green Bank Observatory	8.90	-	9.12	0.22	2.5%
Mid-scale Research Infrastructure	19.17	-	19.50	0.33	1.7%
National Radio Astronomy Observatory (NRAO)	98.21	-	91.16	-7.05	-7.2%
NRAO O&M [2]	*49.53*	-	*40.53*	*-9.00*	*-18.2%*
Atacama Large Millimeter Array (ALMA) O&M	*48.68*	-	*50.63*	*1.95*	*4.0%*
National Solar Observatory (NSO)	24.19	-	25.46	1.27	5.3%
NSO O&M	*4.65*	-	*5.88*	*1.23*	*26.5%*
Daniel K. Inouye Solar Telescope (DKIST) O&M	*19.54*	-	*19.58*	*0.04*	*0.2%*
NSF's National Optical-Infrared Astronomy Research Laboratory (NOIRLab)	60.32	-	58.97	-1.35	-2.2%
NOIRLab O&M (Mid-Scale Observatories & Community Science and Data Center) [3]	*29.95*	-	*25.99*	*-3.96*	*-13.2%*
Gemini Observatory O&M	*24.27*	-	*22.98*	*-1.29*	*-5.3%*
Vera C. Rubin Observatory O&M	*6.09*	-	*10.00*	*3.91*	*64.2%*
Research Resources	7.94	-	7.00	-0.94	-11.8%

[1] FY 2021 Actual includes $10.57 million for emergency cleanup of the Arecibo site following the collapse of the platform above the 305-meter telescope in December 2020. FY 2021 Actual excludes $0.53 million of O&M funding obligated in FY 2020.

[2] FY 2021 Actual includes funding for the ngVLA program office.

[3] FY 2021 Actual includes special projects funding of $9.44 million. FY 2023 Request contains $4.86 million in additional research infrastructure and O&M costs, including additional costs for repairs and maintenance.

About AST

AST is the federal steward for ground-based astronomy in the United States, and funds awards to individual investigators and small research groups as well as provide access to world-leading astronomical laboratories via cooperative agreements. These state-of-the-art telescope facilities enable scientific advances by providing observational capabilities on a competitive basis to thousands of astronomers each year. 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 on the nature of planets, stars, and galaxies and the structure of the universe. This leads to a deeper understanding of the composition and evolution of the cosmos and the nature of the mysterious dark matter and dark energy that comprise more than 95 percent of the universe. AST facilities and research programs have enabled the detection of planets orbiting other stars and are beginning to search for life on these other worlds. AST research probes the universe through three distinct “windows”—electromagnetic waves, high-energy particles, and gravitational waves.

An estimated 20 percent of the AST portfolio is available for new research grants to individual investigators and about 80 percent of the AST budget supports the instrumentation and facilities needed for international leadership and advances at the frontiers of observational astronomy. Through the MREFC appropriation, AST oversight is provided for the construction of the Vera C. Rubin Observatory. For detailed information on AST's individual facilities and the construction of the Vera C. Rubin Observatory, see the Research Infrastructure section of the NSF-Wide Investments chapter.

DIVISION OF CHEMISTRY (CHE) $284,140,000

+$24,540,000 / 9.5%

CHE Funding

(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$259.60**	**-**	**$284.14**	**$24.54**	**9.5%**
Research	**245.09**	**-**	**270.97**	**25.88**	**10.6%**
CAREER	29.37	-	26.00	-3.37	-11.5%
Centers Funding (total)	26.00	-	29.70	3.70	14.2%
Artificial Intelligence Research Institutes	0.36	-	2.00	1.64	455.6%
Centers for Chemical Innovation	25.64	-	27.70	2.06	8.0%
Education	**4.92**	**-**	**4.52**	**-0.40**	**-8.1%**
Infrastructure	**9.59**	**-**	**8.65**	**-0.94**	**-9.8%**
Midscale Research Infrastructure	0.60	-	0.60	-	-
NHMFL	1.88	-	2.10	0.22	11.7%
National Nanotechnology Coordinated Infrastructure (NNCI	0.30	-	0.30	-	-
Research Resources	6.81	-	5.65	-1.16	-17.0%

About CHE

CHE supports discovery research and workforce development in chemistry that have the potential to transform 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, sensor and instrument development, biotechnology, clean energy, and climate research. 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 understanding, invention, and innovation, but also have significant impact on the training and deployment of the future STEM workforce.

In general, about 70 percent of the CHE portfolio is available to support new research grants. The remaining 30 percent supports research grants made in prior years and the research infrastructure needed by the chemistry community.

DIVISION OF MATERIALS RESEARCH (DMR) **$349,920,000**

+$19,850,000 / 6.0%

DMR Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over Amount	Change over Percent
Total	**$330.07**	**-**	**$349.92**	**$19.85**	**6.0%**
Research	**267.51**	**-**	**280.24**	**12.73**	**4.8%**
CAREER	33.45	-	25.00	-8.45	-25.3%
Centers Funding (total)	59.23	-	66.80	7.57	12.8%
Materials Centers	50.08	-	56.80	6.72	13.4%
STC: Center for Integrated Quantum Materials (DMR)[1]	4.15	-	-	-4.15	-100.0%
STC: STC on Real-Time Functional Imaging (DMR)	5.00	-	5.00	-	-
STC: Center for Integration of Modern Optoelectronic Materials on Demand (DMR)[2]	-	-	5.00	5.00	N/A
Education	**5.63**	**-**	**2.50**	**-3.13**	**-55.6%**
Infrastructure	**56.93**	**-**	**67.18**	**10.25**	**18.0%**
Center for High Energy X-ray Science (CHEXS)	9.50	-	7.00	-2.50	-26.3%
Midscale Research Infrastructure	18.47	-	15.34	-3.13	-16.9%
National High-Magnetic Field Laboratory (NHMFL)[3]	24.25	-	37.81	13.56	55.9%
National Nanotechnology Coordinated Infrastructure (NNCI)	2.58	-	2.58	-	-
Other MPS Facilities	1.50	-	3.00	1.50	100.0%
Research Resources	0.45	-	1.45	1.00	222.2%

[1] All Class of 2013 STCs were sunsetted in FY 2021.

[2] The IMOD STC was selected as part of the new STC Class of 2021.

[3] FY 2021 Actual excludes $12.00 million obligated in FY 2020 for FY 2021 operations. FY 2023 Request contains $1.63 million for additional research infrastructure and O&M costs, including costs for repairs and maintenance.

About DMR

Materials research is defined by the broad intersection of many disciplines with materials science & engineering (MS&E), including chemistry, physics, biology, mathematics, and other engineering disciplines that naturally converge in the pursuit of understanding the properties of materials and the phenomena they host. Materials are ubiquitous and pervasive, serving as critical building blocks in technology and innovation. Materials research directly and fundamentally 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, prediction and design of new materials; the discovery, explanation and harnessing of materials phenomena; as well as the development of the next generation of materials scientists, which includes increasing the pathways for participation by underrepresented group. DMR supports fundamental experimental, computational, 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 broad 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 national mid- and large-scale user facilities. Specifically, DMR investments have contributed to U.S. leadership in high-field magnet science and further aim at democratizing national access to high-magnetic fields. DMR also supports materials-relevant instrumentation and technique development broadly in x-ray and neutron science, nanofabrication, as well in automated and autonomous tools coupled to AI.

In general, about 43 percent of the DMR portfolio is available to support new research grants. The remaining 57 percent supports research grants made in prior years and the research infrastructure needed by the materials research community.

DIVISION OF MATHEMATICAL SCIENCES (DMS)

$259,470,000
+$15,810,000 / 6.5%

DMS Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$243.66**	**-**	**$259.47**	**$15.81**	**6.5%**
Research	**229.36**	**-**	**245.32**	**15.96**	**7.0%**
CAREER	16.48	-	15.00	-1.48	-9.0%
Education	**14.30**	**-**	**14.15**	**-0.15**	**-1.0%**

About DMS

DMS provides the major U.S. federal support for fundamental research in the mathematical sciences, leading to accelerated discovery and innovation in all science and engineering fields. Modern computing and 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 current and future national priority areas such as artificial intelligence, quantum information science, biotechnology, and climate science. Another DMS priority is the development and advancement of future researchers in the mathematical sciences, through dedicated workforce and development programs.

DMS also provides leadership in emerging research fields through its support of the Mathematical Sciences Research Institutes program, which advances mathematics and statistics research through thematic programs and workshops on current and emerging trends.

DMS continues to develop strong partnerships to expand the impact of its research investments. Examples of partnerships within NSF include the Transdisciplinary Research in Principles of Data Science program with CISE and a program for developing new models for uncovering phenomena in biology with BIO. DMS also forms partnerships with other federal agencies including: a program in biosciences with NIH, the Joint DMS/National Institute of General Medical Sciences Initiative to Support Research at the Interface of the Biological and Mathematical Sciences; a program with the National Geospatial Intelligence Agency to develop the next generation of mathematical and statistical algorithms for threat analysis; and a program on algorithms for modern power systems with DOE. Finally, DMS partners with private foundations such as the Simons Foundation on programs that support research centers on the Mathematics of Complex Biological Systems and on the mathematical foundations of deep learning.

In general, about 58 percent of the DMS portfolio is available to support new research grants each year. The remaining 42 percent supports research grants made in prior years.

DIVISION OF PHYSICS (PHY) **$316,590,000**
+$12,170,000 / 4.0%

PHY Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$304.42**	**-**	**$316.59**	**$12.17**	**4.0%**
Research	**210.56**	**-**	**222.84**	**12.28**	**5.8%**
CAREER	11.99	-	7.30	-4.69	-39.1%
Centers Funding (total)	7.54	-	7.70	0.16	2.1%
Artificial Intelligence Research Institutes	2.70	-	2.70	-	-
STC: Center for Bright Beams (PHY)	4.84	-	5.00	0.16	3.3%
Education	**5.02**	**-**	**4.92**	**-0.10**	**-2.0%**
Infrastructure	**88.84**	**-**	**88.83**	**-0.01**	**-0.0%**
IceCube	3.53	-	3.83	0.30	8.6%
LHC	20.00	-	20.50	0.50	2.5%
LIGO	45.00	-	45.00	-	-
Midscale Research Infrastructure	1.69	-	18.50	16.81	993.4%
NSCL[1]	15.50	-	-	-15.50	-100.0%
Research Resources	2.75	-	1.00	-1.75	-63.7%

[1] FY 2021 was the final year of NSF stewardship of NSCL, after which NSCL transitioned 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, and optical physics, elementary particle physics, gravitational physics, nuclear physics, particle astrophysics and cosmology, physics of living systems, plasma physics, and quantum information science.

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 quantum information science and artificial intelligence.

In general, about 29 percent of the PHY portfolio is available for new research grants. The remaining 71 percent is used primarily to fund continuing grants made in previous years and to support operations and maintenance for three facilities that are a key part of the division portfolio. Through the MREFC appropriation, PHY also oversees the construction of HL-LHC. For detailed information on PHY's individual facilities and the construction of HL-LHC, see the Research Infrastructure section of the NSF-Wide Investments chapter.

OFFICE OF MULTIDISCIPLINARY ACTIVITIES (OMA) $242,680,000 +$76,390,000 / 45.9%

OMA Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Percent
Total	**$166.29**	**-**	**$242.68**	**$76.39**	**45.9%**
Research	**124.97**	**-**	**190.23**	**65.26**	**52.2%**
CAREER	1.04	-	-	-1.04	-100.0%
Centers Funding (total)	39.84	-	37.00	-2.84	-7.1%
Quantum Leap Challenge Institutes	32.05	-	32.00	-0.05	-0.2%
Spectrum Innovation Initiative Center	7.79	-	5.00	-2.79	-35.8%
Education	**9.67**	**-**	**29.00**	**19.33**	**199.9%**
Infrastructure[1]	**31.65**	**-**	**23.45**	**-8.20**	**-25.9%**

[1] FY 2021 Actual includes $24.35 million for emergency cleanup of the Arecibo site following the collapse of the platform above the 305-meter telescope in December 2020. FY 2023 Request contains additional research infrastructure and O&M for MPS Major Facilities, including additional costs for repairs and maintenance.

About OMA

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

OMA funding will focus on priority areas relevant to MPS: QIS, WoU, AI, SII, and Climate Research. As the steward for QIS, OMA will work with 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. OMA will collaborate with all MPS divisions to support their investments in AI for sciences and the science of AI, clean energy, and climate science research. OMA is the steward for SII, which promotes transformative use and management of the electromagnetic spectrum with a focus on dynamic and agile spectrum utilization, benefiting multiple research areas. OMA will foster broadening participation through the new MPS-Ascend program and the Launching Early-Career Academic Pathways in the Mathematical and Physical Sciences and 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 32 percent of the OMA portfolio is available to support new research grants. The remaining 68 percent supports multidisciplinary research infrastructure and education activities needed by the MPS community.

DIRECTORATE FOR SOCIAL, BEHAVIORAL, AND ECONOMIC SCIENCES (SBE) $330,210,000
+$48,100,000 / 17.0%

SBE Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2021 ARP Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Division of Behavioral and Cognitive Sciences (BCS)	$99.42	$7.63	-	$113.14	$13.72	13.8%
Division of Social and Economic Sciences (SES)	102.91	7.63	-	114.56	11.65	11.3%
Nat'l Ctr. for Science and Engr. Statistics (NCSES)	55.46	-	-	74.89	19.43	35.0%
SBE Office of Multidisciplinary Activities (SMA)	24.32	2.90	-	27.62	3.30	13.6%
Total	**$282.11**	**$18.16**	**-**	**$330.21**	**$48.10**	**17.0%**

About SBE

SBE researchers examine fundamental questions about the dynamic abilities of humans, the strength and resilience of essential institutions, the creation of jobs and industries, national security and relations between nations, and finding new ways to improve quality of life for all Americans. SBE supported research empowers America’s private and public sectors to grow the economy, secure the homeland, improve the health and safety of American families, enhance equitable decision making, and increase the competitiveness of farms, offices, and factories across the Nation.

SBE aggressively seeks opportunities to build a better future. One way it does this is by investing in a new and increasingly diverse, dynamic, and skilled generation of young SBE researchers. 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. SBE researchers, for example, will have increasing opportunity to use and combine data from surveys, administrative records, brain imaging, and biospecimens, as well as output from behavioral, environmental, and geographic sensors to help others learn about how to create opportunity and improve life outcomes. America’s young SBE researchers have limitless potential to produce transformative, socially beneficial science of this kind.

SBE is also home to the National Center for Science and Engineering Statistics (NCSES). NCSES is one of only 13 principal statistical agencies in the federal government, and is the Nation’s source for science and engineering information in a global context. NCSES collects, analyzes, and disseminates information on representation across the scientific enterprise; research and development; innovation; the Science and Engineering (S&E) workforce; the condition and progress of science, technology, engineering, and mathematics (STEM); and U.S. competitiveness in science, engineering, technology, and research and development.

SBE’s FY 2023 Request is shaped by three guiding principles:

Support fundamental research that advances key national priorities. The research emphases include enhancing national security and preparedness; understanding, mitigating, and adapting to climate and global change; strengthening American infrastructure; broadening participation (BP) in STEM and studying the causes of, impacts on, and practices for addressing inequity throughout society; 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 tomorrow; reliability of information networks; and improving quality of life for communities across the country.

Support NCSES, the Nation's premier source for information on the science and engineering enterprise. The Foundations for Evidence-Based Policy Act (Evidence Act), and other initiatives to improve the performance of federal agencies and the productivity of America's S&E enterprise as a whole, require our Nation to make more effective use of the types of data that NCSES collects, analyzes, and disseminates. Increased support for NCSES allows the Nation to be more informed, more effective, and more agile in converting America's incredible talent and ability into better educational outcomes, more opportunity, greater productivity, and higher rates of innovation in all areas of American life.

Support and advance cross-directorate activities that address urgent national challenges. Whether the topic is creating the new jobs and industries that will yield an economic recovery that helps everyone, increasing national security through tools that better identify new and emerging threats, improving community resilience by improving response to natural disasters and pandemics, protecting consumers and institutions against misinformation and other attacks on vital infrastructure, broadening opportunity, or understanding the people involved is critical. SBE works with all of NSF and other agencies to support research that solves big problems by putting people first.

In FY 2023, SBE will prioritize and maximize support in its disciplinary and interdisciplinary programs that support Administration and NSF-wide priorities including activities that contribute to shaping the industries of tomorrow, including advanced manufacturing research; build capacity and enhance research productivity at underrepresented institutions; expanding the STEM talent pool through increased funding for post-doctoral research fellowships; AI; United States Global Research Change Program (USGCRP); and, significantly, to support NCSES's role as the Program Management Office (PMO) for the Standard Application Process (SAP) required under the Evidence Act and for work related to building a National Secure Data Service (NSDS).

The FY 2023 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 include research related to Brain Research through Advancing Innovative Neurotechnologies (BRAIN); National AI Research Institutes; SaTC; Smart and Connected Communities (S&CC); democracy affirming technologies; Smart Health and Biomedical Research in the Era of Artificial Intelligence and Advanced Data Science (SCH); and Dynamics of Integrated Socio-Environmental Systems (DISES). 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.

In FY 2023, SBE will continue to support the next generation of scholars poised to produce transformative and societally beneficial science. SBE will continue its support for early career investigators—Faculty Early Career Development (CAREER); undergraduates—Research Experiences for Undergraduates (REU); graduate students—Doctoral Dissertation Research Improvement Grants

(DDRIG); and post-doctoral research fellows through its SBE Postdoctoral Research Fellowships (SPRF) program.

SBE's FY 2023 Request includes increased support for NCSES. Consistent with recent Executive Orders that highlight the importance of objective and trustworthy data, funding will help NCSES modernize systems and data tools, develop a new website, and address requirements of the Evidence Act.

SBE provides approximately 64 percent of the federal funding for basic research at academic institutions in the social, behavioral, and economic sciences.

Major Investments

SBE Major Investments

(Dollars in Millions)

Area of Investment[1,2]	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual: Amount	Change over FY 2021 Actual: Percent
Advanced Manufacturing	$0.50	-	$3.50	$3.00	600.0%
Artificial Intelligence	15.06	-	19.59	4.53	30.1%
Biotechnology	2.04	-	1.50	-0.54	-26.5%
Climate: USGCRP	18.25	-	25.14	6.89	37.8%
Build and Broaden	6.30	-	8.00	1.70	27.0%
SBE Postdoctoral Research Fellowships	5.91	-	9.00	3.09	52.3%
Secure & Trustworthy Cyberspace	4.00	-	4.00	-	-
Strengthening American Infrastructure	6.16	-	8.00	1.84	29.9%

[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 ($3.50 million): SBE will invest in advanced manufacturing-related activities through support for fundamental research in the social and economic sciences that contribute to the development of new methods, processes, analyses of new or existing manufacturing systems or processes. In addition, SBE is a partner in the Future Manufacturing program.

AI ($19.59 million): SBE will increase support for AI research. 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 NITRD-related AI.

Build and Broaden (B2) ($8.0 million): SBE will continue investments in B2, an innovative program that supports research collaborations and partnerships between scholars at MSIs and scholars in other institutions or organizations. B2 supports research projects that: 1) build capacity and enhance research productivity in the SBE sciences at MSIs; 2) provide researchers with new ways to diversify and sustain collaborations; 3) foster partnerships that strengthen career and research trajectories for faculty at MSIs; 4) broaden participation of underrepresented individuals, organizations and geographies in STEM entrepreneurship and innovation; and 5) contribute to stronger, more innovative science by diversifying research and widening the STEM pathways.

USGCRP ($25.14 million): In FY 2023, SBE will increase funding activities that are encompassed by the USGCRP. Foundational research in the SBE sciences include advancing the fundamental understanding of humans as a component of the Earth system to improve knowledge of the causes and consequences of global change; improving and developing advanced models that integrate across all components of the Earth system, the human with the physical, chemical, and biological; increasing understanding of human and community resilience to global change; improving risk communications; and improving the deployment and accessibility of the SBE sciences to inform mitigation and adaptation decisions. In addition to supporting core programs that support research in this portfolio (including DISES), a portion of SBE's FY 2023 funding will be directed to Coastlines and People (CoPe), which seeks convergent science at the nexus between coastal sustainability, human dimensions, and coastal processes, to transform understanding of interactions among natural, human-built, and social systems in coastal, populated environments.

SBE Postdoctoral Research Fellowship (SPRF) ($9.0 million): In FY 2023, SBE will increase its commitment to SPRF, which promotes fundamental research in the SBE sciences by providing opportunities for recent doctoral graduates to obtain additional training and gain research experience; targets and enhances the participation of underrepresented groups in science and engineering; and encourages doctoral-level scientists (who are not yet in full-time positions) to take advantage of the two-year fellowship to prepare for scientific careers in academia, industry or private sector, and government. FY 2023 funding will expand support for broadening participation with an emphasis on PIs from underrepresented groups, states, and institutions.

SaTC ($4.0 million): SBE will sustain its investment in SaTC to support the 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 ($8.0 million): In FY 2023, SBE will increase its commitment to this 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 human-centered approach to infrastructure is a critical component to building better, smarter, and more cost-effective roads, electric grids, hospitals, and more. Improving infrastructure in these ways spurs private-sector innovation, grows the economy, and is essential to national competitiveness.

SBE Funding for Centers Programs and Major Facilities

SBE Funding for Centers Programs

(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Artificial Intelligence Research Institutes (BCS, SMA)	$1.02	-	$1.02	-	-

For detailed information on individual centers programs, please see the NSF Centers Programs narrative in the NSF-Wide Investments – Cross Theme Topics chapter.

Funding Profile

SBE Funding Profile

	FY 2021 Actual Estimate	FY 2022 (TBD)	FY 2023 Estimate
Statistics for Competitive Awards:			
Number of Proposals	3,956	-	4,000
Number of New Awards	918	-	900
Regular Appropriation	759		900
ARP	159		
Funding Rate	23%	-	23%
Statistics for Research Grants:			
Number of Research Grant Proposals	3,190	-	3,200
Number of Research Grants	638	-	670
Regular Appropriation	591		670
ARP	47		
Funding Rate	20%	-	21%
Median Annualized Award Size	$135,479	-	$135,000
Average Annualized Award Size	$174,028	-	$174,000
Average Award Duration, in years	2.9	-	3.0

SBE supports investment in core research and education activities as well as research infrastructure. In FY 2023, SBE will continue to fund research in areas such as the NSF Big Ideas, AI, BRAIN, and cybersecurity research while continuing to prioritize its disciplinary and interdisciplinary investigator-led research areas. In FY 2023, SBE expects to award approximately 900 competitive grants, including nearly 670 research grants.

People Involved in SBE Activities

Number of People Involved in SBE Activities

	FY 2021 Actual Estimate	FY 2021 ARP Actual Estimate	FY 2022 (TBD)	FY 2023 Estimate
Senior Researchers	2,354	166	-	2,700
Other Professionals	508	36	-	600
Postdoctoral Associates	274	20	-	300
Graduate Students	1,368	185	-	1,500
Undergraduate Students	1,178	480	-	1,300
Total Number of People	**5,682**	**887**	**-**	**6,400**

DIVISION OF BEHAVIORAL AND COGNITIVE SCIENCES (BCS) $113,140,000
+$13,720,000 / 13.8%

BCS Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$99.42**	**-**	**$113.14**	**$13.72**	**13.8%**
Research	**93.51**	**-**	**108.20**	**14.69**	**15.7%**
CAREER	12.44	-	5.00	-7.44	-59.8%
Centers Funding (total)	0.25	-	0.25	-	-
Artificial Intelligence Research Institutes	0.25	-	0.25	-	-
Education	**0.86**	**-**	**0.44**	**-0.42**	**-48.8%**
Infrastructure	**5.05**	**-**	**4.50**	**-0.55**	**-10.9%**
Research Resources	5.05	-	4.50	-0.55	-10.9%

About BCS

BCS supports fundamental research that examines the sources of the human condition and the character of thinking and behavior. Its 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 new approaches to learning, decision making, and problem solving for individuals and groups.

BCS-supported research informs a range of pressing national issues. Exploring how thought and behavior respond to changing situations, environmental characteristics, and cultural differences provides important information for improving disaster response, addressing climate change, and supporting improved security and preparedness. Research on sources of bias in human interaction and strategies for their mitigation are critical to expanding diversity and inclusion across the STEM disciplines. Understanding human thinking is essential for the design and improvement of advanced technologies and built infrastructure. For example, through its Science of Learning and Augmented Intelligence program, BCS research explores how collaborative activities among humans and emerging technologies, especially artificial intelligence, can enhance human cognition and productivity.

BCS also 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 83 percent of the BCS portfolio is available to support new research grants. The remaining 17 percent supports research grants made in prior years and the research infrastructure needed by this community.

DIVISION OF SOCIAL AND ECONOMIC SCIENCES (SES) $114,560,000

+$11,650,000 / 11.3%

SES Funding

(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual	
				Amount	Percent
Total	**$102.91**	**-**	**$114.56**	**$11.65**	**11.3%**
Research	**86.87**	**-**	**108.57**	**21.70**	**25.0%**
CAREER	4.44	-	5.00	0.56	12.6%
Education	**0.21**	**-**	**0.50**	**0.29**	**138.1%**
Infrastructure	**15.83**	**-**	**5.49**	**-10.34**	**-65.3%**
NNCI	0.40	-	0.40	-	-
Research Resources	15.43	-	5.09	-10.34	-67.0%

About SES

SES is concerned with the growth and flourishing of our Nation through the provision of goods, services, opportunities, and wellbeing. The Division therefore supports research on how people live, work, and prosper together in productive businesses and other organizations. Priority topics include: management tools, risk assessment, and strategic planning; workforce measurement, training, and development; fundamental questions about markets, competition, and the economy; social trends, attitudes, and demographics; security and preparedness; accountable institutions and behaviors; the science of and the legal and regulatory aspects of innovation, technology, and science; the safety and trustworthiness of new technologies; as well as the statistics, modeling, and other methodologies that enable such vital research. These techniques are used to study the scientific enterprise itself with the goal of enhancing the rate, value, and communication of basic discoveries. This work thus helps 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. The division also supports innovations in data and methodological infrastructure that advances survey science and technology, such as data collection via different platforms and statistical methods that allow adequate sampling of underrepresented groups.

SES is actively involved in partnerships to increase the value to the public of NSF- and SBE-funded research. One recent major collaboration is The Societal Experts Action Network (SEAN), which consists of experts available via the National Academies of Sciences, Engineering, and Medicine to develop evidence-based recommendations, based on evidence from the SBE sciences, to support local, state, and national responses to urgent policy matters and questions.

In general, about 83 percent of the SES portfolio is available to support new research grants. The remaining 17 percent supports research grants made in prior years and the research infrastructure needed by this community.

NATIONAL CENTER FOR SCIENCE AND ENGINEERING STATISTICS (NCSES) $74,890,000 +$19,430,000 / 35.0%

NCSES Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$55.46**	**-**	**$74.89**	**$19.43**	**35.0%**
Research	0.93	-	-	-0.93	-100.0%
Infrastructure	54.53	-	74.89	20.36	37.3%

About NCSES

NCSES is one of the federal government's 13 principal statistical agencies with a mission to provide information regarding the S&E enterprise in a global context. 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.

NCSES was originally created within NSF 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 (SEI); and Women, Minorities, and Persons with Disabilities in Science and Engineering (WMPD)*. WMPD is a unique source of data and analysis on participation across the science and engineering enterprise. Additionally, the Evidence Act assigned expanded responsibilities to NCSES and other Federal statistical agencies to advance evidence building,

The FY 2023 Request supports NCSES leadership of government-wide evidence building activities and initiatives required of the federal statistical agencies under the Evidence Act. These include standing up the first-ever standard application process for applying to access restricted-use data from statistical agencies and units, as well informing the proposed National Secure Data Service through America's DataHub. The request also supports NCSES's core data collection and analytic activities, including nationally representative surveys of U.S. investment in R&D, innovation, the education of scientists and engineers, and the science and engineering workforce, and preparation of the aforementioned *SEI and WMPD* reports. In FY 2023, NCSES will expand and continue initiatives related to:

- Leading development of the Standard Application Process (SAP)—The SAP is simplifying and easing the process of evidence building by allowing users to securely apply for access to the restricted data they need from statistical agencies in one place.
- Expanding America's DataHub—The DataHub is an NCSES-led collaboration of industry, academia,

non-profits, and government that is expanding the government's capacity for innovation, and which will help to inform the development of a National Secure Data Service.
- Improving the data and informational infrastructure around understanding racial equity and participation by reimagining the WMPD report and supporting efforts to gather data necessary to inform government-wide equity efforts.
- Enhancing the experience of users of NCSES data and information through a robust data, IT, and dissemination infrastructure.
- Furthering the Nation's understanding of the impact of R&D funding on the U.S. and global scientific enterprises.
- Improving the government's classification and measurement of the cybersecurity workforce.
- Informing U.S. policy on the foreign-trained S&E workforce by filling important gaps in knowledge of foreign-born and foreign-degreed scientists and engineers.
- Studying the Skilled Technical Workforce (STW)—with emphasis on the STW's current and potential future relevance to economic recovery and emerging industries 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.
- Furthering the understanding and application of statistical methodologies and experimental survey data collections through funded research.
- Modernizing systems and data tools to ease data access.

A corresponding increase of six FTE and related funding, associated with the SAP and NSDS, is included for FY 2023 in this request. Additional details regarding this staffing increase, can be found in the Personnel, Compensation, and Benefits section of Organizational Excellence chapter.

SBE OFFICE OF MULTIDISCIPLINARY ACTIVITIES (SMA) $27,620,000 +$3,300,000 / 13.6%

SMA Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$24.32**	**-**	**$27.62**	**$3.30**	**13.6%**
Research	**13.18**	**-**	**15.56**	**2.38**	**18.1%**
CAREER	1.52	-	-	-1.52	-100.0%
Centers Funding (total)	0.77	-	0.77	-	-
Artificial Intelligence Research Institutes	0.77	-	0.77	-	-
Education	**10.94**	**-**	**12.06**	**1.12**	**10.2%**
Infrastructure	**0.20**	**-**	**-**	**-0.20**	**-100.0%**
Research Resources	0.20	-	-	-0.20	-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 efforts and activities that seek to improve the scale and effectiveness of the scientific workforce. It supports REU Sites, the Ethical and Responsible Research (ER2) program, and the SPRF program. In FY 2023, SMA will play a major role in several crosscutting NSF investments as well as interdisciplinary research and training, via activities such as the SPRF-Fundamental Research and BP tracks. As the lead directorate for managing the ER2 program, with support from other NSF directorates, SBE coordinates the Online Ethics Center for Engineering and Science award. 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 40 percent of the SMA portfolio is available to support new research grants. The remaining 60 percent supports research grants made in prior years.

DIRECTORATE FOR TECHNOLOGY, INNOVATION AND PARTNERSHIPS (TIP) $879,870,000 +$510,860,000 / 138.4%

TIP Funding[1]
(Dollars in Millions)

	FY 2021 Actual	FY 2021 ARP Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Technology Frontiers (TF)	-	-	-	$145.00	$145.00	N/A
Innovation and Technology Ecosystems (ITE)	74.89	2.00	-	265.00	190.11	253.8%
Translational Impacts (TI)	294.11	17.87	-	419.00	124.89	42.5%
Strategic Partnerships Office (SPO)	-	-	-	50.87	50.87	N/A
Total	**$369.01**	**$19.87**	**-**	**$879.87**	**$510.86**	**138.4%**

[1] FY 2021 funding is adjusted for comparability to reflect the movement of activities to TIP in FY 2022.

About TIP

TIP aims to advance emerging technologies to address societal and economic challenges and opportunities; accelerate the translation of research results from the lab to market and society; and cultivate new education pathways leading to a diverse and skilled future technical workforce comprising researchers, practitioners, technicians, and entrepreneurs. Building on NSF's longstanding leadership in science and engineering research and education, TIP serves as a crosscutting platform that leverages, energizes, and rapidly advances use-inspired research and innovation. Further, TIP opens new possibilities for research and education by catalyzing strategic partnerships that link academia; industry, including startups and small businesses; federal, state, local, and tribal governments; nonprofits and philanthropic organizations; civil society; and communities of practice to cultivate 21st-century innovation ecosystems that give rise to future jobs and enhance the Nation's long-term competitiveness.

TIP collaborates with NSF's other directorates and offices, as well as other agencies, to advance use-inspired, solutions-oriented research and innovation in critical and emerging technologies and industries (e.g., advanced materials, AI, biotechnology, clean energy technology, future manufacturing, next-generation networks and systems, microelectronics and semiconductors, and QIS). Through these investments, TIP addresses a dynamic range of societal and economic challenges including key priorities of the Administration and Congress (e.g., climate change, equity, bioeconomy, supply-chain resilience). In collaboration with CISE and SBE, TIP will advance democracy-affirming technologies, enabling practical privacy solutions. Of particular note, TIP supports the new NSF Regional Innovation Engines (NSF Engines), catalyzing regional-scale innovation ecosystems throughout the U.S.

TIP also accelerates the translation of fundamental science and engineering discoveries into innovative new technologies and solutions. TIP optimizes the NSF Lab-to-Market Platform, allowing researchers to pursue additional prototyping, demonstration, and scale-up work, giving rise to the startups and small businesses that are leading to new markets and economies of scale. In addition, TIP is introducing new translational pathways, for example, facilitating the adoption of NSF-funded research results as secure open-source ecosystems, affording the U.S. a competitive advantage in technology development.

Across its full portfolio of investments, TIP includes equity as a fundamental design principle, seeking to provide opportunities for everyone to engage in the Nation's research and innovation enterprise, regardless of background, organizational affiliation, or geographic location. For example, NSF will work with academia, state, local, and tribal governments, industry, and other educational partners to provide practical experiences to diverse learners at every stage of education, from first-time job seekers to experienced workers looking for new opportunities.

Finally, TIP serves as a central resource to catalyze and scale up public and private partnerships agency wide. Specifically, TIP provides expertise and support to build partnerships, along with co-funding to strategically advance high-impact relationships that deepen and advance NSF's mission across all areas of science, engineering, and education. TIP's efforts will expand the reach of, and increase the return on, NSF's investments across all of its directorates and offices.

Across its portfolio, TIP develops future leaders in critical and emerging technologies capable of accelerating technology development, maturation, and deployment.

Major Investments

TIP Investments[1]
(Dollars in Millions)

Area of Investment	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual: Amount	Change over FY 2021 Actual: Percent
Accelerating Public and Private Partnerships	-	-	$50.87	$50.87	N/A
Assessments for Science & Technology Investments	-	-	40.00	40.00	N/A
Convergence Accelerator	50.70	-	70.00	19.30	38.1%
NSF Entrepreneurial Fellows	-	-	25.00	25.00	N/A
NSF Lab-to-Market Platform:					
PFI	22.32	-	30.00	7.68	34.4%
I-Corps™	39.02	-	40.00	0.98	2.5%
SBIR/STTR, including Operations	232.28	-	283.06	50.78	21.9%
Technology & Innovation Internships for Experiential	-	-	20.00	20.00	N/A

[1] FY 2021 funding is adjusted for comparability to reflect the movement of activities to TIP in FY 2022.

- Accelerating Public and Private Partnerships: TIP, through the SPO, will provide seed funding to incentivize the scale-up of public and private partnerships, providing co-funding to specifically enable strategic, high-impact relationships that will deepen and advance NSF's mission across all areas of science, engineering, and education. TIP will also nurture STEM talent by focusing on the engagement of populations long underrepresented in STEM, along with broad organizational changes in higher education and the inclusion of diverse institution types such as minority-serving institutions.
- Assessments for Science & Technology Investments: TIP will launch assessments of emerging technologies and industries to examine the alignment of federal science and technology research spending and programs with long-term U.S. competitiveness in these areas. As part of this enduring investment, TIP will conduct regular reviews evaluating effectiveness of major federal R&D spending, and whether it is optimized for advancing U.S. competitiveness.
- Convergence Accelerator: TIP will invest in new research tracks informed by community responses to a Request for Information, other external stakeholder input, and current national priorities. The

Convergence Accelerator will continue to leverage foundational advances by other NSF directorates and offices, nurture multi-disciplinary and multi-sector teams, and accelerate use-inspired, solutions-oriented research and piloting in specific areas of national importance such as emerging technologies and industries. Additionally, in FY 2023, the Convergence Accelerator will launch a regional-scale platform, supporting cohorts pursuing location-specific challenges in agriculture, energy, and transportation, to name a few.

- NSF Entrepreneurial Fellows: TIP will invest in NSF Entrepreneurial Fellowships for Ph.D.-trained scientists and engineers to forge connections between academic research and government, industry, and finance. The Fellows will receive training to become leaders capable of maturing promising ideas and technologies from lab to market.
- NSF Lab-to-Market Platform: TIP will optimize NSF's lab-to-market approach. Specifically:
    - Partnerships for Innovation (PFI): Provides researchers funded by NSF from all disciplines of science and engineering the opportunity to enter into partnerships, especially with industry, to accelerate the transition of discoveries from the laboratory to the marketplace for societal benefits. In addition to supporting prototyping, technology demonstration, and scale-up work, including licensing of NSF-funded research outputs, PFI will grow its support for patent expenses for intellectual property resulting from NSF-funded research.
    - NSF Innovation Corps (I-Corps™): Through a set of Hubs, I-Corps™ connects federally-funded science and engineering research with the technological, entrepreneurial, and business communities, linking scientific and engineering discovery with technology development, societal needs, and economic opportunities. I-Corps™ reduces the time and risk associated with translating promising ideas and technologies from the laboratory to the marketplace through entrepreneurial education including customer discovery.
    - SBIR/STTR: Provides 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 new concepts or innovations that could be developed into new products, processes, or services for profound societal and/or economic impacts. TIP will pilot a FastTrack option to accelerate the translation of deep technologies to the market.
- Technology & Innovation Internships for Experiential Learning (TIIEL): TIP will connect companies, governments, and non-profits with STEM learners at all levels and from all backgrounds through paid internships to help the Nation grow its innovation capacity. These internships will be opportunities to develop mutually-beneficial relationships between mentors and learners, many of whom might be pursuing accredited degree programs (e.g., high schools, community colleges, vocational schools, four-year universities, graduate schools), in addition to providing STEM career choices.

TIP Funding for Centers Programs

TIP Funding for Centers Programs
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Percent
NSF Regional Innovation Engines (NSF Engines) (TF, ITE)	-	-	$200.00	$200.00	N/A

NSF Regional Innovation Engines (NSF Engines): TIP will aim to create regional-scale innovation ecosystems throughout the U.S. and spur economic growth by harnessing the Nation's rich science and technology research enterprise and regional-level resources to address societal and economic challenges and promote national competitiveness. The NSF Engines work to catalyze new business and economic growth in those regions of America that have not fully participated in the technology boom of the past several decades. In collaboration with other NSF directorates and offices, TIP will provide funding to support activities focused on use-inspired research, entrepreneurship, and workforce development to nurture and accelerate regional industries.

TIP Funding for NSF-Wide Investments

TIP aims to advance science and engineering research and innovation in emerging technologies to sustain and enhance U.S. competitiveness. TIP funding contributing to NSF-wide investments in emerging technologies and industries are shown in the table below.

TIP Funding for NSF-Wide Investments[1]
(Dollars in Millions)

Area of Investment[2,3]	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Percent
Advanced Manufacturing	$44.30	-	$54.63	$10.33	23.3%
Advanced Wireless Research	0.75	-	30.55	29.80	3973.3%
Artificial Intelligence	86.79	-	101.55	14.76	17.0%
Biotechnology	11.84	-	69.06	57.22	483.3%
Climate: Clean Energy Technnology[4]	37.21	-	52.47	15.26	41.0%
Microelectronics and Semiconductors	12.78	-	50.23	37.45	293.0%
Quantum Information Science	20.53	-	38.42	17.89	87.1%

[1] FY 2021 funding is adjusted for comparability to reflect the movement of activities to TIP in FY 2022.
[2] NSF-Wide investments may have funding overlap and thus should not be summed.
[3] 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
[4] Funding includes resources for agency-wide initiatives.

People Involved in TIP Activities

Number of People Involved in TIP Activities

	FY 2021 Actual Estimate	FY 2021 ARP Actual Estimate	FY 2022 (TBD)	FY 2023 Estimate
Senior Researchers	2,458	81	-	5,800
Other Professionals	1,688	103	-	3,000
Postdoctoral Associates	117	-	-	700
Graduate Students	262	-	-	3,600
Undergraduate Students	215	9	-	3,000
Total Number of People	**4,740**	**193**	-	**16,100**

DIVISION OF TECHNOLOGY FRONTIERS (TF) **$145,000,000**
+$145,000,000 / N/A

TF Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**-**	**-**	**$145.00**	**$145.00**	**N/A**
Research	**-**	**-**	**125.00**	**125.00**	**N/A**
Centers Funding (total)	-	-	50.00	50.00	N/A
NSF Regional Innovation Engines (NSF Engines)	-	-	50.00	50.00	N/A
Education	**-**	-	**20.00**	**20.00**	**N/A**

About TF

TF works to accelerate breakthroughs in emerging technology areas to sustain and grow U.S. competitiveness and security. These investments spur high-priority innovations in advanced materials, AI, biotechnology, clean energy technology, future manufacturing, next-generation networks and systems, microelectronics and semiconductors, and QIS, among other areas. As part of this investment, TF will advance democracy-affirming technologies, including privacy-preserving technologies, in collaboration with CISE and SBE. TF additionally focuses on nurturing diverse talent by engaging individuals of all backgrounds, organizational affiliations, and geographic locations, thereby ensuring sustained leadership.

To achieve the above outcomes, TF partners with the other TIP units, other NSF directorates and offices, and other agencies, private industry, philanthropy, state and local governments, civil society, and investors. Specifically, TF pursues innovative partnerships and collaborations across sectors, along with transformative mechanisms to accelerate research activities and scale up outputs and impacts.

Finally, TF will lead the assessment of emerging technologies and industries to examine the alignment of federal science and technology research spending and programs with long-term U.S. competitiveness in these areas. Relatedly, TF will conduct regular reviews evaluating the implementation of major federal R&D spending, and whether that implementation is optimized for advancing U.S. competitiveness.

DIVISION OF INNOVATION AND TECHNOLOGY ECOSYSTEMS (ITE) $265,000,000 +$190,110,000 / 253.8%

ITE Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Percent
Total	**$74.89**	**-**	**$265.00**	**$190.11**	**253.8%**
Research	**74.89**	**-**	**255.00**	**180.11**	**240.5%**
Centers Funding (total)	-	-	150.00	150.00	N/A
Regional Innovation Engines (NSF Engines)	-	-	150.00	150.00	N/A
Education	**-**	**-**	**10.00**	**10.00**	**N/A**

About ITE

ITE strengthens the unique U.S. innovation ecosystem, engaging a broad, diverse set of individuals and organizations spanning government, academia, industry, philanthropy, civil society, and investors in the Nation's research, innovation, and education enterprise. ITE specifically brings together researchers, practitioners, and users to catalyze iterative co-design and co-creation, developing breakthrough technologies and addressing societal challenges. In this way, ITE enhances U.S. competitiveness and paves the way for new, high-wage, good-quality jobs.

Among its investments, ITE supports efforts that accelerate use-inspired, convergent research in areas aligned with Administration and Congressional priorities. The Convergence Accelerator builds upon NSF investments in fundamental research and discovery to accelerate solutions toward societal impact. The Convergence Accelerator funds and synergizes teams together in cohorts to work interactively toward solving national-scale societal challenges that require novel ideas, approaches, and techniques from a wide range of diverse disciplines, experts, and sectors. For example, the Convergence Accelerator is advancing the frontiers of quantum technology, the networked blue economy, and worker reskilling and upskilling platforms. Additionally, in FY 2023, the Convergence Accelerator will launch a regional-scale platform, supporting regionalized cohorts pursuing location-specific challenges in agriculture, energy, and transportation, to name a few.

ITE also supports NSF Regional Innovation Engines (NSF Engines). ITE will provide funding to support activities focused on use-inspired research, entrepreneurship, and workforce development to nurture and accelerate regional industries. The NSF Engines program specifically emphasizes the meaningful engagement of the consumers of research outcomes in motivating that research as well as in the subsequent prototyping and piloting of research-based solutions (i.e., co-design and co-creation), along with the translation of research results to practice, entrepreneurship, and direct economic growth.

ITE also seeks to develop inclusive workforce-training pathways for the innovation-driven jobs of the future. For example, ITE connects a highly diverse set of aspiring students and professionals interested in deep-technology disciplines with internship opportunities across the country that match their interests, providing them with much-needed experience to land well-paying jobs.

DIVISION OF TRANSLATIONAL IMPACTS (TI) $419,000,000 +$124,890,000 / 42.5%

TI Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$294.11**	**-**	**$419.00**	**$124.89**	**42.5%**
Research	294.11	-	404.00	109.89	37.4%
Education	-	-	15.00	15.00	N/A

About TI

TI investments aims to accelerate the translation of scientific excellence and technological innovation from the laboratory to society. By investing federal funds in a portfolio of universities, startups, small businesses, and open-source communities, TI will stimulate the creation of novel products, services, and solutions that grow the national economy; catalyze public-private partnerships that increase the depth and relevance of research activities; and nurture and grows the US workforce, especially by fostering and encouraging participation by socially- and economically-disadvantaged individuals and groups.

In particular, TI aims to provide an effective “lab-to-market” platform comprising the NSF Innovation Corps (I-Corps™), Partnerships for Innovation (PFI), Small Business Innovation Research (SBIR), and Small Business Technology Transfer (STTR) programs.

I-Corps™ connects federally-funded science and engineering research with technological, entrepreneurial, and business communities, addressing the skill and knowledge gaps associated with the transformation of fundamental research into deep technology ventures. I-Corps™ reduces the time and risk associated with translating promising ideas and technologies from the laboratory to the marketplace through entrepreneurial education including customer discovery.

The PFI program offers researchers the opportunity to accelerate commercialization by entering into partnerships, especially with industry, to develop proof-of-concept work that leverages NSF-funded research. PFI additionally includes an option to defray costs associated with evaluation and protection of intellectual property, thereby combatting disparities in patent budgets across institutions of higher education and enabling the participation of the entire country in the innovation ecosystem.

The SBIR and STTR programs further transform scientific discovery into societal and/or economic benefits by catalyzing private-sector commercialization of technological innovations. The SBIR and STTR programs provide the opportunity for startups and small businesses to undertake cutting-edge, high-quality science and engineering research and development to determine the scientific and technical feasibility of new concepts or innovations that could be developed into new products, processes, or services for societal and/or economic impacts. SBIR and STTR technology topics draw upon the full breadth of NSF scientific and engineering research disciplines and are aligned with national and societal priorities, such as advanced materials, AI, biotechnology, clean energy technology, future manufacturing, next-generation networks and systems, microelectronics and semiconductors, and QIS.

TI also supports entrepreneurial education through the NSF Entrepreneurial Fellowships. The NSF Entrepreneurial Fellowships provide Ph.D.-trained scientists and engineers with resources, including lab space, to mature promising ideas and technologies from lab to market. Along the way, the NSF Entrepreneurial Fellows become leaders in technology translation.

Additionally, TI supports new pathways for translation, impacting government services, policy making, and education. For example, through the new Pathways to enable Open-Source Ecosystems (POSE) program, TI facilitates the creation and growth of sustainable, high-impact collaborative environments that produce tools and products designed to be publicly accessible, modifiable, and distributable by anyone at no cost. Benefiting communities far beyond the initial applications, the resulting open-source ecosystems are expected to catalyze broad adoption across academia, industry, government, non-profits, and other sectors, and result in a growing, civic-minded community of users and developers.

Finally, TI fosters cultural change within institutions of higher education, supporting the adoption of use-inspired research, translational research, and entrepreneurial training. Through novel prize competitions, inventors' camps and hackathons, and Entrepreneurs-in-Residence programs, TI combines workforce development with mentorship and educational activities focusing on experiential customer discovery as a linchpin linking deep technology with societal benefits.

STRATEGIC PARTNERSHIPS OFFICE (SPO) $50,870,000
+$50,870,000 / N/A

SPO Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Percent
Total	**-**	**-**	**$50.87**	**$50.87**	**N/A**
Research	-	-	50.87	50.87	N/A

About SPO

SPO serves as an agency-wide resource to catalyze and scale up public and private partnerships in order to amplify and further the impact of NSF investments in research, innovation, and education. Specifically, SPO provides expertise and support to build partnerships, along with co-funding to strategically advance high-impact relationships that will deepen and advance NSF's mission across science, engineering, and education. SPO assists these partnerships in expanding the reach of, and increasing the return on, NSF's investments across its directorates and offices.

NSF's partnerships unite broad and diverse communities and coalitions in the pursuit of discovery and innovation by leveraging unique experiences and strengths of government, industry, academia, philanthropy, civil society, and investors to motivate the understanding of research problems and iteratively pilot research-based solutions through co-design. In addition to advancing the Nation's research enterprise, SPO-facilitated partnerships nurture STEM talent by focusing on the engagement of populations long underrepresented in or underserved by STEM, along with the inclusion of diverse organization types such as minority-serving institutions. SPO also advances testbeds and other infrastructure critical to furthering the research and education enterprise.

OFFICE OF INTERNATIONAL SCIENCE AND ENGINEERING (OISE) $74,040,000

+$22,751,058 / 44.4%

OISE Funding

(Dollars in Millions)

FY 2021 Actual	FY 2021 ARP Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Percent
$51.29	$1.45	-	$74.04	$22.75	44.4%

About OISE

OISE is the focal point for NSF's international science and engineering activities and promotes an integrated Foundation-wide international engagement strategy. The Office manages and coordinates catalytic internationally-focused programs, and advances international activities that offer opportunities for U.S. researchers through active engagement and outreach with international counterparts. OISE's FY 2023 Request focuses on three activities: (1) facilitating and supporting international teams and partnerships, (2) providing opportunities for the U.S. to shape the global science and engineering agenda, and (3) promoting the development of a globally engaged U.S. workforce.

In FY 2023, OISE proposes to launch Global Centers (GC). This international center-level activity will enable interdisciplinary and international teams to address grand societal challenges through use-inspired research. Year one will focus on topics related to climate change and clean energy. OISE will prioritize GC investments in convergent center-level activities that drive scientific breakthroughs and lead to use-inspired solutions. To select the first cohort of recipients for FY 2023, OISE will release a solicitation in FY 2022 for the inaugural competition. In preparation for an FY 2023 launch, OISE is developing GC-related partnerships with international counterpart funding agencies. The solicitation will encourage international research teams to seek additional partners from multiple sectors in the U.S. and abroad to leverage financial contributions and augment team capabilities. The GCs will facilitate the education and development of a globally-engaged workforce to support the climate and clean energy disciplines.

In FY 2023, 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 aligned with Administration and agency priorities and 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. 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 2023, OISE will continue to provide opportunities for U.S. STEM undergraduate and graduate students to participate in international research through the International Research Experiences for Students (IRES) program. The long-term goal of IRES is to enhance U.S. leadership by developing the next generation of STEM leaders. 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. In FY 2023, IRES will include two tracks:

- Track I supports international research experiences for cohorts of U.S. undergraduate and graduate students at international labs and research sites under the mentorship of host country scientists; and
- Track II supports advanced studies institutes that engage U.S. graduate students in active learning at the frontiers of knowledge with leading international experts.

In FY 2023, OISE will continue to execute MULTIPlying Impact Leveraging International Expertise in Research (MULTIPLIER) missions, pending COVID-19 pandemic restrictions, with emphasis placed on Administration and agency priorities. These missions transitioned to virtual engagements in FY 2021 because of the pandemic. MULTIPLIER missions focus on fields of science and engineering where researchers outside of the United States are making significant advances and where collaborations 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 NSF international specialists an opportunity to assess international capabilities and develop scientific 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.

The Global Venture Fund (GVF) resources new awards and supplements that include international collaborations, as well as projects which broaden participation by lowering barriers to international research. GVF funding augments programs resourced by the Research and Education Directorates. In FY 2023, OISE will continue its support for collaborative research that will enable innovative international connections not otherwise possible for U.S. researchers and students.

In FY 2022, OISE launched its final Partnerships for International Research and Education (PIRE) program solicitation. This PIRE competition was aimed at building team capacity and research community awareness and interest in OISE programs in preparation for the planned FY 2023 GC launch. Thus, this PIRE competition invited interdisciplinary, use-inspired research proposals related to climate change and/or clean energy at the Principal Investigator level.

In FY 2023, OISE will contribute to the following NSF cross-foundational activities.

- OISE will continue its support for Advanced Manufacturing at a level up to $500,000 to increase knowledge in emerging areas to enable a new generation of manufacturing industries that do not exist today, that are compatible with human needs, that make U.S. manufacturing competitive far into the future, and that builds in resilience to global disruptions for the Nation's manufacturing infrastructure.
- OISE will continue to fund NNA at a level up to $500,000. OISE's funds 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 continue its investment of $1.0 million in QIS to promote international cooperation. QIS 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 propel the Nation forward as a leading developer of quantum technology.

Funding Profile

OISE Funding Profile

	FY 2021 Actual Estimate	FY 2022 (TBD)	FY 2023 Estimate
Statistics for Competitive Awards:			
Number of Proposals	272	-	550
Number of New Awards	79	-	90
Regular Appropriation	78	-	90
ARP	1		
Funding Rate	29%	-	16%
Statistics for Research Grants:			
Number of Research Grant Proposals	270	-	545
Number of Research Grants	77	-	85
Regular Appropriation	76		85
ARP	1		
Funding Rate	29%	-	16%
Median Annualized Award Size	$100,000	-	$150,000
Average Annualized Award Size	$147,525	-	$200,000
Average Award Duration, in years	2.9	-	3.0

In FY 2023, the number of research grant proposals is expected to increase by approximately 275 compared to the FY 2021 Actual, due to the launch of Global Centers. Average annual award size and duration as well as funding rate are not expected to materially fluctuate from the FY 2021 Actual and FY 2022 Request.

People Involved in OISE Activities

Number of People Involved in OISE Activities

	FY 2021 Actual Estimate	FY 2021 ARP Actual Estimate	FY 2022 (TBD)	FY 2023 Estimate
Senior Researchers	381	4	-	400
Other Professionals	77	2	-	100
Postdoctoral Associates	13	2	-	20
Graduate Students	76	23	-	120
Undergraduate Students	36	-	-	50
K-12 Teachers	-	-	-	-
K-12 Students	-	-	-	-
Total Number of People	**582**	**31**	**-**	**690**

OFFICE OF POLAR PROGRAMS (OPP) $547,100,000

+$63,060,000 / 13.0%

OPP Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2021 ARP Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Research	**$115.84**	**$14.47**	**-**	**$130.14**	**$14.30**	**12.3%**
Long Term Ecological Research (LTER)	2.77	-	-	3.38	0.61	21.8%
STC: Center for OLDest Ice EXploration (COLDEX)	-	-	-	5.00	5.00	N/A
Education	**4.97**	**0.05**	**-**	**5.00**	**0.03**	**0.6%**
Infrastructure	**363.23**	**-**	**-**	**411.96**	**48.73**	**13.4%**
Antarctic Infrastructure Modernization for Science (AIMS)	0.22	-	-	-	-0.22	-100.0%
Arctic Research Support and Logistics	48.22	-	-	58.00	9.78	20.3%
Geodetic Facility for the Advancement of GEoscience (GAGE)	1.43	-	-	1.30	-0.13	-9.1%
IceCube Neutrino Observatory (ICNO)	3.56	-	-	3.83	0.27	7.7%
Polar Environment, Safety, and Health (PESH)	7.59	-	-	9.00	1.41	18.5%
Research Resources	8.00	-	-	5.29	-2.71	-33.9%
Seismological Facility for the Advancement of GEoscience (SAGE)	0.94	-	-	0.87	-0.07	-7.1%
U.S. Antarctic Facilities and Operations (AFO)	216.27	-	-	243.67	27.40	12.7%
U.S. Antarctic Logistical Support	77.00	-	-	90.00	13.00	16.9%
Total	**$484.04**	**$14.52**	**-**	**$547.10**	**$63.06**	**13.0%**

About OPP

OPP invests in polar scientific research and education and provides research support and logistics, including infrastructure such as permanent stations and temporary field camps, in the Antarctic and the Arctic. OPP's FY 2023 Request is influenced by three key priorities: (1) maintaining strong disciplinary programs that provide the basis for investments in cross-disciplinary system science; (2) supporting critical facilities that enable research in Earth's polar regions; and (3) the Antarctic Infrastructure Recapitalization (AIR) program. These priorities reflect opportunities for fundamental scientific discovery uniquely achievable 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.

Beginning in FY 2020 and carrying through FY 2022, Antarctic field science, infrastructure construction, and Arctic field science were substantially deferred due to global pandemic travel restrictions and the need to manage the health and safety concerns in remote enclosed settings that have limited medical capacities. In FY 2023, OPP is planning for a higher operating tempo relative to FY 2021-22 in both polar regions. However, the final operating plans and deployment schedules will be dependent on future changes in COVID protocols and border requirements.

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, the National Oceanic and Atmospheric Administration, the U.S. Geological Survey, the Smithsonian Institution, the

Department of Energy, and the National Institute of Standards and Technology. NSF's U.S. Antarctic Program (USAP) research activity 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, which are covered in the Program Evaluation and Monitoring Information section of the Performance and Management chapter, to identify priority areas and ensure effective polar research programs. Highlights of OPP's activities and collaborations include:

- In FY 2023, OPP research funding is $130.14 million. To accommodate its core research priorities, OPP will continue to leverage interagency and international partnerships.
- OPP will continue to support three Long-Term Ecological Research (LTER) projects, two in the Antarctic and one in the Arctic, at $3.38 million.
- IARPC's Arctic Research Plan informs Arctic science investment priorities and efforts to build an integrated research capacity that address the potential opportunities and challenges of Arctic change for the Nation's security and economics and for the well-being of Arctic residents.
- Arctic programs will continue to complement Agency wide investments in the Navigating the New Arctic (NNA) 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. OPP support includes logistical assistance for NNA projects.
- Arctic research support and logistics funding is increased by $9.78 million to $58.0 million to support Arctic field science programs as the deployment tempo is anticipated to increase as travel restrictions are lifted.
- The Center for Oldest Ice Exploration (COLDEX) is a new NSF Science and Technology Center launched in FY 2021 with the goals of finding and studying the oldest possible ice core records of Earth's climate and environmental history, and to help make polar science more inclusive and diverse. COLDEX is a collaboration among 13 universities and several community-serving non-profits. Over the next five years, the project will use its partnerships to expand the community of scientists, students, and educators working on Antarctic climate science and, with the support of OPP, conduct reconnaissance for new coring sites and collect and analyze new ice cores.
- In 2018, OPP initiated support of a multiyear deep-field program to study the Thwaites Glacier region that was the highest priority in a 2015 study by the National Academies of Science, Engineering, and Medicine.[1] The Thwaites program is jointly supported, including shared logistics, with the Natural Environment Research Council of the U.K. The intensive field work of this program was started in the 2019-2020 austral summer season, was largely suspended in FY 2021, and resumed with a marine cruise and some land-based work in FY 2022. Two major land-based field seasons are being planned to complete the field component by FY 2024.
- Support for climate change research, aligned with USGCRP, is a particular emphasis in FY 2023 and includes OPP's continued investment in the Southern Ocean Carbon and Climate Observations and Modeling (SOCCOM) project. This project integrates observations, using innovative autonomous floats, and modelling to unlock the mystery of the vast Southern Ocean and its role in climate change and global biogeochemistry. SOCCOM is now an integral component of the Global Ocean Biogeochemical Array (GO-BGC) project, a global network of chemical and biological sensors used to monitor ocean health.
- OPP is re-building its aging Ice Core Facility located within the Denver Federal Center and managed

[1] www.mosaic-expedition.org/

by the USGS. The facility stores and preserves the integrity of ice cores sourced from polar and alpine environments. These cores represent one of the most important high-resolution archives of past temperature and carbon dioxide change over the past million years. This facility is critical infrastructure for supporting climate change and USGCRP research.

- Education activities across OPP will be supported through existing programs including Research Experiences for Undergraduates (REU) Supplements, REU sites, and other polar education activities.
- OPP is enhancing investment in cutting edge biotechnological and computational studies needed to illuminate the interplay of environment, genotypes, and phenotypes of uniquely adapted polar organisms, and the implications of such information for future change, other ecosystems, and practical applications.
- To maintain U.S. leadership in the Southern Ocean marine science, OPP will invest $12.43 million in design studies of a future state-of-the-art ice-breaking research vessel.
- The U.S. Antarctic Logistical Support funding is increased by $13.0 million to $90.0 million. This will support field work in the Antarctic and reflects increases in heavy airlift flying hour rates, tanker and cargo ship charter rates, and bulk fuel prices.

Major Investments

OPP Major Investments

(Dollars in Millions)

Area of Investment[1,2]	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual: Amount	Change over FY 2021 Actual: Percent
Biotechnology	$1.60	-	$2.00	$0.40	25.0%
Climate: USGCRP	56.11	-	56.11	-	-

[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.

- Biotechnology: OPP, together with other NSF directorates and offices, will invest in fundamental research, infrastructure, and education that advance foundational knowledge needed to understand and harness biological processes for societal benefit.
- Climate: OPP's investments in climate change research are framed around five major themes: Ocean's Role in Climate Change, Terrestrial-Climate Interactions and Water Sustainability, Cryosphere and Climate Change, Forcings and Feedbacks, and Earth System Predictability.

OPP Funding for Major Facilities

OPP Funding for Major Facilities
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Antarctic Infrastructure Modernization for Science (AIMS)[1]	$0.22	-	-	-$0.22	-100.0%
Geodetic Facility for the Advancement of GEoscience (GAGE)	1.43	-	1.30	-0.13	-9.1%
IceCube Neutrino Observatory (ICNO)	3.56	-	3.83	0.27	7.7%
Seismological Facility for the Advancement of GEoscience (SAGE)	0.94	-	0.87	-0.07	-7.1%
U.S. Antarctic Facilities and Operations (AFO)	216.27	-	243.67	27.40	12.7%
Total	**$222.41**	**-**	**$249.67**	**$27.26**	**12.3%**

[1] Final design costs obligated in FY 2021.

For detailed information on individual facilities and construction projects, please see the Research Infrastructure section of the NSF-Wide Investments chapter.

Funding Profile

OPP Funding Profile

	FY 2021 Actual Estimate	FY 2022 (TBD)	FY 2023 Estimate
Statistics for Competitive Awards:			
Number of Proposals	411	-	530
Number of New Awards	234	-	225
Regular Appropriation	201		225
ARP	33		
Funding Rate	57%	-	42%
Statistics for Research Grants:			
Number of Research Grant Proposals	366	-	500
Number of Research Grants	208	-	200
Regular Appropriation	175		200
ARP	33		
Funding Rate	57%	-	40%
Median Annualized Award Size	$235,434	-	$245,000
Average Annualized Award Size	$309,130	-	$322,000
Average Award Duration, in years	2.9	-	2.9

In general, about 20 percent of the OPP portfolio is available for new research grants. In FY 2023, the number of research grant proposals is expected to increase by about 100 compared to the FY 2021 Actual.

People Involved in OPP Activities

Number of People Involved in OPP Activities

	FY 2021 Actual Estimate	FY 2021 ARP Actual Estimate	FY 2022 (TBD)	FY 2023 Estimate
Senior Researchers	848	115	-	1,000
Other Professionals	330	23	-	500
Postdoctoral Associates	124	15	-	150
Graduate Students	326	60	-	400
Undergraduate Students	241	59	-	300
Total Number of People	**1,869**	**272**	**-**	**2,350**

INTEGRATIVE ACTIVITIES (IA) $545,860,000

+$159,840,000 / 41.4%

IA Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2021 ARP Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
EPSCoR	$200.16	-	-	$247.25	$47.09	23.5%
Equity and Compliance in Research	-	-	-	4.00	4.00	N/A
Evaluation and Assessment Capability	5.67	-	-	7.00	1.33	23.5%
Facility Operations Transition	-	-	-	12.00	12.00	N/A
Growing Convergence Research	15.99	2.28	-	16.00	0.01	0.1%
Growing Research Access for Nationally Transformative Equity and Diversity (GRANTED)	-	-	-	50.00	50.00	N/A
HBCU Excellence in Research	18.81	-	-	37.93	19.12	101.7%
Major Research Instrumentation	75.05	-	-	75.00	-0.05	-0.1%
Mid-scale Research Infrastructure	32.45	-	-	50.00	17.55	54.1%
Modeling and Forecasting	-	-	-	3.00	3.00	N/A
Planning and Policy Support	2.10	-	-	2.50	0.40	19.1%
Research Investment Communications	5.24	-	-	5.40	0.16	3.0%
Research Security Strategy and Policy	-	-	-	2.50	2.50	N/A
STC Class of 2021	25.00	-	-	-	-25.00	-100.0%
STC Class of 2023	-	-	-	27.00	27.00	N/A
STC Admin[1]	0.81	-	-	0.60	-0.21	-25.5%
Science & Technology Policy Institute	4.74	-	-	5.68	0.94	19.8%
Total	**$386.02**	**$2.28**	**-**	**$545.86**	**$159.84**	**41.4%**

[1] FY 2021 Actuals for Science and Technology Center Administration include supplemental funding to STC awards from the 2013 and 2016 cohorts directed to individuals who have been disproportionately impacted by the COVID-19 pandemic. FY 2021 supplemental funding per STC cohort was $535,000 to 2013 Class and $250,000 to 2016 Class.

About IA

IA investments catalyze transformative 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 capacity to use evidence for developing strategy and decision making.

IA invests in strategic activities that span the disciplinary spectrum, incubates new cross-cutting activities, and explores emerging ideas. IA provides a flexible mechanism to support emerging program priorities. Sustained strategic investments include instrumentation, infrastructure, and cross-cutting collaborative research.

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

IA promotes and supports the use of evidence in NSF decision making, leads strategic planning for evidence-building activities, compiles data on key NSF processes, and conducts or oversees studies of NSF activities to guide continuous improvements.

IA FY 2023 Activities

Established Program to Stimulate Competitive Research (EPSCoR)

- 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.
- At the FY 2023 Request level, increased funding will support activities in response to recommendations from two reports anticipated during FY 2022 (1) Future of NSF EPSCoR and (2) one issued by the Government Accountability Office report. Potential capacity-building activities may include extension of programmatic efforts to broaden participation of groups and institutions traditionally underrepresented in STEM research and education within EPSCoR jurisdictions, as well as the advancement of scalable, interjurisdictional research and development capacity across different institution types.

Equity and Compliance in Research

- In FY 2023, NSF will begin a new Equity and Compliance in Research investment. The requested funding will support NSF's diversity, equity, inclusion, and accessibility (DEIA) activities, which will include strategic planning and implementation, training and curriculum development, stakeholder engagement, complaint processing and investigation, and recruitment and outreach activities. These activities respond to recent executive orders (EO) (e.g., EO 14035 on Diversity, Equity, Inclusion, and Accessibility in the Federal Workforce;[1] EO 13985 on Advancing Racial Equity and Support for Underserved Communities Through the Federal Government;[2] and EO 14020 on Establishment of the White House Gender Policy Council[3]) and are informed by NSF's Racial Equity Task Force Report.

[1] www.whitehouse.gov/briefing-room/presidential-actions/2021/06/25/executive-order-on-diversity-equity-inclusion-and-accessibility-in-the-federal-workforce/

[2] www.whitehouse.gov/briefing-room/presidential-actions/2021/01/20/executive-order-advancing-racial-equity-and-support-for-underserved-communities-through-the-federal-government/

[3] www.whitehouse.gov/briefing-room/presidential-actions/2021/03/08/executive-order-on-establishment-of-the-white-house-gender-policy-council/

Evaluation and Assessment Capability (EAC)

- EAC engages in strategic planning of evidence-building activities in support of the Agency's mission. This includes leading the development of the Agency's learning agenda, annual evaluation plan, inventory and analysis of evidence-building activities, and other activities that support the generation and use of evidence for decision making.
- EAC oversees or conducts evidence-building activities—including evaluations, research, statistics, and other types of studies and analyses—in response to questions prioritized in the Agency's learning agenda, in the annual evaluation plan, or by leadership and staff in response to emerging needs, as experienced this past year in response to COVID-19.
- At the FY 2023 Request level, funding will support studies prioritized in the Agency-wide learning agenda and focused on enabling program improvements that enhance the efficacy of NSF investments. This funding enables EAC to provide needed Agency-wide support that complements the work conducted by NSF directorates and offices.

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).[4] 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. For more information see the Facilities Overview narrative in the Major Facilities section of the Research Infrastructure chapter.

Growing Convergence Research (GCR)

- GCR supports basic research that uses novel, transdisciplinary approaches to solve complex problems. The unifying characteristics of these activities 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 deep integration of knowledge, tools, and ways of thinking from multiple disciplines. GCR also grows the next generation of convergence researchers. GCR incubates the capacity of research teams to address pressing, emerging research challenges that are large in scope, innovative in character, originate outside of any particular NSF directorate, and may require a long-term commitment. In FY 2023, GCR investments will support three to seven new research collaborations and the continuation of three to six projects begun in FY 2021.

Growing Research Access for Nationally Transformative Equity and Diversity (GRANTED)

- In FY 2023, NSF will invest in GRANTED, which will improve the Nation's research support and service capacity at emerging and underserved research institutions. In FY 2023, GRANTED activities will support the enhancement of research administration and post-award management, the implementation of effective practices for competitive proposal development, research-coordination networks (RCNs) and institutional partnership grants, and research enterprise hubs in different geographic regions. GRANTED funding in FY 2023 will focus on support for minority-

[4] www.nsf.gov/pubs/2018/nsb201817/nsb201817.pdf

serving institutions and aim to mitigate the barriers to competitiveness at underserved institutions within the Nation's research enterprise as NSF contributes to the Administration's priority on equity. GRANTED will partner with national and regional professional societies to grow the Nation's research capacity within underserved communities and institutions. Additionally, GRANTED will facilitate the development of leadership in research administration as well as enhance institutional research administrative and research support infrastructure.

<u>Historically Black Colleges and Universities – Excellence in Research (HBCU-EiR)</u>

- The HBCU-EiR program focuses on improving the research capacity and competitiveness of HBCUs by supporting new research opportunities at these institutions. In FY 2023, IA will fund 40 to 75 HBCU-EiR research grants managed by NSF's S&E directorates, and supplements to support postdoctoral fellowships, as well as graduate and undergraduate students. Additionally, HBCU-EiR will build capacity for research teams to succeed in center-scale competitions.

<u>Major Research Instrumentation (MRI)</u>

- MRI invests in shared-use S&E research instrumentation. Approximately 140 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.

<u>Mid-scale Research Infrastructure Track-1 (Mid-scale RI-1)</u>

- 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 program. It aims to significantly advance the Nation's 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 research infrastructure projects. In FY 2023, Mid-scale RI-1 will invest $50.0 million in projects emerging from the FY 2023 competition.

<u>Modeling and Forecasting</u>

- NSF will improve its analytical capability in support of advancing research, improving equity in science, and securing global leadership. NSF will expand its capacity to leverage modeling of internal and external data to generate timely and actionable insights to inform Agency strategy, investments, and programmatic decisions. NSF will harness big data (both structured and unstructured) and data science (including AI techniques such as machine learning) to automate analytical modeling in response to Agency priorities. These priorities include monitoring participation in NSF programs, promoting partnerships, and assessing the outcomes of NSF's investments to advance scientific discovery and achieve societal goals. Results of this work will provide valuable information to promote excellence in achieving NSF's mission.

<u>Planning and Policy Support (PPS)</u>

- PPS includes funding for a wide range of activities, many of which are focused on generating evidence and convening stakeholders in support of planning, policy development, and management efficiencies. Examples include conducting NSF's biennial survey of principal investigators and reviewers, supporting studies of NSF's merit review process, engaging in annual agency award activities (such as the Alan T. Waterman Award and National Medal of Science), and supporting summer science internship programs that target STEM students from underrepresented groups. PPS also provides funding to support collaborations with the National Academies of Science, Engineering, and Medicine (the National Academies) for the Committee on Science, Engineering, Medicine, and Public Policy (CoSEMPuP),[5] the Federal Demonstration Partnership,[6] and studies, workshops, and letter reports spanning multiple research domains. In FY 2023, PPS will continue to invest in catalytic activities—workshops, conferences, and long-term planning exercises, focused on emerging themes and agency innovations—as well as capacity-building activities for national priorities.

Research Investment Communications (RIC)

- RIC invests in leading-edge communication essential to build public and stakeholder awareness and support for S&E. RIC creates products and processes through various digital platforms to make NSF's investments in STEM readily available and easily understandable to everyone. In FY 2023, RIC informs policy makers, stakeholders, the media, and the general public about the impact of NSF's investments on their daily lives and the Nation's future.

Research Security Strategy and Policy

- In FY 2023, NSF will continue expanding capabilities and competencies to protect the U.S. science and engineering enterprise through its Research Security Strategy and Policy activity. Major components and activities of NSF's Research Security portfolio implemented and available by FY 2023 include: developing a common framework for understanding research security within the U.S. research community and with international colleagues; in partnership with other federal research agencies, establishing uniform mechanisms for research investigators to provide consistent information (i.e., their appointments, activities, and sources of financial support); and creating new analytic capabilities to proactively identify conflicts of commitment and vulnerabilities of pre-publication research. Furthermore, NSF develops and refines staff training resources to ensure a clear understanding of research security issues, NSF disclosure requirements, and the tenets of beneficial international collaboration. Several of these activities are responsive to the January 2022 National Science and Technology Council implementation guidance for National Security Presidential Memorandum 33 (NSPM-33) on National Security Strategy for United States Government-Supported Research and Development.[7] NSF's overall activities respond to the JASON report, "Fundamental Research Security,"[8] which was commissioned by NSF and published in December 2019, as well as subsequent legislation passed by Congress. Additionally, NSF will commission a JASON study in FY 2022 to provide guidance on the establishment of a Research on Research Security funding program that is expected to issue awards beginning in FY 2023.
- FY 2023 funding for NSF's Research Security activity is $2.50 million and will support the Research on Research Security program, which will support partnerships and collaborations of U.S. federal agencies and non-profit organizations. Primary goals of the program will include assessment of the characteristics that distinguish research security from research integrity, improving the quantitative understanding of the scale and scope of research security risks, developing methodologies to assess the potential impact of research security threats, and assessing the additional research security risks in an innovation system that includes more use-inspired

[5] www.nationalacademies.org/cosempup/committee-on-science-engineering-medicine-and-public-policy
[6] www.thefdp.org/default/
[7] www.whitehouse.gov/wp-content/uploads/2022/01/010422-NSPM-33-Implementation-Guidance.pdf
[8] www.nsf.gov/news/special_reports/jasonsecurity/JSR-19-2IFundamentalResearchSecurity_12062019FINAL.pdf

research rater than staying well within the bounds of fundamental research. FY 2023 funding will also continue support for a program partnering with the federal government interagency community to develop training resources for the research community.
- In FY 2021, NSF funded a JASON study on cybersecurity[9] at NSF's major research facilities; in response to the JASON recommendations, NSF is developing new guidance for these research facilities and strengthening its major facility oversight in this area.

Science and Technology Centers: Integrative Partnerships Program (STC)
- The STC program supports exceptionally innovative, complex research and education projects that require large-scale, long-term awards. STCs engage the Nation's intellectual talent in world-class research through partnerships across academia, industry, national laboratories, other public and private entities, and via international collaborations. These partnerships create synergies that enhance the training of the next generation of scientists, engineers, and educators and contributes to NSF's mission to broaden the participation of members of underrepresented groups in STEM. Examples of the foci of current centers include improving agricultural production via programmable plants based on digital biology; new technologies and solutions to limit the need for phosphorus use in agricultural practice, while reducing its harmful environmental impacts; advancing the understanding of Earth's climate; realizing a new generation of optoelectronic materials and devices; creating atomic-scale devices and systems based on quantum materials; and elucidating the mechanisms and architecture of intelligence in the human brain. In FY 2023, $27.0 million supports the first year of five Class of 2023 centers.
- STC Administration supports post-award management of STC awards, including site visits by review teams. FY 2023 funding includes program administration costs for the Class of 2023 competition.

Science and Technology Policy Institute (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.

[9] www.nsf.gov/news/special_reports/jasonreportcybersecurity/index.jsp

ESTABLISHED PROGRAM TO STIMULATE COMPETITIVE RESEARCH (EPSCOR) $247,250,000 +$47,090,000 / 23.5%

EPSCoR Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$200.16**	**-**	**$247.25**	**$47.09**	**23.5%**
Research Infrastructure Improvement	135.55	-	197.69	62.14	45.8%
Co-Funding	64.02	-	48.21	-15.81	-24.7%
Outreach and Workshops	0.60	-	1.35	0.75	126.4%

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 17 percent of the EPSCoR portfolio is available to support new research grants. The remaining 83 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 affect 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. In FY 2023, EPSCoR continues the RII Track-2: Focused EPSCoR Collaborations (RII Track-2 FEC), which builds inter-jurisdictional collaborative teams of EPSCoR investigators in scientific focus areas consistent with NSF priorities. These awards have a particular focus on the development of early career/junior faculty. In FY 2023, awards will support the Administration's R&D priority areas.
- In FY 2020, NSF EPSCoR established a memorandum of understanding with NASA EPSCoR with the goal of providing a new NSF/NASA activity within the existing RII Track-4: EPSCoR Research Fellows. This new opportunity, RII Track-4 Fellows Advancing in Science and Technology (RII Track-4 FAST), is intended to allow non-tenured principal investigators to further develop their individual research potential through extended collaborative visits to NASA Centers' research facilities located throughout the U.S. This activity targets faculty at minority-serving institutions, women's colleges, and primarily undergraduate institutions in EPSCoR jurisdictions. In FY 2023, this activity will be in its second cycle, and more NASA research centers may be added as research sites.

Co-Funding

- EPSCoR co-funding enables awards in response to meritorious proposals from individual investigators, collaborative groups, and center-scale teams based in EPSCoR-eligible jurisdictions. These proposals are submitted across all of the Foundation's research and education programs, including crosscutting initiatives, where they undergo merit review and are selected for award based on NSF's intellectual merit and broader impact criteria. EPSCoR prioritizes co-funding for awards that advance its programmatic goals, including those supporting new investigators. In FY 2020, the program began placing increased emphasis on providing co-funding support for center-scale projects and those that make major, potentially transformational impacts toward physical and cyberinfrastructure and the development of a diverse STEM workforce within EPSCoR-eligible jurisdictions. This emphasis will continue in FY 2023; however, at a reduced level. EPSCoR co-funding ensures support for projects that might not be funded without the combined, leveraged resources of EPSCoR and the managing programs.

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 2023, NSF EPSCoR continues to implement a cohesive evaluation framework to study 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.

People Involved in EPSCoR Activities

Number of People Involved in EPSCoR Activities

	FY 2021 Actual Estimate	FY 2021 ARP Actual Estimate	FY 2022 (TBD)	FY 2023 Estimate
Senior Researchers	815	-	-	1,000
Other Professionals	203	-	-	300
Postdoctoral Associates	133	-	-	200
Graduate Students	564	-	-	700
Undergraduate Students	684	-	-	800
K-12 Teachers	1,072	-	-	1,300
K-12 Students	24,336	-	-	30,100
Total Number of People	**27,807**	**-**	**-**	**34,400**

UNITED STATES ARCTIC RESEARCH COMMISSION (USARC) $1,720,000

+$120,000 / 7.5%

USARC Funding
(Dollars in Millions)

FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual: Amount	Change over FY 2021 Actual: Percent
$1.60	**-**	**$1.72**	**$0.12**	**7.5%**

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.

The FY 2023 Request for USARC is $1.72 million and will help to advance Arctic research and to recommend Arctic research policy that is consistent with the Administration's priorities.

The FY 2023 Request will support three FTE funded at USARC, 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.

DIRECTORATE FOR STEM EDUCATION (EDU) $1,377,180,000

+$266,330,000 / 24.0%

EDU Funding[1]
(Dollars in Millions)

	FY 2021 Actual	FY 2021 ARP Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Division of Equity for Excellence in STEM (EES)[2]	$214.00	$5.00	-	$323.88	$109.88	51.3%
Division of Graduate Education (DGE)[3]	420.57	9.00	-	519.12	98.55	23.4%
Division of Res. on Learning in Formal & Informal Settings (DRL)	204.16	9.99	-	242.58	38.42	18.8%
Division of Undergraduate Education (DUE)	272.12	-	-	291.60	19.48	7.2%
Total	**$1,110.85**	**$23.99**	**-**	**$1,377.18**	**$266.33**	**24.0%**

[1] NSF proposes to change the name of the Directorate for Education and Human Resources (EHR) to the Directorate for STEM Education (EDU).

[2] Formerly this division was named the Division of Human Resource Development (HRD). NSF proposes to rename this division as shown.

[3] The Graduate Research Fellowship Program is consolidated within the EHR Division of Graduate Education in FY 2022 and is restated in prior years for comparability.

About EDU

The National Science Foundation proposes to rename the Directorate for Education and Human Resources (EHR) to the Directorate for STEM Education (EDU) and rename the Division of Human Resource Development (HRD) within the EDU to the Division of Equity for Excellence in STEM (EES). This is being done to more accurately capture the totality of the Directorate's work.

The work of EDU closely aligns with the Administration's priorities of advancing equity and addressing systemic racism to remove barriers for diverse communities. Through existing programs, EDU supports activities and research that aim to increase participation in science and engineering of individuals from racial and ethnic groups who are traditionally underrepresented in STEM fields, including at MSIs. When coupled with equally important priorities to expand clean energy, strengthen the economy, and maintain global competitiveness in emerging technologies, it is apparent that STEM education and research play a central role in fostering the necessary social and economic infrastructure to support these initiatives. Now, more than ever, the Nation needs a robust STEM enterprise that includes a diverse, highly skilled U.S. STEM workforce with competitive salaries and a STEM-literate public. Both the STEM workforce and the STEM-literate public are needed to address societal challenges that were exacerbated by the global pandemic and to support a vibrant U.S. economy.

The STEM enterprise is a microcosm of society; the challenges that impact society are reflected and often magnified in STEM education at all levels. To bolster the STEM education communities most challenged in FY 2021 and FY 2022, EDU increased investments in racial equity research across the directorate while also expanding opportunities for community colleges and making supplements to fund post-doctoral training in STEM education. The results from EDU's investments in foundational and future-oriented STEM educational research are used to inform STEM programs and practices, to ensure the prosperity of the Nation through a well-educated STEM workforce that will contribute to efforts to raise the Nation's leadership in STEM education. As with all research, results might be applied more immediately or well into the future. In FY 2023, EDU will deepen efforts to build capacity for STEM education research and identify and tackle the challenges in STEM education that must be met to create a well-paid workforce for the emerging industries that will help drive the U.S. economy.

Thus, EDU invests in projects to address foundational (perennial) issues in STEM education by exploring persistent questions about the learning and teaching of STEM content, as well as future-oriented issues that result from changes in technology, the Nation's demography, the economy, and new directions in STEM. These future-oriented areas include how and what to teach students so that they are prepared to engage with AI, QIS, and computing, and how to do so in a manner (virtually, in-person, or in a blended format) that reduces demographic disparities. Partnerships with the private sector have been and will continue to be used to good advantage. EDU's partnership with Boeing is one model for leveraging public-private partnerships to develop the STEM workforce for emerging industries. In FY 2020, EDU 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 2023, EDU will continue to study the implementation of personalized learning systems in developing the STEM workforce, while engaging in conversations with potential industry partners that build on successful collaborations with Boeing, Accenture, General Electric, and Intel.

EDU allocations across divisions are designed to accomplish the collective work of the directorate, best characterized by three underlying themes: contributing to research on STEM learning and learning environments, broadening participation and institutional capacity in STEM, and developing the STEM professional workforce. Progress in STEM depends on innovators and future leaders in the Nation's science and engineering (S&E) enterprise in both the public and private sectors. Innovators from PreK-12 and informal learning environments are critical members of the future STEM and STEM-related workforce. Through its scholarship, fellowship, and traineeship programs, EDU supports the development of talent at the undergraduate and graduate levels. EDU programs such as the Advanced Technological Education (ATE) support the STEM workforce indirectly or directly, including a data-skilled workforce and the broader workforce that rely on STEM skills, thus addressing the Nation's critical need for a highly skilled technical workforce that reflects the diversity of society and is attractive to employers that offer competitive salaries. The Centers of Research Excellence in Science and Technology (CREST), the Alliances for Graduate Education and the Professoriate (AGEP), and the Graduate Research Fellowship Program (GRFP) serve to provide graduate students and faculty with the research experiences needed for them to participate fully in the workforce of the future. In FY 2023, the divisions will collaborate to sponsor one or more workshops to bring experts in the field to explore synergies amongst existing EDU projects with an eye towards creating a community of practitioners engaged in institutional transformation.

The progress of S&E also depends on a public that can take full advantage of well-paid STEM-related employment opportunities that help drive the U.S. economy, and that values and participates in STEM, both formally and informally. The Discovery Research PreK-12 (DRK-12) program and Advancing Informal STEM Learning (AISL) program both support evidence-based approaches to learning in formal and informal settings. 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, EDU continues to support the Historically Black Colleges and Universities Undergraduate Program (HBCU-UP), the Improving Undergraduate STEM Education: Hispanic-Serving Institutions (IUSE:HSI) program, and the Tribal Colleges and Universities Program (TCUP). EDU's support facilitates the advancement of early career STEM professionals at MSIs and enhances the academic experiences of students studying STEM at MSIs.

As a natural extension of EDU's experience in broadening participation, EDU serves as the lead directorate and the steward of funds designated for the NSF-wide investments for the Big Idea: NSF

INCLUDES. EDU continues to support the generation of new knowledge and its dissemination through NSF INCLUDES to understand what interventions work to broaden participation in STEM and under what conditions. For more information about NSF INCLUDES, see the Big Ideas narrative in the Cross Theme Topics section of the NSF-Wide Investments chapter.

EDU also supports NSF and Administration priorities through participation in Foundation-wide activities. Through existing programs, EDU invests in NSF's Big Ideas Harnessing the Data Revolution, the Future of Work at the Human Technology Frontier, and Navigating the New Arctic. By incorporating the Big Ideas into the NSF Research Traineeship (NRT) program's priority themes, EDU invests in developing researchers with the necessary skills to conduct convergence research. In FY 2023, EDU continues to support the education and workforce aspects of Secure and Trustworthy Cyberspace (SaTC), and Networking and Information Technology Research and Development (NITRD), which provide opportunities for research on the intersection of artificial intelligence and education.

EDU 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 EDU's STEM human capital development programs will inform and guide future actions. EDU 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 support transparency and accountability.

Major Investments

EDU Major Investments

(Dollars in Millions)

Area of Investment[1,2]	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual: Amount	Change over FY 2021 Actual: Percent
Advanced Manufacturing	$22.19	-	$5.00	-$17.19	-77.5%
Artificial Intelligence	29.04	-	50.00	20.96	72.2%
Biotechnology	14.41	-	9.00	-5.41	-37.6%
Graduate Research Fellowship Program[3]	284.45	-	355.51	71.06	25.0%
Improving Undergraduate STEM Education	90.00	-	95.50	5.50	6.1%
NSF INCLUDES	20.00	-	50.50	30.50	152.5%
Quantum Information Science	10.52	-	5.00	-5.52	-52.5%
Secure & Trustworthy Cyberspace[4]	59.99	-	75.00	15.01	25.0%
STEM Education Postdoctoral Research Fellowship	-	-	5.00	5.00	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.

[3] The Graduate Research Fellowship Program is consolidated within the EDU Division of Graduate Education in FY 2022 and is restated in prior years for comparability.

[4] FY 2023 Request funding includes $5.0 million to strengthen the national cybersecurity workforce pipeline, which is complementary to the Cyber Defense Education & Training program at the Cybersecurity and Infrastructure Security Agency. An additional $5.0 million for this program is budgeted within CISE.

- Advanced Manufacturing: EDU invests in workforce development to attract, educate, train, and reskill/upskill diverse workers for the manufacturing workforce of the future.
- AI in Education and Workforce: EDU activities in this area include investments in NRT for AI focused traineeships; the Artificial Intelligence Research Institutes; AI at the intersection of cybersecurity; as well as investments in AI across EDU programs.
- Biotechnology: EDU invests in biotechnology through research and workforce development programs.
- GRFP: In FY 2023, funding for GRFP will continue to be stewarded in EDU. For more information on GRFP, see the Major Investments in STEM Graduate Education narrative within the Cross Theme Topics section of the NSF-Wide Investments chapter.
- IUSE: EDU will lead the NSF-wide IUSE activity. For more information, see the IUSE narrative within the Cross Theme Topics section of the NSF-Wide Investments chapter.
- NSF INCLUDES: EDU will support NSF INCLUDES Alliances. For more information, see the Big Ideas narrative within the Cross Theme Topics section of the NSF-Wide Investments chapter.
- QIS: EDU invests in QIS through education and workforce development programs to prepare a diverse quantum information science and engineering workforce.
- SaTC: EDU will support SaTC activities through the CyberCorps®: Scholarship for Service (SFS) program.
- STEM Education Postdoctoral Research Fellowship (first piloted as an ARP funded activity in FY 2022): The division will formally establish the program to support postdoctoral awards designed to enhance the research knowledge, skills, and practices of recent doctoral graduates in STEM, STEM education, education, and related disciplines.

EDU Major Investments in Broadening Participation

EDU Programs to Broaden Participation
(Dollars in Millions)

	Amount of Funding Captured	FY 2021 Actual	FY 2022 CR Enacted	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Broadening Participation: Focused Programs						
ADVANCE	100%	$18.00	-	$20.50	$2.50	13.9%
Alliances for Grad Ed & the Professoriate (AGEP)	100%	8.00	-	14.00	$6.00	75.0%
Ctrs of Research Excellence in Science & Tech (CREST)	100%	24.00	-	41.00	$17.00	70.8%
Excellence Awards in Science & Engineering (EASE)[1]	100%	3.63	-	7.64	$4.01	110.7%
Historically Black Colleges & Univ Undergraduate Prgm (HBCU-UP)	100%	36.50	-	48.50	$12.00	32.9%
IUSE: Hispanic Serving Institutions (IUSE:HSI)	100%	46.50	-	60.50	$14.00	30.1%
NSF INCLUDES	100%	20.00	-	50.50	$30.50	152.5%
Louis Stokes Alliances for Minority Participation (LSAMP)	100%	49.51	-	70.50	$20.99	42.4%
NSF Scholarships in STEM (S-STEM)[2]	100%	94.70	-	119.15	24.45	25.8%
Tribal Colleges & Universities Program (TCUP)	100%	16.50	-	23.00	$6.50	39.4%
Subtotal, Focused Programs		**$317.35**	**-**	**$455.29**	**$137.94**	**43.5%**
Broadening Participation: Emphasis Programs[3]						
Advancing Informal STEM Learning (AISL)	58%	36.25	-	43.21	6.96	19.2%
Computer Science for All (CSforALL)	62%	6.20	-	15.19	8.99	145.0%
Discovery Research PreK-12 (DRK-12)	56%	53.20	-	55.72	2.52	4.7%
EDU Core Research	62%	47.51	-	63.20	15.69	33.0%
Graduate Research Fellowship Program (GRFP)[4]	67%	189.44	-	236.77	47.33	25.0%
Improving Undergraduate STEM Education (IUSE)	64%	57.60	-	69.54	11.93	20.7%
Innovative Technology Experiences for Students & Teachers (ITEST)[2]	74%	38.34	-	29.39	-8.96	-23.4%
Robert Noyce Teacher Scholarship Program (NOYCE)	59%	39.86	-	39.53	-0.33	-0.8%
Subtotal, Emphasis Programs		**$468.41**	**-**	**$552.54**	**$84.13**	**18.0%**
Total, EDU Broadening Participation Programs		**$785.76**	**-**	**$1,007.83**	**$222.07**	**28.3%**

[1] 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).

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

[3] 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.

[4] The Graduate Research Fellowship Program is consolidated within the EHR Division of Graduate Education in FY 2022 and is restated in prior years for comparability.

For more information on programs that support EDU Major Investments, see the narratives for individual EDU divisions.

EDU Funding for Centers Programs

EDU Funding for Centers Programs
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Artificial Intelligence Research Institutes (DRL)	7.60	-	19.59	11.99	157.9%

For detailed information on individual centers programs, please see the NSF Centers Programs narrative in the Cross Theme Topics section of the NSF-Wide Investments chapter.

Appropriations Language

~~EDUCATION AND HUMAN RESOURCES~~STEM EDUCATION

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, ~~$1,287,270,000~~$1,377,180,000, to remain available until September 30, ~~2023~~2024.

STEM Education
FY 2023 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 2021 Appropriation	$1,029.00	$4.25	-$42.67	$2.08		$992.66
FY 2022 Annualized CR	968.00	42.67				1,010.67
FY 2023 Request	1,377.18					1,377.18
$ Change from FY 2022 Annualized CR						$366.51
% Change from FY 2022 Annualized CR						36.3%

Totals exclude reimbursable amounts.

Explanation of Carryover

STEM Education (EDU; formerly Education and Human Resources)
Within the EDU account, $42.67 million (including $37.0 million in American Rescue Plan Funding) was carried over into FY 2022.

Presidential Award for Excellence and Teaching
- Amount: $1.35 million
- Purpose: These carryover funds will be used to recognize recipients of the Presidential Awards for Excellence in Mathematics, Science Teaching and recipients of the Presidential Awards for Excellence in Science, Mathematics, and Engineering Mentoring.
- Obligation: FY 2022 Quarter 2 and Anticipated FY 2022 Quarter 3.

Robert Noyce Teacher Scholarship Program (Noyce)
- Amount: $4.31 million
- Purpose: These funds will be used to invest in teacher preparation and/or support Noyce fellows during completion of a teaching obligation.
- Obligation: FY 2022 Quarter 3.

American Rescue Plan (EDU)
- Amount: $37.0 million
- Purpose: Funds will be used for awards that were not read for obligation in FY 2021.
- Obligation: FY 2022 Quarter 1–2 and remaining amounts to be obligated in Quarter 3.

Funding Profile

EDU Funding Profile

	FY 2021 Actual Estimate	FY 2022 (TBD)	FY 2023 Estimate
Statistics for Competitive Awards:			
Number of Proposals	4,556		4,850
Number of New Awards	925		1,350
Regular Appropriation	893		1,350
ARP	32		
Funding Rate	20%		28%
Statistics for Research Grants:			
Number of Research Grant Proposals	3,578		3,650
Number of Research Grants	608		950
Regular Appropriation	580		950
ARP	28		
Funding Rate	17%		26%
Median Annualized Award Size	$166,646		$260,000
Average Annualized Award Size	$275,445		$280,000
Average Award Duration, in years	3.1		3.1

In FY 2023, the number of research grant proposals is expected to increase by approximately 100 compared to the FY 2021 Actual, and EDU expects to award about 950 research grants accounting for the increase in overall grant funding. Average annual award size and duration are not expected to materially fluctuate in FY 2021 through FY 2023.

People Involved in EDU Activities

Number of People Involved in EDU Activities

	FY 2021 Actual Estimate	FY 2021 ARP Actual Estimate	FY 2022 (TBD)	FY 2023 Estimate
Senior Researchers	7,829	278	-	8,900
Other Professionals	2,419	22	-	2,700
Postdoctoral Associates	392	18	-	450
Graduate Students	11,600	200	-	14,000
Undergraduate Students	17,100	76	-	19,800
K-12 Teachers	38,800	343	-	45,000
K-12 Students	87,900	8,623	-	102,000
Total Number of People	**166,040**	**9,560**	**-**	**192,850**

DIVISION OF EQUITY FOR EXCELLENCE IN STEM (EES) $323,880,000
+$109,880,000 / 51.3%

EES Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Percent
Total	**$214.00**	**-**	**$323.88**	**$109.88**	**51.3%**
Research	142.87	-	225.24	82.37	57.6%
Education	71.13	-	98.64	27.51	38.7%

About EES

EDU's Division of Human Resource Development (HRD) will be renamed the "Division of Equity for Excellence in STEM" (EES). The new name better reflects the mission, activities, and portfolio of the division. EES serves as a focal point for NSF's agency-wide commitment to broadening participation of groups historically underrepresented in STEM—minorities, women, and persons with disabilities by enhancing the quality and excellence of STEM education and research opportunities. EES's mission is to create and grow a vibrant and diverse U.S. STEM workforce by supporting the inclusion and participation of individuals historically underrepresented in STEM and the institutions that serve them. Programs within EES 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. 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, particularly at MSIs. These investments help to mitigate the deleterious impacts of the COVID-19 pandemic on STEM education and the STEM enterprise by supporting and growing the Nation's diverse STEM talent. EES will continue efforts to better engage and serve persons with disabilities, including activities related to the "Persons with Disabilities – STEM Engagement and Access (PWD-SEA)" Dear Colleague Letter.

FY 2023 Summary

<u>Research</u>

- 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 in STEM. The AGEP program will continue efforts to complete awardee site reviews, share best practices and collaborative partnerships findings, and network through the annual AGEP research conference.
- CREST program focuses on building research capacity at MSIs that have undergraduate enrollments of 50 percent or more of members from minority groups underrepresented among those holding advanced degrees in science or engineering fields. Funding will continue to support CREST centers, HBCUs through the Research Infrastructure for Science and Engineering component, and additional Postdoctoral Research Fellows, fostering increased collaborations across the centers and building research capacity at minority serving institutions.
- The EDU Core Research (ECR) program supports fundamental research and capacity building initiatives. ECR research projects explores persistent and emerging, curiosity-driven and use-inspired basic research questions with the goal of generating foundational knowledge in three

broadly conceived research areas: STEM learning and learning environments, broadening participation in STEM fields, and STEM workforce development. ECR also supports activities that build individuals' capacity to carry out high quality STEM education research. In FY 2023, ECR will continue to support fundamental research that addresses persistent issues and questions in the learning and teaching of STEM content. ECR will also support research that envisions and explores STEM learning environments of the future; examines how learning and teaching will change with advances in technology; explores factors at the institutional, structural, organizational, societal, and systemic levels that affect STEM teaching, learning, and participation in STEM education and the workforce; and develops new methodologies to tackle new questions. In FY 2023 EDU will also continue efforts through the ECR Building Capacity in STEM Education Research initiative to build individuals' capacity to conduct--and broaden the pool of researchers that carry out--the high-quality STEM education research that enhances the Nation's STEM education enterprise.

- HSI 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. Outreach efforts will continue to seek to engage institutions that are new to NSF.
- NSF INCLUDES will continue to fund broadening participation projects and related research through NSF INCLUDES Alliances and other existing NSF broadening participation portfolio programs. These include pilot projects, planning grants, and supplements 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 Big Ideas narrative in the Cross Theme Topics section of the NSF-Wide Investments chapter.
- TCUP funding will support the design, implementation, and assessment of comprehensive institutional improvements in STEM instruction to advance the quality of student preparation in STEM at tribal colleges and universities. TCUP will also continue to support projects to build and enhance STEM 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.

<u>Education</u>

- ADVANCE will continue to support evidence-based systemic change strategies to promote equity in STEM academic workplaces. ADVANCE will continue to support adaptation of successful practices for achieving institutional change.
- Excellence Awards in Science and Engineering (EASE) will continue to coordinate and support the Presidential Awards for Excellence in Mathematics and Science Teaching (PAEMST) and Presidential Awards for Excellence in Science, Mathematics, and Engineering (PAESMEM) awards.
- 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. The program will continue to support broadening participation research through its HBCU-UP Broadening Participating Research Centers.
- Louis Stokes Alliances for Minority Participation (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 and will continue to support activities at the transfer and transition points through the Bridges to the Baccalaureate and Bridges to the Doctorate tracks.

DIVISION OF GRADUATE EDUCATION (DGE) $519,120,000

+$98,550,000 / 23.4%

DGE Funding

(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$420.57**	**-**	**$519.12**	**$98.55**	**23.4%**
Research	**18.12**	**-**	**21.11**	**2.99**	**16.5%**
Education[1]	**402.45**	**-**	**498.01**	**95.56**	**23.7%**

[1] GRFP is consolidated within the EDU Division of Graduate Education in FY 2022 and is restated in prior years for comparability.

About DGE

DGE provides leadership for cross-Foundation investments that support a diverse cadre of U.S. graduate students in STEM and STEM education research, and for improvement and innovation in graduate education to prepare tomorrow's STEM leaders. The division pursues these goals 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 EDU 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 and to assume leadership roles in emerging industries.

FY 2023 Summary

<u>Research</u>

- The ECR program supports fundamental research and capacity building initiatives. ECR is managed and funded across all EDU divisions. For a full description, see the EES Division narrative.

<u>Education</u>

- NSF GRFP will be fully funded in EDU in FY 2023 at a total funding level of $355.51 million to support 2,750 new fellowships, with a cost of education allowance of $12,000 and a stipend of $37,000 per fellow. The GRFP program will continue to align awards with Administration priorities. In addition, DGE will continue efforts to ensure that GRFP recipients reflect the diversity of the STEM graduate student population and to improve professional development opportunities for program participants.
- The NRT program will advance transformative efforts that combine interdisciplinary training with innovative professional development activities to educate the next generation of scientists, including those from groups currently under-represented in the field, to solve convergent

research problems in areas of national need, and to assume leadership roles across emerging industries. Additionally, the monitoring and evaluation program for NRT will continue to collect data from existing programs to inform future efforts. Innovations in Graduate Education (IGE), a part of the NRT program, will focus on research into graduate student training, including efforts to recover effectively from the impacts of the COVID-19 pandemic on graduate education. IGE will also support an Innovation Acceleration Hub through which the results of IGE projects can be disseminated to the STEM graduate education community.

- 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, including projects that span educational aspects of the frontier between AI and cybersecurity. Focus will be placed on K-12 cybersecurity education, and improving how students from community colleges, veterans, and other groups who have been traditionally underrepresented in their participation in the cybersecurity field are prepared for successful entry and retention in the workforce.
- STEM Education Postdoctoral Research Fellowship piloted as an ARP funded activity in FY 2022. DGE will formally establish this program in FY 2023 to support postdoctoral awards designed to enhance the research knowledge, skills, and practices of recent doctoral graduates in STEM, STEM education, education, and related disciplines, with a goal of advancing their preparation to engage in fundamental and applied research in STEM education.

For more information about GRFP and NRT, see the Major Investments in STEM Graduate Education narrative within the Cross Theme Topics section of the NSF-Wide Investments chapter.

DIVISION OF RESEARCH ON LEARNING IN FORMAL AND INFORMAL SETTINGS (DRL) $242,580,000 +$38,420,000 / 18.8%

DRL Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$204.16**	**-**	**$242.58**	**$38.42**	**18.8%**
Research	194.16	-	232.58	38.42	19.8%
Education	10.00	-	10.00	-	-

About DRL

DRL invests in foundational research to advance understanding about teaching and learning in STEM, across settings ranging from preK-12 schools to the Nation's science museums. These investments address learning in all STEM fields—including computer science and emerging fields such as data science, QIS, and AI. With a focus on equity, the DRL portfolio addresses the design, implementation, and study of learning environments, models, and online learning 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. 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. DRL's programs inform and support lifelong access to high-quality STEM learning opportunities.

FY 2023 Summary

Research

- AISL resources will support design, adaptation, implementation, and research on innovative modes of lifelong learning in informal environments such as science museums, community centers, and public media that have been economically challenged and serve vulnerable populations. Emphases will include equity in STEM, workforce development, adult and family learning of STEM, public participation in scientific research, remote/online learning, and climate education.
- DRK-12 focuses on research and development of resources, models, and tools to help U.S. preK-12 students learn STEM, including computer science and emerging fields such as data science, quantum information science, and artificial intelligence. Students benefit from a strong start in STEM education beginning in early childhood. DRK-12 supports research and development of resources for teachers and schools across diverse educational settings, including remote/online learning environments.
- The EDU Core Research (ECR) program supports fundamental research and capacity building initiatives. ECR is managed and funded across all EDU divisions. For a full description, see the EES Division narrative.
- National Artificial Intelligence Research Institutes: EDU will support research on AI in relation to education and the workforce, with an emphasis on Augmented Learning for Individuals with Disabilities. The overall goal of the 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.

Education

- CSforAll addresses the national need to build computer science education opportunities and teacher preparation at the preK-12 level, as part of building the U.S. economy. CSforAll projects are expected to address equity issues in computer science education, including the participation of girls and women, and other underrepresented groups. In FY 2023, CSforAll will be supported at $10.0 million in EDU, with an additional $14.50 million in support from CISE.

DIVISION OF UNDERGRADUATE EDUCATION (DUE) $291,600,000 +$19,480,000 / 7.2%

DUE Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$272.12**	**-**	**$291.60**	**$19.48**	**7.2%**
Research	128.10	-	149.60	21.50	16.8%
Education	144.02	-	142.00	-2.02	-1.4%

About DUE

DUE supports excellence in undergraduate STEM education for all students. It achieves this goal by funding 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 and impacts of those experiences. DUE investments promote educational innovations across the full range of public and private U.S. institutions of higher education, which can help to increase retention and degree attainment by undergraduates. STEM graduates have more employment opportunities and career options, as well as greater lifetime earning potential. 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. In FY 2023, DUE will continue a research emphasis, initiated in FY 2022, on the learning and teaching of STEM content at 2-year institutions, which often attract diverse populations of students at various point in their careers.

FY 2023 Summary

<u>Research</u>

- The ECR program supports fundamental research and capacity building initiatives. ECR is managed and funded across all EDU divisions. For a full description, see the EES Division narrative.
- HSI funds enable 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. Outreach efforts will continue to seek to engage institutions that are new to NSF.
- IUSE funds enable the study of: increased use of evidence-based educational practices; increased understanding of and gains in diversity, equity, and inclusion in STEM education; advancements in the knowledge base concerning undergraduate research, including course-based research; development or identification of indicators, metrics, and assessments to measure readiness for and progress toward institutional and national improvements in undergraduate STEM education; and educational innovations arising from the mitigation of COVID-19 impacts on undergraduate education. For more information, see the IUSE narrative in the Cross Theme Topics section of the NSF-Wide Investments chapter.

Education

- ATE funding will support understanding and development of effective preparation that will educate the skilled technical workforce, including technicians in advanced technological industries such as advanced manufacturing.
- Noyce funding will invest in teacher preparation and support teacher leaders during completion of a teaching obligation in high-need school districts. Noyce funds also enable the study of effective K-12 STEM pre-service teacher preparation and the retention and development of in-service teachers in high-need school districts. Outreach efforts will continue to seek to engage institutions that are new to NSF and that are MSIs.

H-1B NONIMMIGRANT PETITIONER FEES $158,860,000

In FY 2023, H-1B Nonimmigrant Petitioner Fees are projected to be $158.86 million.

H-1B Nonimmigrant Petitioner Fees Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Percent
H-1B Nonimmigrant Petitioner Fees Funding	$146.51	-	$158.86	$12.35	8.4%

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).

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.

- <u>Low-income Scholarship Program: S-STEM</u>. 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 8,500 proposals from all types of colleges and universities and has made more than 2,300 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-demand technology-rich fields through graduation and into employment. In FY 2023, in addition to the long-standing scholarship support, all S-STEM projects will continue to conduct activities to inform the accumulation of knowledge about 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. To this end, the S-STEM program, through the S-STEM NET solicitation[1], fosters a network of S-STEM stakeholders and further develops the infrastructure needed to generate and disseminate new knowledge, successful practices and effective design principles arising from NSF S-STEM projects nationwide. The program is able to synthesize current achievements and investigate evolving barriers to the success of this student population and disseminate the context and circumstances by which interventions and practices that support graduation of domestic low-income students pursuing careers in STEM are successful. Approximately 90 awards are anticipated in FY 2023, with a continued emphasis on increasing involvement of community colleges, especially Hispanic-serving institutions. S-STEM activities in FY 2023 will leverage efforts in IUSE: EDU, LSAMP, IUSE: HSI, and the IUSE: Two Year College (TYC) 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

[1] www.beta.nsf.gov/funding/opportunities/scholarships-stem-network-s-stem-net

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 4,550 grant proposals and made more than 540 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. The ITEST program encourages proposals relating to emerging industries such as artificial intelligence, data science, and quantum information science. Funded projects draw on a wide mix of community partnerships, 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 24-33 awards in FY 2023.

H-1B Financial Activities from FY 2012 - FY 2021

(Dollars in Millions)

	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Receipts	**$128.99**	**$120.94**	**$132.49**	**$143.00**	**$138.80**	**$141.07**	**$155.99**	**$156.72**	**$153.03**	**$213.50**
Annual receipts due to NSF										*153.50*
DOL 2020 temporary rescission to NSF										*60.00*
Unobligated Balance start of year	**$60.93**	**$99.31**	**$108.31**	**$111.39**	**$116.02**	**$74.63**	**$96.86**	**$64.68**	**$77.47**	**$124.67**
Appropriation Previously unavailable (Sequestered)			**$5.10**	**$9.54**	**$7.30**	**$6.80**	**$9.73**	**$10.30**	**$9.72**	**$9.03**
Appropriation Currently unavailable (Sequestered)			**-$9.54**	**-$7.30**	**-$6.80**	**-$9.73**	**-$10.30**	**-$9.72**	**-$9.03**	**-$8.75**
Rescission										**-$60.00**
Obligations incurred:										
Scholarships in STEM	72.57	83.98	92.18	109.34	140.54	84.38	156.40	114.76	79.91	94.70
Private-Public Partnership in K-12[1]	21.59	31.51	37.23	29.83	44.35	35.11	35.86	34.24	34.87	51.81
Total Obligations	**$94.16**	**$115.49**	**$129.41**	**$139.17**	**$184.89**	**$119.49**	**$192.26**	**$149.00**	**$114.78**	**$146.51**
Unallocated Recoveries	0.96	3.55	-	4.95	1.60	3.58	4.66	4.49	8.26	5.30
Unobligated Balance end of year	**$96.72**	**$108.31**	**$111.39**	**$122.41**	**$72.03**	**$96.86**	**$64.68**	**$77.47**	**$124.67**	**$137.24**

[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, $137.24 million was carried over into FY 2022. Subject to P.L. 116-260, $60.0 million was rescinded in FY 2021.

Innovation Technology Experiences for Students (iTEST)

- Amount: $6.93 million ($21.93 million carryover less $15.0 million rescinded)

- Purpose: Since NSF typically receives the largest amounts from H-1B visa fees in August and September, there was insufficient time to obligate these funds before the end of the fiscal year.
- Obligation: $4.0 million was committed/obligated in Quarter 1-2, remaining amounts to be obligated in FY 2022 Quarter 3.

Scholarships in Science, Technology, Engineering, and Mathematics (S-STEM)
- Amount: $70.31 million ($115.31 million carryover less $45.0 million rescinded)
- Purpose: Since NSF typically receives the largest amounts from H-1B visa fees in August and September, there was insufficient time to obligate these funds before the end of the fiscal year.
- Obligation: $62.60 million was committed/obligated in Quarter 1-2, remaining amounts to be obligated FY 2022 Quarter 3.

ORGANIZATIONAL EXCELLENCE

$719,060,000
+$153,740,000 / 27.2%

Organizational Excellence Funding Summary
(Dollars in Millions)

	FY 2021 Actual	FY 2021 ARP Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Percent
Organizational Excellence[1]	$565.33	$12.00	-	$719.06	$153.74	27.2%
Percent of NSF Total	6.7%	5.0%	-	6.9%	0.2%	N/A

[1] Includes Administrative Cost Recoveries (ACRs) totaling $5.42 million in the FY 2021 Actual. In FY 2022, NSF is moving away from the practice of including ACRs as a source of funds to meet its Organizational Excellence requirement and ACRs are not factored into NSF's budget plans for the FY 2023 Request.

The NSF's FY 2023 Request funding for the Organizational Excellence portfolio is $719.06 million, about seven percent of the total NSF FY 2023 Request. The Organizational Excellence portfolio underpins the agency's programmatic activities and is critical to the accomplishment of NSF's mission, "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense…" NSF fulfills this mission chiefly through the annual merit review of approximately 42,000 proposals and the issuance of approximately 12,000 new awards. In a typical year, NSF works with about 1,900 institutions in all 50 states, the District of Columbia, and four U.S. territories. In FY 2021, more than 33,000 members of the science and engineering community participated in the merit review process as panelists and reviewers.[1] At present, NSF has a total workforce of about 2,100 at its Alexandria, VA, headquarters, including approximately 1,400 career employees, 200 scientists from research institutions on temporary duty, about 450 contract workers, and the staff of the NSB office and the Office of the Inspector General. All of these activities—the merit review process, the issuance of awards, management of awards and awardees, maintaining and securing the headquarters building and NSF's IT infrastructure, and providing for NSF staff and visitors—are supported via the Organizational Excellence portfolio.

The FY 2023 Request represents NSF's commitment to organizational excellence and reflects the agency's true operational, staffing, and administrative needs. The requested funding level will enable NSF to continue to grow agency administration and operations, including additional staffing needs, to effectively and efficiently meet the needs of a growing $10.5 billion federal research agency. The FY 2023 Request also includes funding for an anticipated cost of living adjustment for FY 2023.

The presentation of the Organizational Excellence portfolio is organized around the major functional components instead of sorted solely by appropriation account. This presentation aligns accurately and transparently with how NSF plans and executes the budget for the Organizational Excellence portfolio activities funded by the AOAM, R&RA and EDU accounts. A summary of the FY 2023 Request justification by appropriation account is provided in this Overview, and the budget requests from OIG and NSB are presented separately within the Organizational Excellence chapter.

[1] For more information about NSF's merit review process, see www.nsf.gov/bfa/dias/policy/merit_review/ and *NSF's Merit Review Process, FY 2019 Digest* (NSB-2020-13) at www.nsf.gov/nsb/publications/2020/merit_review/FY-2019/nsb202038.pdf

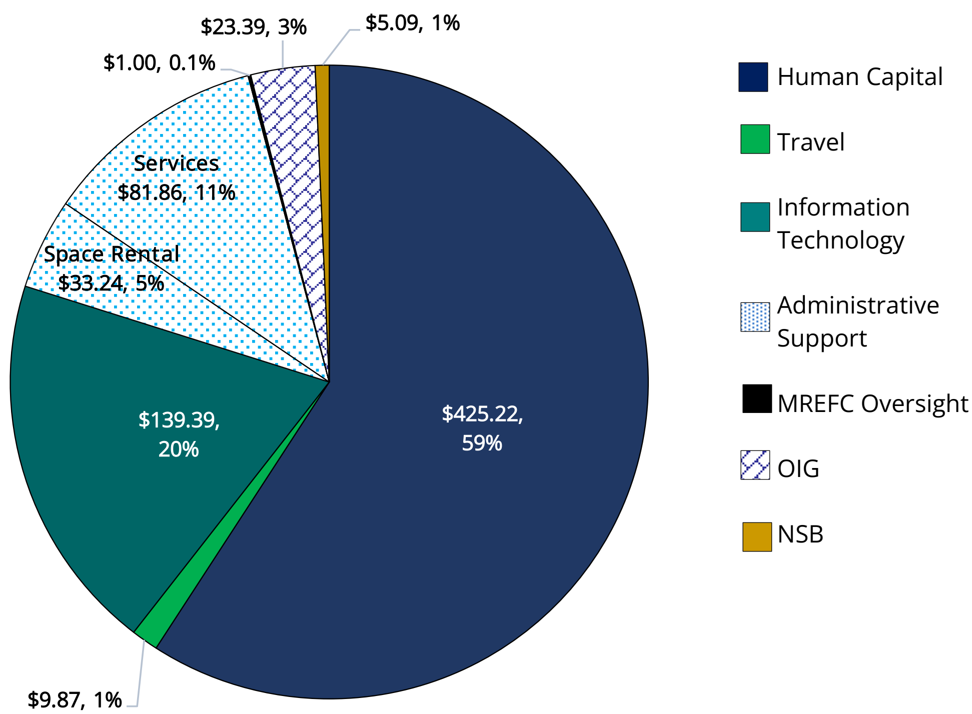
The following section of the overview presents a summary of the FY 2023 funding for the Organization Excellence portfolio by Major Component. This is followed by an overview section presenting the same information but organized by appropriation.

Organizational Excellence by Major Component

The chart below shows the Organizational Excellence portfolio by its major components—Human Capital, Travel, Information Technology (IT), Administrative Support, MREFC Oversight, and support for OIG and NSB.

FY 2023 Funding Summary: Organizational Excellence by Major Component

Dollars in Millions



In this overview, NSF focuses its discussion on the three largest components—Human Capital, Information Technology and Administrative Support. With the exception of MREFC Oversight, every Organizational Excellence component is addressed directly in its specific chapter following the overview. A discussion of MREFC Oversight of major facility projects is discussed in the MREFC narrative of the Research Infrastructure Theme.

<u>Human Capital</u>

The largest component accounting for over half of Organizational Excellence, Human Capital drives the overall funding of the portfolio. It is comprised of funding for NSF's federal staff and IPAs as well as human capital management. This investment area is increased about 31 percent over FY 2021 resulting from a cost of living adjustment of 4.6 percent for FY 2023, increased FTE resources across all types (federal FTE, IPA FTE as well as student FTE), and increased resources for the tools, activities, and programs to both manage and grow NSF’s workforce.

NSF Workforce
The table below shows the agency's total workforce for FY 2023. A discussion of NSF's FTE allocation and usage is included in the Human Capital section of this chapter. The OIG and NSB sections of this chapter and the U.S. Arctic Research Commission section of the R&RA chapter include a discussion of their respective workforces.

NSF Workforce
Full-Time Equivalents (FTE)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Percent
FTE Allocation					
AOAM	1,372	-	1,497	125	9.1%
Regular	1,330	-	1,445	115	8.6%
Pathways Interns[1]	42	-	52	10	23.8%
IPAs	*193*		*275*	82	42%
FTE Usage (Actual/Projected)					
AOAM	1,366	-	1,497	131	9.6%
Regular	1,345	-	1,445	100	7.4%
Pathways Interns[1]	21	-	52	31	149%
Office of Inspector General	68	-	93	25	36.8%
Office of the National Science Board	17	-	18	1	5.9%
Arctic Research Commission	3	-	3	-	-
Total, Federal Employees (FTE) Usage	**1,454**	**-**	**1,611**	**157**	**10.8%**
IPAs (FTE)	193	-	275	82	42.4%
Detailees to NSF	3	-	3	-	-
Total, NSF Workforce (FTE)	**1,650**	**-**	**1,889**	**239**	**14.5%**

[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,

Information Technology (IT) and Administrative Support
IT and Administrative Support are the second and third largest components of the Organizational Excellence portfolio, respectively. While NSF's Human Capital investments have seen steady growth from year to year, particularly for Personnel Compensation and Benefits, funding for IT and Administrative Support activities has been more sporadic. In FY 2023, NSF's IT investments are increased 24 percent over FY 2021 for a total investment of $139.39 million. This funding level will preserve secure, reliable information technology operations while continuing to deliver incremental modernization of the agency's IT infrastructure and systems that support the business operations of the agency. The FY 2023 Administrative Support budget is $115.10 million and fully covers NSF's estimated cost of doing business. This funding level is increased approximately 10 percent over FY 2021 for strategic investments in areas of science and security, business operations, award monitoring, and financial management.

The table on the next page provides details behind the seven major components of Organizational Excellence noted above including their funding sources, as several are funded through more than one appropriation. It also frames the discussions by major component found in the rest of this chapter, with the exception of MREFC funding for oversight of major facility projects that is in the Research Infrastructure Theme.

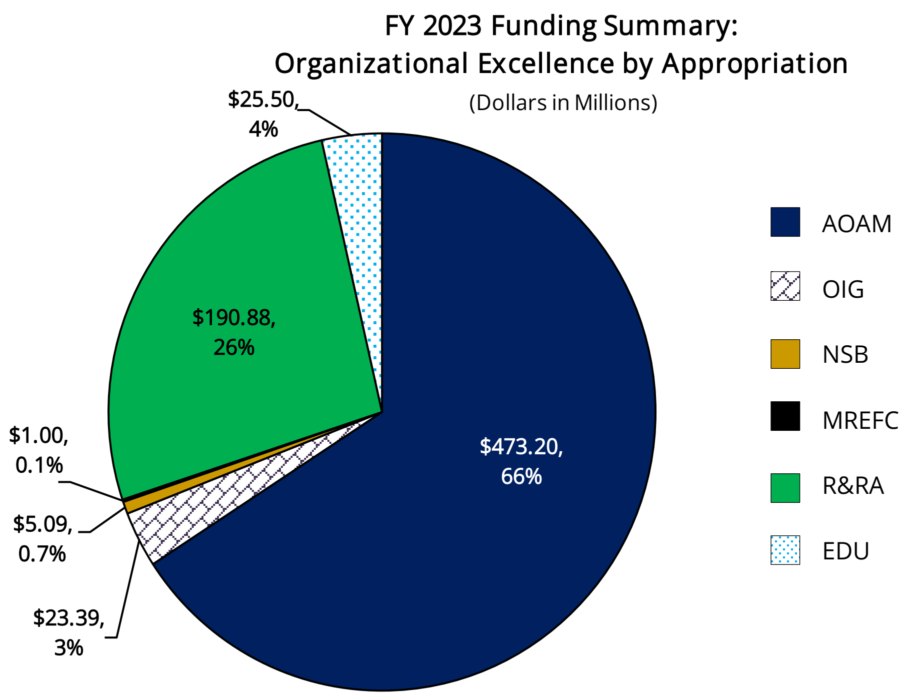
Organizational Excellence by Major Component
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent	Funding Source
Human Capital	$325.74	-	$425.22	$99.48	30.5%	
Personnel Compensation & Benefits	262.68	-	333.55	70.87	27.0%	AOAM[1]
Management of Human Capital	13.49	-	16.32	2.83	21.0%	AOAM
IPA Appointments	49.57	-	75.35	25.78	52.0%	
Compensation	47.26	-	70.04	22.78	48.2%	R&RA/EDU
Per Diem	2.31	-	5.31	3.00	130.2%	R&RA/EDU
Travel	$0.26	-	$9.87	$9.61	3751.5%	
NSF Federal Employee Staff	0.16	-	6.03	5.87	3634.0%	AOAM
IPA Appointments	0.09	-	3.84	3.75	3951.6%	R&RA/EDU
Information Technology	$112.36	-	$139.39	$27.03	24.1%	
Agency Operations IT	24.27	-	30.67	6.40	26.4%	AOAM
Administrative Applications Services & Support	7.18	-	7.91	0.73	10.1%	AOAM
Administrative IT Operations & Infrastructure	13.40	-	17.95	4.55	34.0%	AOAM
Administrative Security & Privacy Services	3.21	-	4.26	1.05	32.7%	AOAM
Administrative IT Management	0.48	-	0.55	0.07	14.6%	AOAM
Program Related Technology (PRT)	88.08	-	108.72	20.64	23.4%	R&RA/EDU
Mission-Related Applications & Services	57.69	-	67.91	10.22	17.7%	R&RA/EDU
Mission-Related IT Operations & Infrastructure	26.32	-	31.63	5.31	20.2%	R&RA/EDU
Mission-Related Security & Privacy Services	3.88	-	6.86	2.98	76.9%	R&RA/EDU
Mission-Related IT Management	0.20	-	2.32	2.12	1037.3%	R&RA/EDU
Administrative Support	$104.76	-	$115.10	$10.35	9.9%	
Space Rental	46.54	-	33.24	-13.29	-28.6%	AOAM
Operating Expenses	20.95	-	30.27	9.32	44.5%	AOAM
Building & Administrative Services	21.84	-	23.12	1.28	5.9%	AOAM
Other Program Related Administration	3.39	-	7.55	4.16	122.9%	
E-Government Initiatives	1.37	-	1.55	0.18	12.8%	R&RA/EDU
General Planning & Evaluation Activities	2.01	-	6.00	3.99	198.0%	R&RA/EDU
Other Organizational Excellence Activities	12.04	-	20.92	8.88	73.7%	
Major Facilities Admin Reviews and Audits	0.98	-	0.17	-0.81	-82.7%	RRA-various
Public Access Initiative	1.98	-	1.75	-0.23	-11.7%	RRA-CISE
Equity and Compliance in Research	-	-	4.00	4.00	N/A	RRA-IA
Evaluation and Assessment Capability	5.67	-	7.00	1.33	23.5%	RRA-IA
Modeling and Forecasting	-	-	3.00	3.00	N/A	RRA-IA
Planning and Policy Support	3.41	-	2.50	-0.91	-26.6%	RRA-IA
Research Security Strategy and Policy	-	-	2.50	2.50	N/A	RRA-IA
MREFC Oversight	$0.17	-	$1.00	0.83	489.7%	MREFC
Office of Inspector General	$17.61	-	$23.39	$5.78	32.8%	OIG
Office of the National Science Board	$4.43	-	$5.09	$0.66	14.8%	NSB
Total	**$565.33**	-	**$719.06**	**$153.74**	**27.2%**	

[1] Includes Administrative Cost Recovery (ACR) estimates totaling $5.42 million for FY 2021. In FY 2022, NSF is moving away from the practice of including ACRs as a source of funds to meet its Organizational Excellence requirement and ACRs are not factored into NSF's budget plans for the FY 2023 Request.

Organizational Excellence by Appropriation

The following presentation details NSF's Organizational Excellence portfolio by appropriation, which is funded through all of NSF's appropriation accounts.



Organizational Excellence by Appropriation

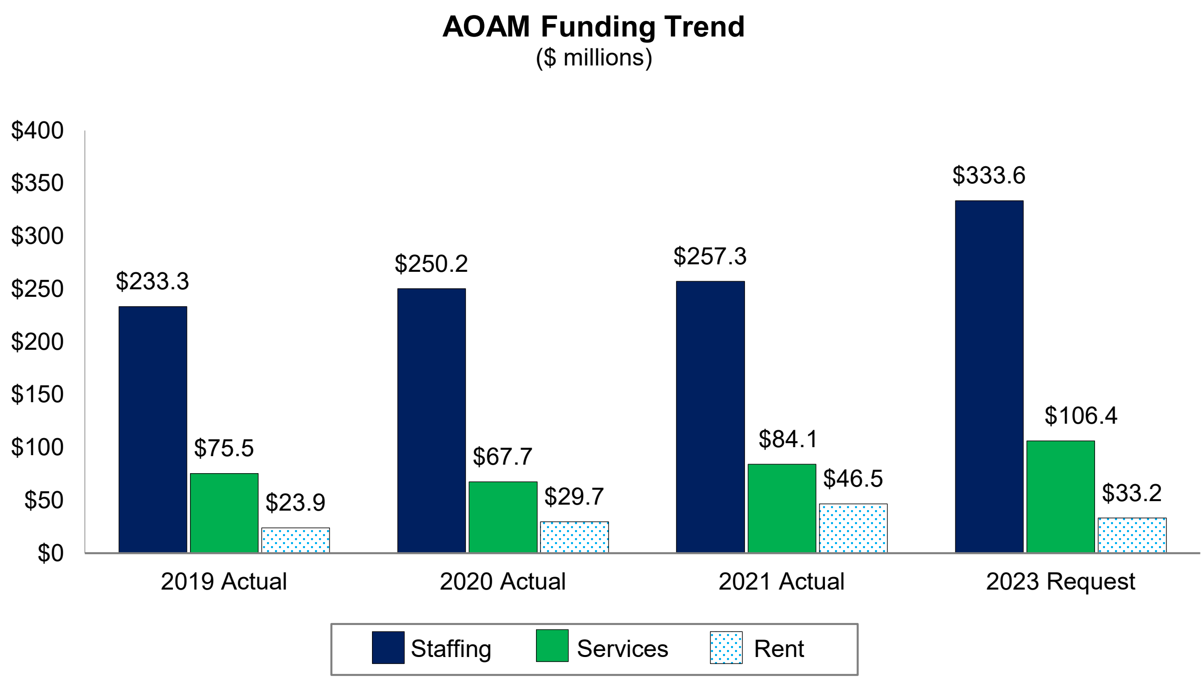
(Dollars in Millions)

	FY 2021 Actual	FY 2021 ARP Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Agency Operations & Award Management	$384.52	$12.00	-	$473.20	$88.68	23.1%
Office of Inspector General	17.61	-	-	23.39	5.78	32.8%
Office of the National Science Board	4.43	-	-	5.09	0.66	14.8%
Maj. Rsrch Equipment & Facilities	0.17	-	-	1.00	0.83	489.7%
Program Support:						
Research & Related Activities	135.05	-	-	190.88	55.83	41.3%
STEM Education	18.12	-	-	25.50	7.38	40.7%
Total NSF Appropriated Funds	**$559.91**	**$12.00**	**-**	**$719.06**	**$159.15**	**28.4%**
Administrative Cost Recoveries (ACRs)	5.42	-	-	-	-5.42	-100.0%
Total Organizational Excellence	**$565.33**	**$12.00**	**-**	**$719.06**	**$153.73**	**27.2%**

<u>Agency Operations and Award Management (AOAM)</u>

Investments in the AOAM account continue to be a priority in the FY 2023 Request. This activity provides the fundamental framework through which the Foundation's science and engineering research and education programs are administered.

At the FY 2023 Request level, AOAM funding is $473.20 million representing 66 percent of the Organizational Excellence portfolio but under five percent of the total NSF FY 2022 Request. While NSF continues to operate as a lean agency, this funding level emphasizes the importance and prioritization of current services and additional functions supporting the mission of NSF and reflects an increase for pay and benefits for NSF's federal workforce—including a 4.6 percent cost of living adjustment for FY 2023. Over three quarters (78 percent) of the requested FY 2023 AOAM funds support staffing and space rental while about one quarter (22 percent) are for mission support services.



Agency Operations and Award Management Funding Summary

(Dollars in Millions)

	FY 2021 Actual	FY 2021 ARP Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Personnel Compensation & Benefits (PC&B)[1]	$257.27	$8.63	-	$333.55	$76.28	29.7%
Management of Human Capital	13.49	-	-	16.32	2.83	21.0%
Travel	0.16	-	-	6.03	5.87	3634.0%
Information Technology	26.76	2.49	-	30.67	3.91	14.6%
Space Rental	46.54	-	-	33.24	-13.29	-28.6%
Operating Expenses	21.83	0.88	-	30.27	8.44	38.6%
Building & Administrative Services	21.84	-	-	23.12	1.28	5.9%
Total	**$387.89**	**$12.00**	-	**$473.20**	**$85.31**	**22.0%**

[1] PC&B levels reflect direct appropriated funds only. In FY 2021, $5.42 million in Administrative Cost Recoveries (ACRs) were received bringing the total PC&B obligation to $262.68 million. In FY 2022, NSF is moving away from the practice of including ACRs as a source of funds to meet its Organizational Excellence requirement and ACRs are not factored into NSF's budget plans for the FY 2023 Request.

For information on NSF's AOAM account by object class, see the AOAM by Object Class table at the end of this narrative.

Office of Inspector General

FY 2023 funding for the OIG is $20.39 million. The staffing and operations of the OIG are supported through a separate OIG appropriation. Details about the OIG FY 2023 Request can be found in the OIG narrative.

Office of the National Science Board

FY 2023 funding for the NSB is $5.09 million. The staffing and operations of the NSB office are supported through a separate NSB appropriation. Details about the NSB FY 2023 Request can be found in the NSB narrative.

Major Research Equipment and Facilities Construction

The FY 2023 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 narrative within the Research Infrastructure section of the NSF-Wide Investments chapter.

Program Support

Funding from program accounts R&RA and EDU ($216.38 million) covers approximately 30 percent of the total Organizational Excellence portfolio. Three activities comprise program-funded Organizational Excellence: Intergovernmental Personnel Act (IPA) costs, Program Related Administration including Program Related Technology, and other Organizational Excellence activities.

R&RA and EHR Organizational Excellence Funding Summary

(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
IPA Costs	**$49.66**	**-**	**$79.19**	**$29.53**	**59.4%**
IPA Compensation	47.26	-	70.04	22.78	48.2%
IPA Per Diem	2.31	-	5.31	3.00	130.2%
IPA Travel	0.09	-	3.84	3.75	3951.6%
Program Related Administration	**$91.47**	**-**	**$116.27**	**$24.80**	**27.1%**
Program Related Technology	88.08	-	108.72	20.64	23.4%
Other Program Related Administration	3.39	-	7.55	4.16	122.9%
Other Organizational Excellence Activities	**$12.04**	**-**	**$20.92**	**$8.88**	**73.7%**
Major Facilities Admin Reviews and Audits	0.98	-	0.17	-0.81	-82.7%
Public Access Initiative	1.98	-	1.75	-0.23	-11.7%
Equity and Compliance in Research	-	-	4.00	4.00	N/A
Evaluation and Assessment Capability	5.67	-	7.00	1.33	23.5%
Modeling and Forecasting	-	-	3.00	3.00	N/A
Planning and Policy Support	3.41	-	2.50	-0.91	-26.6%
Research Security Strategy and Policy	-	-	2.50	2.50	N/A
Total	**$153.18**	**-**	**$216.38**	**$63.20**	**41.3%**

AOAM by Object Class

AOAM by Object Class
(Dollars in Thousands)

	FY 2021 Actual	FY 2021 ARP Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Personnel Compensation	$193,745	$6,512	-	$247,540	$53,795	27.8%
Personnel Benefits	63,027	2,115	-	86,015	22,988	36.5%
Travel and Transportation of Persons	165	-	-	6,030	5,865	3559.2%
Transportation of Things	677	-	-	305	-372	-54.9%
Rental Payments to GSA	40,485	-	-	26,480	-14,005	-34.6%
Rental Payments to Others	282	-	-	300	18	6.3%
Communications, Utilities and Misc. Charges	1,270	-	-	1,200	-70	-5.5%
Printing and Reproduction	75	-	-	80	5	7.3%
Advisory and Assistance Services	43,722	2,255	-	50,490	6,768	15.5%
Other Services	26,483	1,118	-	37,510	11,027	41.6%
Purchases of Goods & Srvcs from Gov't. Accts	11,910	-	-	13,600	1,690	14.2%
Operations and Maintenance of Equipment	200	-	-	200	0	0.2%
Supplies and Materials	333	-	-	1,150	817	245.3%
Equipment	2,144	-	-	2,300	156	7.3%
Total	**$384,517**	**$12,000**	**-**	**$473,200**	**$88,683**	**23.1%**

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, 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 Department of Homeland Security/Federal Protection Agency for security guard services; General Service Administration for 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. The FY 2021 level for this category was unusually low due to significantly less in-person activity at NSF. The FY 2023 level is consistent with increased staffing and pre-pandemic levels of spending.

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; ~~$468,300,000~~$473,200,000: 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 ~~2022~~2023 for maintenance and operation of facilities and for other services to be provided during the next fiscal year.

Agency Operations and Award Management
FY 2023 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 2021 Appropriation	$357.64	9.20	$0.00	$0.39	29.29	$396.52
FY 2022 Annualized CR	345.64	0.00				345.64
FY 2023 Request	473.20					473.20
$ Change from FY 2022 Annualized CR						$127.56
% Change from FY 2022 Annualized CR						36.9%

Totals exclude reimbursable amounts.

HUMAN CAPITAL

$425,220,000
+$99,480,000 / 30.5%

Human Capital
(Dollars in Millions)

	FY 2021 Actual	FY2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent	Funding Source
Personnel Compensation & Benefits[1]	$262.68	-	$333.55	$70.87	27.0%	AOAM
Management of Human Capital	13.49	-	16.32	2.83	21.0%	AOAM
IPA Compensation and Per Diem[2]	49.57	-	75.35	25.78	52.0%	R&RA/EHR
Total, Human Capital	**$325.74**	**-**	**$425.22**	**$99.48**	**30.5%**	
Total AOAM	270.76	-	349.87	79.12	29.2%	
Total R&RA	43.65	-	67.17	23.52	53.9%	
Total EDU	5.92	-	8.18	2.26	38.2%	

[1] FY 2021 Actual funding for PC&B includes $5.42 million in Adminsitrative Cost Recoveries (ACRs). For FY 2022, NSF is moving away from the practice of including ACRs as a source of funds to meet its Organizational Excellence requirement and ACRs are not factored into NSF's budget plans for the FY 2023 Request.

[2] Costs for IPA travel are found within the Travel section of this chapter.

Support for NSF's human capital activities is the largest component of Organizational Excellence, accounting for almost 60 percent of the total portfolio. The Human Capital component includes personnel compensation and benefits (PC&B) 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 EDU.

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.

The Human Capital component also includes support for the Management of Human Capital, which includes:

- Human resources systems accessed through shared service providers, including the Federal Personnel Payroll System, the time and attendance system (WebTA), and eRecruit capabilities using USAJobs.
- Operational activities including recruiting, hiring, and on-boarding of permanent and rotating staff, as well as processing support for pay and benefits and awards.
- Workplace and career-life balance support for employees including the Health Unit, the Employee Assistance Program, and childcare subsidy.
- Contracts that support training and development programs, on-line training capabilities, networking activities including the NSF mentoring program, executive and supervisory training, and program management training.

Personnel Compensation and Benefits (PC&B)

Personnel Compensation & Benefits
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Regular FTE Usage (projected)	1,345	-	1,445	100	7.4%
Pathways Intern FTE Usage (projected	21	-	52	31	*148.7%*
Regular FTE Base Salary[1]	$189.56	-	$233.20	$43.65	23.0%
Pathways Intern Salary	1.00	-	2.91	1.91	190.6%
Other Compensation[2]	2.30	-	2.78	0.48	20.9%
Awards	6.51	-	8.64	2.13	32.6%
Subtotal, FTE Compensation	**$199.37**	**-**	**$247.54**	**$48.16**	**24.2%**
Benefits	62.48	-	84.67	22.19	35.5%
Other Benefits[3]	0.84	-	1.35	0.51	61.3%
Subtotal, Benefits	**$63.31**	**-**	**$86.02**	**$22.70**	**35.9%**
Total, PC&B	**$262.68**	**-**	**$333.55**	**$70.87**	**27.0%**
Source of Funds					
AOAM Appropriation	$257.27	-	$333.55	$76.28	29.7%
Administrative Cost Recoveries[4]	5.42	-	-	-5.42	-100.0%
Total	**$262.68**	**-**	**$333.55**	**$70.87**	**27.0%**

[1] Includes full support for a 4.6 percent COLA in FY 2023 ($10.88 million).
[2] Includes reimbursable details to NSF and terminal leave.
[3] Includes Federal Employee's Compensation Act (FECA) funding and transit subsidies.
[4] ACRs estimates are not factored into NSF's PC&B budget for the FY 2023 Request.

The FY 2023 Request for PC&B is $333.55 million. As implemented in the FY 2022 Request, FY 2023 funding includes AOAM appropriated funds only; no Administrative Cost Recoveries (ACRs) are factored into NSF's AOAM budget plans for the FY 2023 budget submission. The FY 2023 PC&B cost estimate will support the projected year-end usage of 1,445 regular FTE employees, a total of 52 Pathways intern FTE, associated cost of benefits, general workforce performance awards (GWFPA), and Senior Executive Service (SES) bonuses. It includes funding to cover a Cost of Living Adjustment in FY 2023 of 4.6 percent and also contains approximately $1.0 million for the Federal Transit Benefits Program. In total, NSF believes this PC&B estimate presents a realistic estimate of these costs in FY 2023 and, if provided at the requested level, should minimize the amount of any transfer should NSF need to exercise its transfer authority.

NSF AOAM Workforce

NSF AOAM Workforce
(Full-Time Equivalent (FTE) and Other Staff)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
NSF AOAM FTE Allocation					
NSF AOAM -- Regular	1,330	-	1,445	115	8.6%
NSF AOAM -- Pathways Intern	42	-	52	10	23.8%
Subtotal, FTE Allocation	**1,372**	**-**	**1,497**	**125**	**9.1%**
NSF AOAM FTE Usage					
NSF AOAM -- Regular	1,345	-	1,445	100	7.4%
NSF AOAM -- Pathways Intern	21	-	52	31	148.7%
Subtotal, FTE Usage	**1,366**	**-**	**1,497**	**131**	**9.6%**
Detailees to NSF	3		3	-	-
Total	**1,369**	**-**	**1,500**	**131**	**9.5%**

NSF's FY 2023 FTE allocation is 1,497. The FY 2023 FTE estimated usage is 1,445 regular and 52 Pathways FTE.

NSF's regular FTE level are increased by 115 FTE in FY 2023. Six of these FTE will support NCSES' role as Program Management Office for the Standard Application Process and for work related to building a National Secure Data Service. The remaining FTE are for the TIP Directorate and for NSF to achieve the program objectives set forth by the Director in the FY 2023 Request.

Currently, planning is underway to expand NSF's internship program in FY 2023 to grow the program by an additional 10 Pathways Intern FTE. Within NSF, the Pathways Program is working as designed and NSF is converting interns to permanent positions at a highly successful rate. These additional FTE will support NSF efforts to uphold Section 6 of Executive Order 14035, Advancing Diversity, Equity, Inclusion and Accessibility (DEIA) in the Federal Workforce, as these entry level positions often create a real opportunity for candidates in underserved communities to gain access to the Federal workforce.

Management of Human Capital

Management of Human Capital
(Dollars in Millions)

FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
$13.49	-	$16.32	$2.83	21.0%

The FY 2023 Request level for Management of Human Capital is $16.32 million. This funding level will enable NSF to maintain operational support activities, learning and development programs essential for NSF's permanent and rotator staff, and contractual support for human capital initiatives. Specifically, NSF's FY 2023 Management of Human Capital investments support the following activities:

Learning and Development Programs (4.76 million)
Investments in this category fund contracts in support of learning and development programs, such as the Learning Management System, LearnNSF, and related on-line learning capabilities, as well as support for learning and capacity-building activities including the NSF mentoring program, executive and supervisory training, and program management training. These learning and development activities 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 whether working onsite or offsite.

Operations Support ($4.53 million)
This category includes contract support for recruiting, hiring, and on-boarding of permanent and rotating staff, outreach, and employee surveys as well as processing support for pay, benefits, and incentive and other awards. These investments ensure that initiatives related to the NSF work environment focus on keeping NSF competitive in the labor market, able to attract, recruit, retain, and empower top talent, and advance diversity, equity, inclusion, and accessibility. The FY 2023 funding level is guided by costs associated with these employee-driven human capital activities. Included within the FY 2023 funding level is increased support for Pathways Program management in support of the program's FTE growth. The increased funding will allow NSF to ramp up recruitment and outreach efforts, to include campus outreach, internship-focused training/networking, and DEIA program enhancements.

Strategic Human Capital Support ($3.98 million)
NSF relies on strategic human capital support contracts for assistance in developing new approaches to critical human resource needs. FY 2023 funding reflects NSF's planned investment in business intelligence and other tools anticipated to bring agility and process efficiency to the agency and enable workload analysis and workforce planning in support of strategic management of human capital resources. Within this investment category, FY 2023 funds will continue support for talent teams established in the FY 2022 Request, to identify assessments which are appropriate for NSF, and to improve internships and Pathways Programs. Additional support is also provided to advance position management, competency assessment, and career path navigation activities associated with NSF' s Operational Reforms initiative (formerly Renewing NSF).

Workplace and Work-Life Support ($2.09 million)
The Workplace and Work-Life Support investment is focused on helping NSF's employees by providing health and family-friendly programs and activities, including an onsite health unit, onsite fitness center, the employee assistance program, childcare subsidy, backup dependent care program, and student loan repayment program. These activities address the future of employee support and help the agency remain competitive in the labor market and support Federal employees in a hybrid work environment.

Human Resource Systems and Shared Services ($960,000)
This category represents 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 2023 funding reflects the rising costs of the Interior Business Center's (IBC) shared services support for various critical personnel management systems. The required funding level is a result of agency identified resources needed (or savings identified) to operate effectively and support the federal workforce.

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 assignments. 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. Since January 31, 2020, NSF has required that institutions provide a minimum of 10 percent cost share of an IPA's base salary and fringe benefits for every full-time IPA agreement.[1]

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 Compensation and Per Diem by Appropriation

(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
IPA FTE Allocation[1]	205	-	275	70	34.1%
IPA FTE Usage (Actual/Projected)[1]	193	-	275	82	42.4%
Research and Related Activities (R&RA)					
IPA Compensation	$41.67	-	$62.64	$20.97	50.3%
IPA Per Diem	1.98	-	4.53	2.55	128.3%
Subtotal, R&RA Costs	**$43.65**	**-**	**$67.17**	**$23.52**	**53.9%**
STEM Education (EDU)					
IPA Compensation	$5.60	-	$7.40	$1.80	32.2%
IPA Per Diem	0.32	-	0.78	0.46	142.1%
Subtotal, EDU Costs	**$5.92**	**-**	**$8.18**	**$2.26**	**38.2%**
Total[1]	**$49.57**	**-**	**$75.35**	**$25.78**	**52.0%**

[1] IPA FTE of approximately one in FY 2021 and four in FY 2023 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 Operating Expenses section of this chapter.

The FY 2023 IPA FTE allocation increases 70 IPA FTE over the FY 2021 Actual, reflecting the creation of the TIP directorate and a growth in the number of IPA FTE commensurate with the growth in the total NSF Request. The FY 2023 funding for IPA compensation and per diem costs are associated with full use of NSF's IPA FTE allocation for FY 2023.

For both R&RA and EDU, IPA costs in FY 2021 were below normal due to restrictions imposed by COVID-19, especially as it related to travel and per diem costs. For FY 2023, NSF expects normal activities to resume and IPA costs are increased consistent the increase in IPA FTE and no assumed

[1] If a home institution is unable to provide the full 10 percent cost share, the institution may submit requests for NSF to waive the cost-sharing requirement. Such requests must include the rationale for not being able to provide the required amount.

restrictions. Per IPA compensation costs for the FY 2023 Request are estimated based on projected IPA FTE utilization, current IPA funding, and the need to provide competitive salaries to recruit the best researchers in the STEM fields. The per Diem costs are increased to levels consistent with historical averages and also reflects new NSF policy, beginning October 1, 2021, raising the maximum annual per Diem level to $24,984.

Information on costs associated with travel for NSF's IPAs is found within the Travel section of this chapter.

TRAVEL

$9,870,000
+$9,610,000 / 3,751.5%

NSF Travel
(Dollars in Millions)

	FY 2021 Actual[1]	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent	Funding Source
NSF Federal Employee Staff	$0.16	-	$6.03	$5.87	3634.0%	AOAM
IPA Appointments	0.09	-	3.84	3.75	3951.6%	R&RA/EHR
Total Travel	**$0.26**	**-**	**$9.87**	**$9.61**	**3751.5%**	
Total AOAM	0.16	-	6.03	5.87	3634.0%	
R&RA	0.09	-	3.50	3.41	3782.1%	
EDU	0.00	-	0.34	0.34	7259.3%	

[1] FY 2021 funding for Federal Employee Staff and IPA travel is lower than normal due to travel restrictions related to COVID-19. This results in the large percent increases shown.

The FY 2023 Request level for staff and IPA travel is $9.87 million. NSF employee travel accounts for about 61 percent of this total and is provided from the AOAM account. Travel for IPA appointments, which is supported by the R&RA and EDU accounts, is the remaining 39 percent.

As part of the review of the agency's operational and administrative needs used to develop the FY 2023 budget request, NSF analyzed historical travel data and projected estimated travel costs related to the amount of program activities anticipated at the FY 2023 Request level for NSF. In addition, travel restrictions in place for FY 2021 and into FY 2022 due to the COVID-19 pandemic were considered to be no longer in place in FY 2023 in the formulation of NSF's FY 2023 travel budget request.

NSF Employee Travel

FY 2023 funding for NSF employee full-time equivalent (FTE) travel is estimated at $6.03 million. NSF's employee FTE travel costs are increased in FY 2023 to levels consistent with historical averages, in anticipation of COVID restrictions being lifted and travel resuming as normal. NSF employee FTE travel is also based on the travel activity associated with utilization of 1,445 regular FTE. It includes travel-related funding for training, site reviews, outreach activities, and post-award monitoring and oversight.

IPA Travel

The FY 2023 funding for IPA travel is $3.84 million, representing an IPA usage level of 275 IPA FTEs. The per IPA travel costs are increased in FY 2023 to levels consistent with historical averages, in anticipation of COVID restrictions being lifted and travel resuming as normal. Travel is essential to the successful completion of an IPA's duties while at NSF, which include responsibilities for oversight and stewardship of NSF's programs and awards, outreach to and engagement with scientific communities and other external stakeholders as NSF ambassadors, and maintaining their own professional prevalence (including, but not limited to, independent research and development activities).

INFORMATION TECHNOLOGY (IT) $139,390,000

+27,030,000 / 24.1 %

NSF's FY 2023 Congressional Request for IT investments total $139.39 million. Funding for NSF's IT investment is provided from the AOAM, R&RA, and EDU accounts.

NSF IT Portfolio Investments by Appropriation

NSF IT Portfolio Investments by Appropriation
(Dollars in Millions)

	FY 2021 Actual	FY 2021 ARP Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent	Funding Source
AOAM IT	$24.27	$2.49	-	$30.67	$6.40	26.4%	AOAM
Program Related Technology (PRT)	88.08	-	-	108.72	20.64	23.4%	R&RA/EHR
Total	**$112.36**	**$2.49**	**-**	**$139.39**	**$27.03**	**24.1%**	
Total AOAM	24.27	2.49	-	30.67	6.40	26.4%	
Total R&RA	75.88	-	-	92.84	16.96	22.3%	
Total EDU	12.20	-	-	15.88	3.68	30.2%	

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 almost one quarter (22 percent) of NSF's total IT investment at the FY 2023 Request level.

Program Related Technology (PRT) investments support NSF's programmatic activities and associated services and are funded through the R&RA and EDU accounts. PRT investments are mission-related IT and data management 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 just over three quarters (78 percent) of NSF's FY 2023 total funding for IT investments.

NSF's IT priorities for FY 2023 are to preserve secure, reliable information technology operations, while continuing to deliver incremental modernization of the agency's IT infrastructure and systems that support the business operations of the agency. Advances supported by this submission include: additional automation and streamlining of work performed by NSF staff; implementing new business rules, workflows, and/or reporting needs as a result of business process and organizational changes as well as any Congressional oversight and transparency/stewardship requirements; updates to public and researcher facing systems and websites to respond to user experience input and increased interest in NSF's work; reducing administrative burden on our external partners; and changes to make additional data available to the public as well as university and corporate partners. NSF's IT investments will also focus on how technology can be used to augment and amplify human performance, a continued effort on implementing and scaling solutions that will further priorities stemming from continuing the agency's commitment to enterprise excellence. At the FY 2023 Request, incremental development and modernization efforts will continue based upon agency priorities, including:

- Technology transformations geared toward improving the customer experience both internally

and for public-facing digital services, with a continued focus on modernization and digitization;
- Expand development and implementation of advanced technologies such as artificial intelligence (AI), robotic process automation (RPA), and advanced data analytics tools to support NSF's mission;
- Employ innovative and emerging technology capabilities in support of agency priorities, increasing agility within NSF's merit review and administrative functions while enabling the continued transformation of the agency's workforce and providing platforms for development and testing of new technology tools and capabilities;
- Support for the IT infrastructure and systems that serve the agency, preserving secure, reliable operations while enabling risk-based prioritization of cybersecurity improvements, including continued focus on mitigating supply chain risk;
- 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;
- Support continued use and refinement of the Technology Business Management (TBM) framework for managing IT as a business.

NSF IT Portfolio Investments by Category

Investments in NSF's IT Portfolio can be grouped across five main categories: Administrative Applications Services and Support; Mission-Related Applications and Services; IT Operations and Infrastructure; IT Security and Privacy; and IT Management. Funding for the activities under these investment categories is split between AOAM and PRT.

NSF IT Portfolio Investments by Category

(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Percent	Funding Source
Admin. Applications Services & Support	$7.18	-	$7.91	$0.73	10.1%	AOAM
Mission Related Applications & Services	57.69	-	67.91	10.22	17.7%	PRT
IT Operations & Infrastructure	39.72	-	49.58	9.86	24.8%	AOAM/PRT
Security & Privacy Services	7.09	-	11.12	4.03	56.9%	AOAM/PRT
IT Management	0.68	-	2.87	2.19	319.6%	AOAM/PRT
Total	**$112.36**	**-**	**$139.39**	**$27.03**	**24.1%**	

Administrative Applications Services and Support ($7.91 million: AOAM only)

Investments in this category support administrative applications, such as the NSF website, NSF's human resources management systems, and NSF's financial management system.
- iTRAK is NSF's financial management system. Seventy percent will be funded by PRT through the R&RA and EDU accounts and 30 percent will be funded by the AOAM account. The AOAM portion of the FY 2023 funding supports ongoing operations and maintenance of the system as well as updates and enhancements to support intragovernmental transactions.
- Other administrative applications services which provide for operations and maintenance of agency administrative and collaboration tools, such as the NSF website. FY 2023 funding in this area will support operations and maintenance of both NSF's legacy website and beta.nsf.gov as the agency continues to transition site content.

- Operations and maintenance of the systems that support the strategic management of NSF human capital, including those that enable the effective recruitment, retention, reskilling, and rewarding of NSF staff . Funding in FY 2023 continues support for operations of the agency's core human capital management systems and invests in new capabilities and expanded services to accommodate the workforce.

<u>Mission-Related Applications and Services ($67.91 million: PRT only)</u>
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, which include support for a wide range of activities:
    - 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. In FY 2023, additional costs are expected in this area, as long-term investments in Proposal Management Efficiencies (PME) and Website Modernization move into production and will require operational support and maintenance.
    - Continuous modernization of systems and services that support the merit review process. FY 2023 efforts will continue to prioritize modernization of public-facing digital services. Specific investments include:
        - Web Modernization: Continues efforts to expand the capabilities and information shared through NSF's website, which provides the general public, science and engineering research communities, and education communities with access to high quality information and services. In FY 2023, NSF will continue enhancement of NSF.gov with features and content to better serve all audiences and will initiate modernization of the agency's intranet site using human centered design principles.
        - Public Access: 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. FY 2023 efforts continue system updates that enhance access to research outputs within the federated cross-agency repository.
        - Intelligent Automation of Grants Management Systems: This investment provides for enhancements to IT systems/applications that support the grants management lifecycle, including those formerly related to the PME investment. Investments aligned to this initiative in FY 2023 will focus on improvements to enhance non-financial aspects of the merit review process, including continued efforts related to identity management capabilities and services as well as beginning work to replace NSF's system that facilitates the clearance and publication of solicitations.
        - Improve Service Delivery: In FY 2023 this initiative will continue focusing on tools to enhance IT service delivery, such as strengthened infrastructure and tools that support hybrid work and improved collaboration.
        - Interactive Panel Systems (IPS) Replacement: A continuing modernization effort to replace the current interactive panel system, which provides reviewers an application for collaborating with fellow panelists to review and rank proposals and recommend the proposals deemed most meritorious. This effort is expected to be completed in FY 2023.

    - Innovation Management: Continues the adoption and implementation of advanced tools and technologies to promote innovation, research and development, and emerging technologies in support of the renewed merit review process. Specifically, FY 2023 funding will continue efforts to consolidate, integrate, and streamline services through the expansion of advanced technology such as AI, RPA, and machine learning, reducing administrative burden on the user.
    - PME: This investment will be completed in FY 2022 and will not require funding in FY 2023.
- NSF's Data Management and Delivery investment: NSF's IT governance groups have prioritized agency initiatives to strengthen the agency use of data and evidence. FY 2023 funding includes continued investments in infrastructure, services and systems that accelerate access to secured, timely, well-documented enterprise data, enabling agency staff to leverage data and analytics to achieve NSF's mission.
- Operations and maintenance of NSF's core financial system, iTRAK: As noted above 70 percent of this request is funded by PRT with the remaining 30 percent funded by AOAM under Administrative Applications Services and Support.
- Financial services support: Enables continued agency efforts to increase transparency and accuracy of reporting between iTRAK and other mission systems, such as through account code structure modernization and completion of Awards system modernization efforts. FY 2023 efforts will also focus on enhancements to core business and operations systems serving business professionals and awardees.
- Human Resource System Modernization: This is an ongoing investment that will modernize and enhance core agency systems for strategic management of human capital and administrative resource management. In FY 2023, NSF will prioritize enhancements to the agency's learning management system.

<u>IT Operations and Infrastructure ($49.58 million: $17.95 million in AOAM, $31.63 million in PRT)</u>
The FY 2023 Starting Point will support NSF's ongoing enhancements to agency capabilities related to network, infrastructure, data center, customer support, and database administration. Specifically, the investments in this category are classified as:

- Network: Provides access to administrative applications, services, and technologies for virtual collaboration via a single network with wired and Wi-Fi connectivity for NSF staff and visitors. FY 2023 funding supports continuous modernization of NSF's infrastructure, network, and telecommunications, including costs associated with the agency's continued adoption of Internet Protocol Version 6 (IPv6) technologies, as well as voice services via NSF's modernized voice over internet protocol (VoIP) solution and other telecommunications requirements delivered through the federal Enterprise Infrastructure Services (EIS) contract.
- Data Center and Cloud: Continues the agency use of cloud services and technologies, including the use of cloud-based email and collaboration tools, to enable further reductions in NSF's data center footprint, as the agency continues to expand cloud services adoption. FY 2023 funding will support continued cloud migrations to increase resilience of IT services and applications, improve speed of deployment, and support NSF's service recovery capability. Support for Data Center Facilities and Power is not included in the AOAM IT or PRT budgets discussed in this narrative but is included in the agency's IT Portfolio summary reporting and mentioned here for transparency. Funding for Data Center Facilities and Power is supported under Space Rental and referenced in that section of the Administrative Support narrative.
- End User: Provides help desk services and customer care support for internal users (NSF staff) and external users (the research community including institutions, principal investigators, reviewers,

and NSF visitors), as well as support for agency-provided workstations, mobile devices, and peripherals. FY 2023 funding in this area supports continuing improvements to service delivery, including deployment of new technology capabilities to NSF staff and customers who are working remotely, as well as ongoing modernization of services and devices.

- Platform: Reflects NSF's use, management, and acquisition of hyper-converged hardware, software, and services. In FY 2023, NSF will continue efforts to modernize database platforms.
- Output: Supports NSF's Print Center services. These costs are not part of the AOAM IT or PRT budget discussed in this narrative but are included in the agency's IT Portfolio summary reporting and mentioned here for transparency. Funding for Print Center services are supported under Building and Administrative Services and discussed in that section of the Administrative Support narrative.

<u>Security and Privacy Services ($11.12 million: $4.26 million in AOAM, $6.86 million in PRT)</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 and mission support systems under the direction of the NSF Chief Information Security Officer (CISO). The FY 2023 level prioritizes preservation of secure, reliable operations, including the agency's Security Operations Center (SOC) capability providing 24/7/365 security monitoring, detection, and response capabilities and adds support for information technology operations and maintenance for a new Sensitive Compartmented Information Facility (SCIF) in the Alexandria facility. This funding level also enables NSF to continue current approaches to manage, modernize, and secure agency information, including efforts to manage supply chain risks, implement operational procedures related to cybersecurity vulnerability and incident response, and mature capabilities to protect agency information, endpoints, and enterprise identity management solutions. In FY 2023, NSF anticipates ongoing investments in staff, tools, and professional services to mitigate the increasing risks of a larger, hybrid workforce operating in a more complex and rapidly growing infrastructure environment, to continue providing secure, reliable operations and around-the clock security monitoring. The investment includes: offerings from the Department of Homeland Security (DHS) Continuous Diagnostics and Mitigation (CDM) shared services program, which provides NSF with security monitoring tools that supplement agency capabilities; 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; vulnerability management activities, including activities related to assessment, management, and disclosure; remediation and intrusion detection services; zero trust architecture; and activities related to cybersecurity assessment and authorization, including supply chain risk management.

<u>IT Management ($2.87 million: $550,000 in AOAM, $2.32 million in PRT)</u>
IT Management includes support for the Chief Information Officer, Chief Data Officer, Senior Agency Official for Privacy, and senior IT leadership in the areas of IT strategy and planning, enterprise architecture, capital planning, vendor management, IT budget/finance, IT strategic communications, and support for policy and reporting efforts related to Federal IT, including compliance with the Federal Information Technology Acquisition Reform Act (FITARA). In FY 2023, investments in this category will enable NSF to continue implementation of the TBM framework, further enhancing the agency's ability to manage IT as a business.

Individual Directorate/Office IT Costs Outside of NSF's Central IT Budget

In an effort to increase transparency and show continuous improvement in NSF's reporting and understanding of its IT expenditures, NSF's Chief Information Officer continues to expand reporting of IT investments at NSF that are made outside of the central IT budget (AOAM IT and PRT) discussed above. Currently, NSF has identified about $5.33 million of non-central IT costs that are being actively tracked and are included in the FY 2023 IT Portfolio summary reporting. These investments are coordinated through the Division of Information Systems (DIS) in OIRM—the organization that manages NSF's central IT budget—and are realized when other NSF divisions apply their funds (either R&RA, EDU, or AOAM account funds) onto DIS vendor labor contracts for various IT-related efforts.

NSF Funding for E-Government Initiatives

The tables below show NSF's contributions and service fees for various E-Government initiatives. These costs are not part of the AOAM IT or PRT budget discussed in this narrative but are included in the agency's IT Portfolio summary reporting and mentioned here for transparency. Both the FY 2022 and FY 2023 levels are consistent with the funding amounts provided by the initiatives' respective managing partners.

NSF FY 2022 Request Funding for E-Government Initiatives

	FY 2022			Appropriations Account	
Initiative	Agency Contributions	Agency Svc. Fees	NSF Total	AOAM	R&RA
Grants.gov	$326,000	-	$326,000	-	$326,000
Geospatial LoB	25,000	-	25,000	-	25,000
E-Rulemaking	-	21,627	21,627	21,627	-
USA Jobs	-	10,399	10,399	10,399	-
Integrated Acquisition Environment (IAE)	-	719,644	719,644	21,000	698,644
Human Resources Management LoB	68,478	-	68,478	-	68,478
Hiring Assessment LoB	66,000	-	66,000	-	66,000
Financial Management LoB	139,094	-	139,094	-	139,094
Budget Formulation/Execution LoB	120,000	-	120,000	-	120,000
Total	**$744,572**	**$751,670**	**$1,496,242**	**$53,026**	**$1,443,216**

LoB: Line of Business

NSF FY 2023 Request Funding for E-Government Initiatives

	FY 2023			Appropriations Account	
Initiative	Agency Contributions	Agency Svc. Fees	NSF Total	AOAM	R&RA
Grants.gov	$325,000	-	$325,000	-	$325,000
Geospatial LoB	25,000	-	25,000	-	25,000
E-Rulemaking	-	23,474	23,474	23,474	-
USA Jobs	-	10,399	10,399	10,399	-
Integrated Acquisition Environment	-	719,644	719,644	21,000	698,644
Human Resources Management LoB	68,478	-	68,478	-	68,478
Hiring Assessment LoB	66,000	-	66,000	-	66,000
Financial Management LoB	139,094	-	139,094	-	139,094
Budget Formulation/Execution LoB	120,000	-	120,000	-	120,000
Federal Executive Board	100,000	-	100,000		100,000
Total	**$843,572**	**$753,517**	**$1,597,089**	**$54,873**	**$1,542,216**

LoB: Line of Business

ADMINISTRATIVE SUPPORT

$115,100,000
+$10,35,000 / 9.9%

FY 2023 funding for Administrative Support is $115.10 million, the third largest component of the Organizational Excellence portfolio. The activities that comprise this major component are Space Rental, Operating Expenses, Building and Administrative Services, Other Program Related Administration, and Other Organizational Excellence Activities.

Administrative Support
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Percent	Funding Source
Space Rental	$46.54	-	$33.24	-$13.29	-28.6%	AOAM
Operating Expenses	20.95	-	30.27	9.32	44.5%	AOAM
Building & Administrative Services	21.84	-	23.12	1.28	5.9%	AOAM
Other Program Related Administration	3.39	-	7.55	4.16	122.9%	R&RA/EHR
Other Organizational Excellence Activities	12.04	-	20.92	8.88	73.7%	R&RA
Total Administrative Support	**$104.76**	**-**	**$115.10**	**$10.35**	**9.9%**	
Total AOAM	89.33	-	86.63	-2.70	-3.0%	
Total R&RA	15.43	-	27.37	11.94	77.4%	
Total EDU	-	-	1.10	1.10	N/A	

Each activity within Administrative Support is addressed separately below.

Space Rental

Space Rental
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Percent
Building Rental & Taxes	$39.29	-	$25.61	-$13.68	-34.8%
Utilities	1.20	-	1.10	-0.10	-8.3%
Security	4.85	-	5.66	0.81	16.7%
Parking Rental (including parking credits)	1.20	-	0.88	-0.33	-27.1%
Total	**$46.54**	**-**	**$33.24**	**-$13.29**	**-28.6%**

[1] The Parking Rental estimate includes parking credits for the FY 2021 Actual.

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 (DHS). In addition, rent paid for the parking structure to the owner of the NSF headquarters building in Alexandria, Virginia is included. Parking credit estimates will be applied to the FY 2023 level during the current plan process when remote/hybrid work impacts are better understood.

In FY 2023, NSF will occupy over 700,000 square feet of space, primarily in one leased office building located in Alexandria, Virginia. The FY 2023 level for Space Rental is $33.24 million. This amount is in line with the base Space Rental costs in FY 2022 and FY 2021 with expected inflationary increases. In

FY 2021, NSF received supplemental funding through the American Rescue Plan (ARP) some of which NSF used to support salaries. The utilization of ARP funds to support FY 2021 salaries, along with some FY 2021 operating costs coming in less than estimated, allowed NSF to forward fund rent into FY 2022. This approach to NSF's FY 2021 budget was a key facet enabling NSF to maintain normal operations under a Continuing Resolution at the start of FY 2022 and the reason the FY 2021 Actual for Space Rental appears higher than the FY 2023 Request.

Funds are included in the FY 2023 Request to cover the expected increased cleaning costs, in accordance with GSA LA-20-06 guidelines and utilizing the latest Centers for Disease Control and Prevention recommendations for keeping a facility clean and for sanitizing an area after COVID-19 exposure, are applied to the lease as is a wage adjustment and inflation for guard services and basic building security based on the Federal Protective Service's (FPS) fee structure. Utilities and parking estimates are derived from historical billing and actual contract costs, respectively.

IT expenditures related to NSF's on-site Information Technology Data Center are included in the total FY 2023 Space Rental budget. These costs align to the TBM cost pool for "Facilities and Power." This activity is also referenced in the Information Technology narrative for transparency.

Operating Expenses

Operating Expenses
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Percent
Distributed	$8.74	-	$7.98	-$0.76	-8.7%
Science & Security	-	-	3.00	3.00	N/A
Award Monitoring	4.95	-	6.32	1.37	27.6%
Financial Management	3.34	-	5.07	1.73	51.8%
Reporting & Other	3.92	-	5.18	1.27	32.3%
Business and Operations	-	-	2.72	2.72	N/A
Total	**$20.95**	**-**	**$30.27**	**$9.32**	**44.5%**

The FY 2023 Request for Operating Expenses is $30.27 million. NSF's Operating Expenses can be categorized into six main activity areas that support the agency's operational and administrative needs and includes funding for federal FTE training, supplies, and equipment; leadership activities centered around science and security; support for a wide variety of financial management, award monitoring, and agency reporting investments; and other activities focused on innovation and continuous organizational improvement. The total estimate for Operating Expenses reinforces NSF's commitment to organizational excellence and reflects NSF's prioritization of providing mission support services levels in FY 2023 necessary for the increased NSF total appropriation and other mandated activities.

The key activities funded by NSF's FY 2023 submission for Operating Expenses include:

<u>Distributed ($7.98 million)</u>
Total Distributed AOAM funds federal FTE training, equipment, communications devices, and supplies for NSF's directorates and offices. The FY 2023 Request is based on historical NSF employee needs

and the utilization of 1,445 regular FTE. Distributed AOAM funds for travel are discussed in the Travel section of the Organizational Excellence chapter.

<u>Science and Security ($3.0 million)</u>
FY 2023 investments for activities related to Science and Security within the AOAM account will continue and build upon those initiated in FY 2022. Mainly this includes continuing to build and expand NSF's analytic capabilities to proactively identify conflicts of commitment, vulnerabilities of pre-publication research, and risks to the merit review system. The effort will include a communication hub which will coordinate with grantee institutions on specific information identified by either NSF or the institutions, as well as targeted outreach to academic associations and individual universities. The hub will also provide critically important training and information for research communities on this topic. The Chief of Research Security Strategy and Policy (CRSSP) team will provide key topical support as NSF establishes new funding opportunities in partnership with academic institutions and private organizations to evaluate the structural, political, and international dynamics that contribute to research integrity and science and security issues. The team will coordinate with other agencies in developing tools to respond to the Administration's implementation guidance for National Security Presidential Memorandum 33 (NSPM-33) on National Security Strategy for United States Government-Supported Research and Development.[1] As part of the response to NSPM-33 and to ensure clear understanding of research security issues and NSF disclosure requirements, as well as the tenets of beneficial international collaboration, the CRSSP team will continue development of training resources for its own program officers and grant management officials as well as training resources for the external research community to ensure clear understanding of research security issues including recommended actions to mitigate risks. Through separate but coordinated investments within the R&RA account, NSF will also pursue additional research security-related efforts led by the CRSSP and funded in the Integrative Activities organization similar to FY 2022. More details on the efforts funded through IA can be found in the IA narrative in the R&RA chapter.

<u>Award Monitoring ($6.32 million)</u>
This investment category supports activities related to award administration and stewardship of NSF's portfolio of STEM awards. The FY 2023 Request will ensure current services level funding for award monitoring (pre and post) and small business pre-award reviews. It also provides the necessary resources to support major research facility and mid-scale research infrastructure program monitoring and business system reviews to ensure NSF awardees are able to fulfill financial and related requirements. The increase in FY 2023 provides contractor support for pre and post award monitoring and review for new programs and activities associated with the TIP directorate initiated in FY 2022, as well as for increased programmatic investments across the agency as outlined in this FY 2023 Budget Request. Activities supported under Award Monitoring include:

- Oversight of major facilities including business systems reviews, and portfolio risk assessment.
- 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. These advanced monitoring activities help ensure NSF awards are administered in compliance with federal regulations and NSF terms and conditions. Additionally, the results of the oversight activities are leveraged for the Financial Statement Audit and support agency efforts to manage risk and continually improve grant operations.
- Major facilities audit resolution support services which are procured by NSF in response to the

[1] www.whitehouse.gov/wp-content/uploads/2022/01/010422-NSPM-33-Implementation-Guidance.pdf

American Innovation and Competitiveness Act (AICA) audit requirements and enhanced major facilities oversight activities. Additionally, financial assistance award audit services support incurred cost audits, accounting system audits, estimating system audits, and special projects that provide NSF with information that assists in the negotiation, award, administration, repricing, and settlement of major facilities financial assistance awards.
- The congressionally-mandated Committee on Equal Opportunities in Science and Engineering (CEOSE) activity. This covers contractor services and meeting support for CEOSE, an NSF advisory committee that provides advice on policies and programs to broaden participation of women, minorities, and persons with disabilities.

Financial Management ($5.07 million)
Investments in this category support NSF's financial policy and reporting activities. The FY 2023 level increases contractor support resources to maintain our financial reporting model, transactions, and financial monitoring. It will also provide increased support for planning and documentation of any needed oversight and monitoring enhancements given growth or changes in NSF's award portfolio, such as a new auditable Improper Payments Risk Assessment due to significant increases in appropriations and potential new programs and implementation of a BFA concept of operations and change management strategy to support the growth of NSF. Financial Management activities include:
- Contract staff support in BFA's Division of Financial Management (DFM) to aid in accounting operations; financial statements and external report submission; grant financial monitoring; NSF property reporting; financial systems support and internal reporting; and audit deficiencies resolution assistance. This contract support enables NSF to meet its federal financial reporting requirements and audit requirements.
- NSF's non-IT activities related to G-Invoicing, such as reconciling intragovernmental balances with federal trading partners, resolving differences between agencies, redesigning the Interagency Agreement processes and controls NSF-wide, and transitioning to Treasury's G-Invoicing system. This activity directly supports Treasury's mandate to convert all intragovernmental transactions to G-Invoicing to resolve the significant, long-standing government audit issue.
- The Data Analytics Assurance Program (DAAP), which provides internal control support to improve mission delivery and the accountability and effectiveness of NSF's federal programs and operations by establishing, assessing, correcting, and reporting on internal control through innovative uses of data analytics technology. DAAP also provides enterprise risk management support for emerging mission risks such as long-term pandemic impacts or growth scenarios related to grants oversight and monitoring. The investment in NSF's DAAP also supports Administration priorities for the Payment Integrity Information Act of 2019 (PIIA)(P.L. 116-117) and OMB Memorandum M-21-19.

Reporting and Other ($5.18 million)
This investment category supports a wide range of reporting and other activities and the FY 2023 Request reflects a current services level of funding. Investments in this category include activities such as:
- Contract writing software. The Automated Acquisition Management Solution (AAMS) is NSF's system for contract writing/E-procurement. The AAMS contract is set to expire in FY 2022, and NSF will issue a competitive solicitation to modernize its contracting writing software. NSF expects this will increase the speed of the acquisition process, facilitate the implementation of innovative contracting methodologies, ensure the selection of proper terms and conditions, efficiently adopt OMB Office of Federal Procurement Policy guidance, and ensure accurate reporting. This will allow

NSF to more effectively leverage its acquisition function to meet emerging mission needs as well as modernizing our electronic contract filing system to facilitate internal controls and oversight.

- Increased resources for contract personnel in BFA's Division of Acquisition and Cooperative Support to aid with contract execution, simplified acquisition, and database management.
- 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 federal efforts to manage data as a strategic asset. Also included is support for budget formulation capabilities and activities to better ensure Section 508 compliance and accessibility.
- Simplified acquisitions which include purchase card program oversight, contract execution, and database management. Support for oversight of the purchase card program will be supplemented with purchase card rebates, reducing the total costs to be paid from NSF's AOAM account.
- NSF in-house and contract support for grant outreach, as well as contract close-out, outreach activities, and guidance document development for NSF's major facilities. Also supported is the annual Large Facilities Workshop and associated Knowledge Sharing Gateway, which are used to coordinate the sharing of good practice and lessons learned, an agency priority related to statutory requirements under the AICA. The FY 2023 Request levels is increased to support greater outreach and information sharing with NSF's grantees and research communities.
- In FY 2023, resources are increased to continue NSF-wide implementation of changes associated with the Program Management Improvement Accountability Act (PMIAA) and recommendations resulting from the Gap analysis conducted across FY 2020 and FY 2021.
- 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.
- An interagency agreement with the Department of Interior's Business Center (IBC) for the negotiation and issuance of indirect cost rates for over half the organization of which NSF is the cognizant agency. This interagency agreement for a shared service is critical to NSF and its recipients to help ensure timely and accurate indirect cost rate agreements are established and ready to be used by all Federal funding agencies in accordance with OMB 2 CFR §200.
- Support for other Operating Expenses, including the AOAM-funded portion of the Integrated Acquisition Environment, an e-government initiative managed by the General Services Administration; 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; new tools to support data visualization and data cleanup; annual Robotic Processing Automation (RPA) licensing for NSF's financial management systems, design and printing services for NSF's annual reports including the Annual Financial Report, performance highlights brochure, and the Congressional Request.

<u>Business and Operations ($2.72 million)</u>

FY 223 Request funding for Business and Operations will enhance internal NSF systems and processes in order to provide an agile business operations environment that enables NSF to integrate and scale efforts to form and sustain new partnerships in research and innovation.

Building and Administrative Services

Building and Administrative Services
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Information Dissemination	$2.43	-	$2.81	$0.38	15.7%
Workplace Management[1]	14.02	-	13.52	-0.50	-3.6%
Panel Support, Meeting Mgmt, & Proposal Services	5.39	-	6.79	1.40	26.0%
Total	**$21.84**	**-**	**$23.12**	**$1.28**	**5.9%**

[1] Includes funding for the the operations, maintenance, and technical security requirements of NSF's Sensitive Compartmented Information Facility (SCIF).

The FY 2023 Request for building and administrative services is $23.12 million, providing the full fiscal year requirement estimated to effectively perform these three sets of activities: Information Dissemination; Workplace Management; and Panel Support, Meeting Management, and Proposal Services.

<u>Information Dissemination ($2.81 million)</u>
Investments in this category fund activities that support records management; extensive web-based and electronic information distribution tools that provide information to both NSF staff and the public; graphic design and commercial printing; and regulatory reporting processing and production. Activities include:

- Records management and the establishment and execution of records management policies and procedures. NSF continues to enhance data management practices which includes reducing records storage requirements at the Federal Records Center and the National Archives and Records Administration while transitioning to electronic records by December 2022. The requested funding level includes increased resources to enable operations and maintenance of controlled unclassified information (CUI) marking in IT systems pursuant to Executive Order 13556, Controlled Unclassified Information. The implementation of a software plugin to enable CUI markings in IT systems is expected to be completed in FY 2022.
- Communications contract support providing information to both the public and NSF staff regarding the NSF mission and related content.
- NSF website and application development and support for NSF's external website, NSF.gov.
- Graphic design including the design and creation of layouts, graphics, animation, style sheets, and color schemes for use in NSF communications in print and on the web.
- Congressional Record and Code of Federal Regulations requests for the Foundation.

<u>Workplace Management ($13.52 million)</u>
Workplace Management provides funding for a wide range of core business activities and infrastructure support related to space management and facility operations, property management, as well as security and emergency management. Investments for this category include:

- Space management and facility operations, including development of space plans and assignments, space reconfigurations, facility service and maintenance, and transportation. The FY 2023 Request supports renovation and reconfiguration to accommodate remote/hybrid staff and support increased program staff at NSF. Furthermore, it includes inclusion of a refresh of onsite building furniture and equipment reaching the end of its lifecycle to continue delivery of cutting-edge space solutions for onsite staff.

- Operations and maintenance for the Integrated Workplace Management System which supports space, workplace and move management, conference room scheduling, and asset inventory management.
- Activities related to property to include the oversight and planning of mailroom, shipping and receiving operations and property receipt, inventory, tracking, and reporting.
- Core business activities and infrastructure support related to security and emergency management, 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. Also included are cost estimates related to the operations, maintenance, and technical security requirements of NSF's Sensitive Compartmented Information Facility (SCIF).
- Enhancement of the agency sustainability program through adherence to all federal guidance, including Executive Order 14008, Tackling the Climate Crisis at Home and Abroad.
- Maintenance of the Small and Disadvantaged Business procurement system in compliance with government wide and agency socioeconomic goals.
- Commitment to the implementation of personnel vetting transformation activities under the Trusted Workforce 2.0 initiative including continuous vetting of the workforce.

<u>Panel Support, Meeting Management, and Proposal Services ($6.79 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. The FY 2023 level provides resources for these investments supporting the full estimated cost necessary to manage current services level workload requirements and maintain services for the agency. Activities include:

- Management and support of agency printing devices including copier and printer maintenance and supplies. Resources are increased in FY 2023 in anticipation of greater demand due to the creation of TIP in FY 2022 and the return of a significant portion of NSF's workforce to the building.
- Print Center services for FY 2023. For transparency, these costs are reported by NSF as part of its Information Technology portfolio Infrastructure: Output.
- Library and research assistance for the Foundation. NSF Program Directors rely on the library electronic content to understand conflicts of interest, identify panelists, search for citations, identify who is published, research innovations, and other critical merit review ancillary support.
- 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 2023 funding provides the resources necessary to schedule, coordinate, and conduct NSF's onsite and virtual meetings and panels in a post-COVID work environment. This activity also includes increased funding to mature the role of accessibility and 508 compliance at NSF in support of a hybrid operational state in FY 2023.
- Travel management services, reflecting NSF's requirement to fully support NSF staff, panelists, members of advisory committees, COVs, and guests. Transportation of household goods and relocation assistance is also covered under this activity. FY 2021 funding for this activity was unusually low due to travel restrictions related to COVID. FY 2023 funding levels are increased as NSF anticipates travel to return to normal.

Other Program Related Administration

Other Program Related Administration

(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
E-Government Initiatives	$1.37	-	$1.55	$0.18	12.8%
General Planning & Evaluation Activities	2.01	-	6.00	3.99	198.0%
Total	**$3.39**	**-**	**$7.55**	**$4.16**	**122.9%**

In FY 2023, $7.55 million for NSF's Other Program Related Administration 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.

E-Government Initiatives ($1.55 million)

The FY 2023 funding level for NSF program-supported and mission-related E-Government (E-Gov) initiatives is consistent with the FY 2023 funding amounts provided by the initiatives' respective managing partners. It also includes the addition of a new Line of Business (LoB) called the Federal Executive Board (FEB). For funding level details by LoB activity, see the *NSF Funding for E-Government Initiatives* section of the Information Technology narrative within the Organizational Excellence chapter.

General Planning and Evaluation (P&E) Activities ($6.0 million)

FY 2023 funding for general P&E activities supports investments on broad programmatic and policy matters of NSF-wide scope and benefit. This includes activities such as Renewing NSF, the verification and validation of performance information; IPA FTE in BFA and the Office of the Director; and certain costs associated with the American Association for the Advancement of Science fellowships program. The total FY 2023 funding level is based on the level of general P&E activities and projects that occurred across FY 2021 and FY 2022 to date and anticipated activities for FY 2023. The expected additional IPAs in operations offices and upward pressure on activities seeking P&E funding are driving the FY 2023 increase. The FY 2023 P&E request is an estimated level for these activities to provide a funding envelope for planning purposes; specific requests for P&E funding for specific activities will not occur until FY 2023 and may be lower than the estimate presented.

Other Organizational Excellence Activities

Other Organizational Excellence Activities
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Percent	Program Directorate/ Office
Major Facilities Admin Review and Audit	$0.98	-	$0.17	-$0.81	-82.7%	various
Public Access Initiative	1.98	-	1.75	-0.23	-11.7%	CISE
Equity and Compliance in Research	-	-	4.00	4.00	N/A	IA
Evaluation and Assessment Capability (EAC)	5.67	-	7.00	1.33	23.5%	IA
Modeling and Forecasting	-	-	3.00	3.00	N/A	IA
Planning and Policy Support	3.41	-	2.50	-0.91	-26.6%	IA
Research Security Strategy and Policy	-	-	2.50	2.50	N/A	IA
Total	**$12.04**	**-**	**$20.92**	**$8.88**	**73.7%**	

<u>Major Facilities Administrative Reviews and Audits ($170,000)</u>
NSF includes FY 2023 cost estimates of administrative reviews and audits for major facilities to be funded via the R&RA account. This estimate is based on the Annual Major Facilities Portfolio Risk Assessment conducted by staff in BFA in close coordination with cognizant program staff. Besides risk, this assessment also considers event-driven oversight activities per NSF policy, which are based, in part, on the AICA. Funding levels for the annual assessment are estimated two fiscal years out. During the current assessment period, the status of risks from the previous cycle are revisited as are the needs for oversight and monitoring. These updates are incorporated into the plans for the entire portfolio and projected funding estimates from an earlier assessment cycle often change. For FY 2023, the current level of funding estimated to be needed from the R&RA account for administrative reviews and audits of NSF's major facilities is less that than the FY 2021 Actual.

<u>Public Access Initiative ($1.75 million)</u>
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 following activities are funded out IA. Brief summaries are provided below but additional information for each can be found within the IA narrative in the R&RA chapter.

<u>Equity and Compliance in Research (4.0 million)</u>
In FY 2023, NSF will begin investing in this activity, which supports NSF's diversity, equity, inclusion, and accessibility (DEIA) activities, which will include strategic planning and implementation, training and curriculum development, stakeholder engagement, complaint processing and investigation, as well as recruitment and outreach activities.

<u>Evaluation and Assessment Capability (EAC) ($7.0 million)</u>
EAC is an integral part of NSF's operations and conducts, oversees, and engages in strategic planning of NSF's evidence-building activities, which may inform decision making. FY 2023 funding supports studies prioritized in the Agency-wide learning agenda and focused on enabling program improvements that enhance the efficacy of NSF investments.

<u>Modeling and Forecasting ($3.0 million)</u>
NSF will enhance its analytical capability in support of advancing research, improving equity in science, and securing global leadership. NSF will leverage modeling of internal and external data to generate timely and actionable insights to inform agency strategy, investments, and programmatic decisions.

<u>Planning and Policy Support ($2.50 million)</u>
Planning and Policy Support is a foundation-wide activity in the IA budget that supports select NSF-wide policy and planning activities.

<u>Research Security Strategy and Policy ($2.50 million)</u>
NSF will expand capabilities and competencies to protect the U.S. science and engineering enterprise through its Research Science Security and Policy activity. It is complementary to the Science and Security activity funded via AOAM described within the Operating Expenses section of this narrative.

OFFICE OF THE NATIONAL SCIENCE BOARD (NSB) $5,090,000

+$660,000 / 14.9%

The Appropriations Act that funds the National Science Foundation (NSF) contains a separate appropriation for NSF's National Science Board. Accordingly, this FY 2023 Budget Request identifies the resources needed to support the NSB, including amounts for personnel compensation and benefits (PC&B), contract services, training, travel, supplies, materials, and equipment.

The FY 2023 Budget Request for the Office of the National Science Board is $5.09 million, an increase of $660,000 above the FY 2021 Actuals of $4.43 million. This FY 2023 Request level will enable the NSB to fulfill its policymaking and oversight responsibilities for NSF and continue its statutory responsibilities as outlined in the NSF Act, including activities related to the authorization of major research facilities projects.

NSB Funding

(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$4.43**	**$4.50**	**$5.09**	**$0.66**	**14.9%**
Full-Time Equivalents (FTEs)	17	17	18	1	5.9%

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.), ~~$4,600,000~~$5,090,000: Provided, That not to exceed $2,500 shall be available for official reception and representation expenses.

National Science Board
FY 2023 Summary Statement

(Dollars in Millions)

	Enacted/ Request	Expired	Obligations Actual/ Estimates
FY 2021 Appropriation	$4.50	-$0.07	$4.43
FY 2022 Annualized CR	4.50		4.50
FY 2023 Request	5.09		5.09
$ Change from FY 2022 Annualized CR			$0.59
% Change from FY 2022 Annualized CR			13.1%

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 are determined through requests from Congress or the President, and as the Board identifies in consultation with the community and NSF management. Recent reports 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.

In May 2020, the Board released its *Vision 2030*[1] report, which provides a framework for Board oversight and accountability for the next decade. *Vision 2030* lays out a roadmap focused on four goals: delivering benefits from research, developing STEM talent for America, expanding the geography of innovation, and fostering a global science and engineering community. These goals align with and support Administration priorities, such as advancing equity, tackling the climate crisis, advancing management and performance to deliver results, and emphasizing evidence and evaluation in priority policy and mission areas.

In its first year of *Vision 2030* implementation, the NSB conducted more than 25 engagement activities with federal and state-level leaders as well as academic, scientific, and education organizations; met with Members of Congress and congressional committee staff; and engaged with the current and previous Administrations. It also highlighted issues related to talent, diversity, equity, and inclusion, and reaching the "Missing Millions" (i.e., people from under-represented groups in the S&E workforce) through several external panels held during NSB meetings and by engaging NSF in discussions about the agency's strategies, goals, and metrics for measuring progress in these areas. In addition, the Board worked closely with NSF leadership to ensure that the agency is ready for an increased budget,

[1] www.nsf.gov/nsb/publications/2020/nsb202015.pdf

expanded mission, and new directorate focused on technology, innovation, and partnerships (TIP), which will contribute significantly to achieving the NSB's *Vision 2030* goals of delivering benefits from research, developing STEM talent, and expanding the geography of innovation.

Structure

The Board has several standing committees 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 (OIG) 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 **Sub-Committee on Technology, Innovation, and Partnership (S-TIP)** was constituted in August 2021 to consult with the NSF Director on strategies, goals, and organizational changes to realize the agency's new TIP strategic priority and identify, for NSB discussion, relevant governance matters.

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 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.

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 OIG 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.

Financial Discussion

This FY 2023 Request will enable the NSB to fulfill its policymaking and oversight responsibilities for NSF and continue its statutory responsibilities as outlined in the NSF Act, including activities related to the authorization of major research facilities projects. The Request will enhance the Board's ability to provide strategic guidance and conduct the oversight required as NSF's budget and mission expand with a new TIP strategic focus, to engage with stakeholders, and to respond to Congressional requests.

Office of the National Science Board
Personnel Compensation and Benefits and Other Operating Expenses
(Dollars in Thousands)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actuals Amount	Percent
Personnel Compensation & Benefits (PC&B)[1]	$3,084	-	$3,800	$716	23.2%
Staff Development & Training	16	-	21	5	31.3%
Advisory & Assistance Services	1,301	-	991	-310	-23.8%
Travel & Transportation of Persons	-	-	250	250	N/A
Communications, Supplies, & Equipment	31	-	25	-6	-19.4%
Representation Costs	-	-	3	3	N/A
Total	**$4,432**	**-**	**$5,090**	**$658**	**14.8%**
Full-Time Equivalents (FTE)	17	17	18	1	5.9%

[1] PC&B includes base salary costs and anticipated within grade and promotion increases.

Personnel Compensation and Benefits

The Board's FY 2023 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 planned increases in NSB Office staff pay, including a 4.6 percent cost-of-living adjustment, and assumes in-person Board meetings and activities in FY 2023. It will allow the NSB Office to increase its staff by one additional FTE. This staffing level will enable the NSB Office to support the NSB more effectively in exercising its governance role by working with NSF to implement *Vision 2030* and advance the Administration's critical priorities, particularly with accountability related to improving diversity, inclusion, equity, and accessibility in STEM education and the S&E research workforce; measure progress towards reaching the Missing Millions; and ensure success of the new TIP directorate.

Other Operating Expenses

The Staff Development and Training budget line supports various training events such as Contracting Officer Representative (COR) training and recertification and federal leadership training for one NSBO management staff member, 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 *Indicators*. To facilitate accessibility and use of *Indicators* data in policy decisions, analysis, and assessing progress toward *Vision 2030* goals and other critical national S&E priorities, the Board creates interactive digital products, including an electronic state data tool that allows for more frequent and timely updates and state one-pagers that highlight select data by state. 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; 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. This budget line also supports website maintenance costs.

Anticipating a need for project management (PM) support due to increased Board activity with the release of *Vision 2030* and using savings accrued from the lack of NSB member travel due to COVID-19 pandemic restrictions, in FY 2020/2021, the NSB Office procured the services of a PM contractor within the Board's Advisory and Assistance Services budget line. This contract has supported the introduction of a PM software tool and capacity building among NSB Office staff to plan NSB *Vision 2030* and other activities and track progress more efficiently. The FY 2023 Request will provide the resources necessary to continue contracted PM support at 50 percent of the FY 2022 level, which would ensure more sustainable PM capacity building of staff and lead to greater support of the Board as its activities increase in line with NSF's expansion.

The NSB's Travel and Transportation of Persons budget line primarily covers costs related to Board member travel to NSF headquarters for four annual meetings and a member-only retreat, for oversight of NSF's large programs and facilities, and for engaging stakeholders. In implementing its *Vision 2030*, the Board convenes partners and stakeholders for discussions about specific action items in the Vision Roadmap and invites speakers to participate on panels at NSB meetings. These activities help disseminate the Board's vision, galvanize momentum around key NSF and Administration priorities, elevate and understand the concerns of segments of the S&E community that are often unheard, and cultivate existing and new partners. Since the beginning of the COVID-19 pandemic, the Board has conducted such activities virtually but plans to return to in-person events when circumstances allow and when cost-effective.

The Communications, Supplies, and Equipment budget line funds communications services and information technology. This budget line item includes the refreshment of IT equipment in accordance with NSF's Workstation Refresh Cycle schedule, funding of wireless equipment, and purchase of office supplies upon return to on-site facilities.

The FY 2023 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 help the NSB improve the usefulness of the resources it produces to ensure that Congress, the Administration, academia, private industry, and the public continue to have access to timely, comprehensible, and objective S&E data and policy guidance.

The Request sets aside funds that the NSB will use, if necessary, to cover costs associated with reception and representation activities connected to official NSF business, per GAO guidance.

OFFICE OF INSPECTOR GENERAL (OIG)

$23,393,000
+$5,782,000 / 32.8%

The Appropriations Act that funds the National Science Foundation contains a separate appropriation for NSF's Office of Inspector General. Accordingly, this FY 2023 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 2023 Budget Request for OIG is $23.39 million, an increase of $5.78 million over the FY 2021 Actual of $17.61 million

OIG Funding
(Dollars in Millions)

	FY 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actual Amount	Change over FY 2021 Actual Percent
Total	**$17.61**	-	**$23.39**	**$5.78**	**32.8%**
Full-Time Equivalents (FTEs)	68	79	93	25	36.8%

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 (IT) specialists. OIG's FY 2021 appropriation was just 0.21 percent of NSF's nearly $8.50 billion appropriation and just 0.04 percent of its $39.8 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. Recognizing the value of work done by OIGs, President Biden has stated that he expects executive departments and agencies to restore the integrity and independence of inspectors general and to work with them to ensure resources provided for federal relief programs are safeguarded.

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, the Office of Counsel, and the IG's Immediate Office. Highlights of the OIG's operational impact and strategic focus by functional area follow.

Appropriations Language

For necessary expenses of the Office of Inspector General as authorized by the Inspector General Act of 1978, $~~17,850,000~~23,393,000, of which $400,000 shall remain available until September 30, ~~2023~~2024.

Office of Inspector General
FY 2023 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 2021 Appropriation	$17.85	$0.40	-$0.40	-$0.24	$17.61
FY 2022 Annualized CR	17.85	0.40			18.25
FY 2023 Request	23.39				23.39
$ Change from FY 2022 Annualized CR					$5.14
% Change from FY 2022 Annualized CR					28.2%

Totals exclude reimbursable amounts.

Explanation of Carryover

Within the OIG two-year account, $400,000 was carried over into FY 2022.

Office of the Inspector General

- Amount: $400,000
- Purpose: Funds are expected to be used to procure financial and performance 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 2022 Quarter 3

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.

From FY 2017 through FY 2021, OIG audited approximately $9.30 billion in NSF funding in 31 states and Washington, D.C.—resulting in 122 audit and other engagement reports containing a total of $15.92 million in questioned costs and 995 recommendations to recover misspent funds and improve awardee and NSF operations.

In FY 2021, OA identified more than $3.70 million in questioned costs and made 256 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. NSF also took other corrective actions in FY 2021 in response to recent audits. For example, NSF updated its Standard Operating Guidance to better account for and monitor government-owned equipment purchased with award funds. This improvement made NSF a better steward of federal funds.

<u>Areas of Risk for Potential Audit Coverage in FY 2023</u>
Much of OIG's audit work is mandatory, including the annual financial statement audits, as well as

audits required by the *Federal Information Security Modernization Act of 2014,*[1] and the *Payment Integrity Information Act of 2019.* [2] For discretionary audits, OA uses a risk-based approach to identify the highest priority issues that would benefit from OIG review. Although additional areas may emerge by FY 2023, the top six current high-risk areas include:

The Antarctic Infrastructure Modernization for Science Project. The NSF Office of Polar Programs manages the U.S. Antarctic Program (USAP), through which it operates three year-round research stations and two research vessels and coordinates all U.S. science and logistical support on the southernmost continent. The Antarctic Infrastructure Modernization for Science (AIMS) project is a key component of the Future USAP. AIMS includes a series of redevelopments and upgrades to the buildings, utilities, logistics, and technology that make up the USAP stations. This work, budgeted at $90.0 million in 2021, will serve the continent's ongoing scientific mission over a 35 to 50-year planning horizon and is aimed at reducing costs, finding efficiencies, conserving energy, and supporting Antarctic science. AIMS' construction at the largest USAP facility, McMurdo Station, has been put on hold due to the COVID-19 global pandemic. There was no AIMS-related construction in McMurdo during the 2020-2021 or 2021-2022 seasons due to COVID-19 related travel restrictions and supply chain delays. NSF is currently working with the USAP contractor to re-baseline the Vehicle Equipment and Operations Center (VEOC) and Lodging Building modules of the AIMS' construction contract, with associated cost increases and possible work extending beyond the end of the current USAP contract. Additionally, NSF has identified needed investments in USAP facilities and infrastructure that cannot be deferred until after completion of the AIMS' modules and is transitioning into a broader recapitalization of Antarctic infrastructure under the Antarctic Infrastructure Recapitalization (AIR) program. In FY 2023 OA will evaluate NSF's oversight of these critical, highly visible, long-term projects and assess the adequacy of the re-baselining process.

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 the award recipient completes construction, 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. The American Innovation and Competitiveness Act (P.L. 114–329),[3] requires NSF to address divestment as part of the lifecycle plans for its major facilities. At a time of rising costs, divestment is an essential part of NSF's responsibilities for managing its major facilities. OA is assessing the adequacy of NSF's processes for prioritizing, planning for, and managing divestment of its major facilities.

Public-Private Partnerships. NSF plans to scale up public-private partnerships agency-wide. Some of these partnerships share the following characteristics: industry review or participation in part of the merit review process; joint (but distinct) funding by NSF and industry; and industry funders' participation as advisors and fellow researchers at awardee universities if universities permit. Potential risks of these partnerships include conflicts of interest; proposals tailored to accommodate specific companies' needs; cultural differences; reputational damage; and inadequate controls over

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[1] www.congress.gov/113/plaws/publ283/PLAW-113publ283.pdf
[2] www.congress.gov/116/bills/hr5389/BILLS-116hr5389ih.pdf
[3] www.congress.gov/114/plaws/publ329/PLAW-114publ329.pdf

company employees working with university researchers. OA plans to assess the effectiveness of NSF's oversight of public-private partnerships, including operations at selected awardees.

Mid-scale Research Infrastructure. In its FY 2022 Budget Request, NSF requested about $180 million for mid-scale projects agency wide. These projects, which cost between $6.0 and $100.0 million, include research instrumentation, equipment, and upgrades to major research facilities or other research infrastructure investments. NSF's *Major Facilities Guide*[4] provides guidance for these projects. OA may review management requirements in mid-scale solicitations, controls for mid-scale projects, and training and experience of NSF staff responsible for making and providing oversight of mid-scale awards.

NSF's Oversight of Awardee Compliance with Harassment Policies. NSF added an award term and condition, effective October 22, 2018, requiring awardees to notify the agency of harassment based on ethnicity, race, gender, or disability, among other categories, on NSF awards. In response, NSF indicates that it has received about 1.5 notifications a month. NSF's Office of Equity and Civil Rights receives the notifications and works with NSF staff to evaluate the notifications and determine the appropriate course of action. NSF's current *Proposal and Award Policies and Procedures Guide* (PAPPG)[5] states that "NSF expects all research organizations to establish and maintain clear and unambiguous standards of behavior to ensure harassment-free workplaces wherever science is conducted." It further requires awardees to notify NSF if senior personnel have violated the institution's harassment rules or if the institution imposes an administrative action against senior personnel related to a harassment finding or claim. Our audit or audits will evaluate NSF's policies regarding harassment and its oversight over institutions and selected awardees.

Hybrid NSF Workforce. As a result of the COVID-19 pandemic, NSF will likely be managing a hybrid workforce in FY 2023, which will require support for both on-site and remote workers. This development will create new individual and collective risks for NSF management. To assess NSF's response to these risks, OA envisions audits on topics such as the adequacy of NSF's IT infrastructure; utilization of space at the Alexandria headquarters; management of personnel hiring, supervision, and retention; structure and location of merit review panels; and controls over the award lifecycle and NSF's assets.

<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 to provide this much-needed audit coverage over the recipient community. The coverage of each of these audits at recipients ranged from $9.8

[4] www.nsf.gov/pubs/2019/nsf19068/nsf19068.pdf

[5] www.nsf.gov/pubs/policydocs/pappg20_1/nsf20_1.pdf

million to $440.0 million from 2017 to 2021. Beyond the findings specific to the institutions being audited, these audits may identify evidence of behavior that could violate criminal or civil laws, which OA would refer to the Office of Investigations. Additionally, these audits may identify inconsistent treatment of similar charges across the academic community, which OA would share with NSF staff so they could address the inconsistencies. 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. OA will also conduct multiple 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. OI also evaluates and investigates allegations of research misconduct—data fabrication, data falsification, and plagiarism—related to NSF-funded research, and investigates allegations of whistleblower retaliation. 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, research misconduct, and other wrongdoing.

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 the high-risk status of the program or institution. From FY 2017 through FY 2021, OI's investigative oversight of NSF's multi-billion-dollar award portfolio included 645 investigations spanning 50 states and the District of Columbia, as well as Puerto Rico and Antarctica. OIG investigations—civil, criminal, and administrative—led to financial recoveries to the federal government of more than $40 million during this period. Investigators also helped protect NSF research funds through 47 debarments of individuals and entities, 14 voluntary exclusions of individuals, 22 award suspensions, and 17 award terminations. More than 290 other administrative actions, such as reprimands; directed remedial training, certifications, and assurances in communications with NSF; and prohibitions from serving as an NSF reviewer, advisor, or consultant, have also resulted from OI work during this time. Investigative staff also worked with NSF to remedy numerous administrative practices and procedures that insufficiently protected the integrity of NSF funding processes.

<u>Research Security Plan Investigations</u>
OI continues to be a leader in the response to 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 enterprise. In FY 2018, OI initiated its first criminal investigations focused on potential fraudulent application for and misuse of NSF funding by members of foreign talent plans. The volume and complexity of such investigations has steadily increased through FY 2021. These complicated investigations now account for over half of OI's workload.

Although China is not the only foreign government exploiting the openness of American universities, many of our research security investigations concern Chinese talent plans. OI has confronted this national security threat in several ways. In addition to dedicating a significant portion of investigative resources to these investigations, in FY 2019 OI hired an analyst to perform immediate, onsite translation of Chinese documents. Within one month the analyst saved OIG more than the FTE salary in translation costs. The addition of this FTE has been a force multiplier; knowledge of the cases and ability to quickly bring matters to the attention of the investigators saved months of investigative time and greatly increased investigation efficiency. OI has also adopted new analytical tools to enhance efficiencies in research and data correlation efforts. OI's investigative work on these cases has resulted in award suspensions and terminations, recoveries of NSF funds, and many referrals to the U.S. Attorney's Office for prosecution.

In addition to conducting research security investigations, OI also:

- Founded and now serves as co-leader of a Council of the Inspectors General on Integrity and Efficiency (CIGIE) Working Group, which informs and assists investigative colleagues with threat identification, case predication, and best practices in conducting research security 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.
- Conducts outreach and provides education to NSF, which has resulted in the issuance of new or amended agency advisories and policies to address the threat, including an express prohibition of talent plan members serving as federal employees or Intergovernmental Personal Act (IPA) rotators, requiring IPA rotators to be U.S. citizens, and increasing disclosure requirements for researchers seeking NSF funding.
- Supports the operation of a Sensitive Compartmented Information Facility (SCIF) at NSF to enhance the efficiency and effectiveness of research security investigations by facilitating essential communication and coordination with investigative partners across the government.

<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. With NSF's total active SBIR/STTR awards now approximately $590.0 million, protecting SBIR/STTR funds from fraud and abuse remains a significant concern for OI. 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, which provides guidance to the small business community on how to properly handle federal funds and the consequences of not following the rules. In addition, OI has led an OIG community working group focused on fraud in these programs to share best practices and lessons learned. OI's efforts have produced significant programmatic improvements and enhanced understanding throughout the research community. As a result, there has been a substantial decrease in the number of allegations, investigations, prosecutions, and recoveries relating to SBIR/STTR. This great success in identifying and resolving a significant threat to federal research funding provides a model for our posture towards research security investigations and other emerging threats.

Support Offices' Actions and Impacts

<u>Office of Management</u>

OIG's Office of Management (OM) is responsible for directing OIG's financial management, procurement, and administrative functions, as well as managing the OIG Hotline operation. Working in partnership with the other OIG divisions, OM guides the strategic vision of the OIG and ensures that all operational needs are met. Critical functional areas include:

Human Capital. Having a strong human capital strategy is vital to the success of any organization. OIG's competitive advantage has long been its highly skilled staff. Expediting the onboarding process, finding ways to improve employee retention, developing leaders from within, and providing specialized training are all OM priorities. Recent adoption of a fully automated Performance Management system has allowed supervisors to spend less time on administrative tasks and more on providing direct guidance to their employees.

Information Technology. OM strives for continuous process improvement. Investment in IT plays a critical part in achieving that goal. From providing recommendations to senior management on modernization to protecting OIG information systems and data to handling day-to-day hardware and software issues, OM supports all aspects of IT for OIG.

Data Analytics. Every year, the amount of data that is received is exponentially growing and being able to analyze it efficiently is a core component of OIG's ability to provide effective oversight. To that end, OM employs an in-house forensic accountant to assist OI in managing the large amounts of information that investigators receive through subpoenas and other means. Moreover, OM utilizes data analytics to streamline internal processes such as procurement oversight and budget execution. These applications yield great efficiency and allow OIG management to make more informed decisions.

Office of Counsel

The Office of Counsel (OC) consists of the Counsel to the IG and two assistant counsels. It provides comprehensive legal advice and critical analysis to the IG and all OIG offices, including legal review of externally issued OIG work products and correspondence. OC handles a myriad of subject areas, including audit-related support, ethics, appropriations law, contract law, information disclosure, privacy, federal personnel law, and IG Act authorities. OC also supports the larger IG community through active participation in CIGIE projects and committees. On average, OC handles about 250 actions per year, including legal sufficiency reviews of reports and other externally focused documents, proposed procurements; Freedom of Information Act (FOIA) 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 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. The Chief of Staff handles all matters relating to external affairs, including congressional relations and 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 began serving as the Chair of the Council of the Inspectors General for Integrity and Efficiency in January 2021, having served as the vice chair of CIGIE since 2015.
- 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:
    - Prevent fraud within the SBIR/STTR programs;

- Increase the use of government-wide suspension and debarment as tools to deter and reduce instances of fraud, waste, and abuse;
- Foster the next generation of senior investigative leaders within the IG community; and
- 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 2021 Actual	FY 2022 (TBD)	FY 2023 Request	Change over FY 2021 Actuals	
				Amount	Percent
Personnel Compensation & Benefits[1]	$14,311	-	$20,249	$5,939	41.5%
Travel & Transportation of Persons[2]	11	-	270	259	2418.4%
Advisory & Assistance Services[3]	2,322	-	1,976	-347	-14.9%
Rent[4]	326	-	-	-326	-100.0%
Information Technology	178	-	205	27	15.3%
Communications, Supplies, Equipment, and Other Services	464	-	693	229	49.5%
Training	*269*	-	*255*	*-14*	*-5.4%*
Other [5]	*137*	-	*354*	*217*	*159.2%*
CIGIE Assessment [6]	*58*	-	*84*	*26*	*45.9%*
Total	**$17,611**	**-**	**$23,393**	**$5,782**	**32.8%**
Full-Time Equivalents	68	79	93	25	36.8%

[1] FY 2023 includes the addition of 25 FTE over FY 2021 (or 14 FTE over FY 2022), an anticipated 4.6 percent COLA, and expected within grade increases.

[2] OIG anticipates travel will return to pre-pandemic levels by FY 2023.

[3] This line includes the costs of the annual financial statements audit and the outsourcing of contracting services.

[4] In FY 2021, OIG closed a field office in Denver, CO.

[5] Other Services includes the cost for Sensitive Compartmented Information Facility (SCIF), which began construction in FY 2022.

[6] In FY 2023, the CIGIE assessment is expected to increase from 0.33% to 0.36% of OIG's appropriation.

FY 2023 Budget Request

Our FY 2023 Budget Request represents a 32.8 percent increase over the FY 2021 Actual. This increase will ensure the continuation of robust oversight of NSF's programs and activities as well as the expansion of our efforts in multiple high-risk and emerging areas of concern.

Specific Impact on the Office of Audits

OA would be able to increase staff by five FTE to expand staffing for oversight of high-risk areas:

- Two auditors to conduct proactive audits, including ones focusing on controls which can prevent talent plan members from engaging in fraudulent or other criminal activity. This area will require continual auditing to identify and respond to the evolving approaches used by adversaries.
- One additional certified information systems auditor to enhance OIG's ability to respond to the complexities of ever-evolving IT systems and the risks posed by increasing reliance on those systems to provide accurate and timely information to decision makers. This need will continue to increase as NSF implements the major AIMS project, which includes significant changes to the USAP IT network.

- Two additional auditors to conduct internal reviews of NSF programs in the high-risk areas identified, including AIMS, public-private partnerships, the move to a hybrid NSF workforce, and expansion of NSF funding to institutions with less grant experience to reach the "missing millions".[6]

OA would have sufficient funds to procure external audits focused on critical issues affecting NSF and its recipients. Among other things, OIG could dedicate resources to outreach and oversight of smaller recipients and others with less experience managing federal awards. Interaction with these types of organizations allows NSF OIG to share lessons learned and best practices through presentations to institutions and research administration communities of practice and capstone reports that help organizations identify ways to reduce administrative burden and effectively and appropriately manage federal funds. In addition to enhancing OIG's staff audit capability, this funding level allows OIG the critical flexibility to extend its oversight of NSF programs and awards.

Funding at this level would ensure that OA staff will be able to perform essential onsite fieldwork at auditees across the U.S. and NSF facilities in Antarctica. Given the significant revisions the pandemic caused to NSF's plans for infrastructure improvements to NSF's facilities in Antarctica, there is a heightened need for OIG to independently review plans and implementation there in order to provide independent insights to NSF, Congress, and taxpayers.

OIG will also maintain the current level of contractor support for audits of NSF's annual financial statements and IT security and have flexibility if new statutory mandates come into being.

<u>Specific Impact on the Office of Investigations</u>
OI would be able to increase staff by six FTE:

- Three criminal investigators: one senior investigator to address planning, policy, and proactive initiatives; and two mid-level investigators to conduct increasingly complex research security investigations as well as essential proactive reviews of higher-risk programs and operations.
- Two investigative attorneys to provide essential legal support during investigations, resulting in additional referrals to DOJ for civil and criminal prosecution, increased expertise in whistleblower protection and retaliation claims, and more robust investigation of the impact of foreign influence on the U.S. research enterprise. In addition, these investigative attorneys will reduce the number of cases to which the head of the investigative legal team is assigned, resulting in greater and more effective management of this critical staff section.
- One junior general investigator/analyst to provide critical investigative and administrative support and assistance to all of the units within OI.

Staffing at this level will provide for expanded oversight of current NSF programs and operations and help reduce per-agent caseloads to manageable levels. It will also allow OI to address the increasing number of research security investigations, which have grown dramatically and now account for more than 50 percent of investigative work. It will allow OI to engage in proactive efforts designed to uncover significant wrongdoing as well as the identification and resolution of systemic weaknesses in NSF programs. Return to this critical mission will enhance OI's ability to assess and address a wide range

[6] NSF leadership and the National Science Board define "missing millions" as those who are yet to be engaged for the science, technology, engineering, and mathematics (STEM) workforce so that it reflects the racial, ethic, and gender representation in the general population.

of high-risk programs and recipients of NSF funds. This staffing level also enables OI to conduct critical outreach to the research community that serves the interests of NSF and the U.S. research enterprise.

Funding at this level will enable OIG investigative teams to conduct the full spectrum of investigative actions including interviews, execution of search warrants, and participation in trial activities. OI will also be able to support the training and professional development necessary to recruit, build, and retain a professional staff, including training necessary for responsible succession planning.

Specific Impacts on the Office of Management and Office of Counsel
OM will have the ability to ensure timely refresh of aging IT equipment, renewal of software licenses, and invest in new technologies and platforms as they become available. OM will continue to invest in new applications, particularly in the areas of analytics, automation, and presentation, that increase efficiency and reduce time spent by managers on administrative tasks. OM will also be able to expand the use of collaborative workspace tools as the need for shared information grows.

OM and OC would hire an additional three FTEs as follows:

- One data analyst/IT specialist to increase the knowledge base and skillsets within OM to support the growing use of data analytics, sophisticated software tools, and increasingly complex applications, and the demand for timely evaluation of emerging technologies as they become available.
- One human resource specialist/management analyst to provide targeted support for the rising number of personnel actions stemming from high attrition rates and the growing size and complexity of the OIG workforce.
- One senior attorney in the Office of Counsel to provide critical legal support to the OIG, including: developing a Privacy Act System of Records Notice that would allow OA to gather and analyze personal data (e.g., to support oversight in the research security area or to examine diversity of merit review panels); undertaking comprehensive research projects and draft papers that shed light on ambiguous, but important, oversight topics; mitigating legal risks across OIG activities through sustained and more frequent proactive measures (training, regular legal updates, greater participation in key meetings); and ensuring transparency of OIG information by reducing processing times for responses to FOIA requests.

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, OIG submits the following summary:

- NSF OIG's FY 2023 Budget Request is $23.39 million.
- The portion for training is $255,000.
- The portion for operation of the CIGIE is $84,000.[7]

The portion of the FY 2023 Budget Request for staff training is expected to suffice for all training needs in FY 2023.

[7] This is an estimate of CIGIE's annual membership assessment, which is tied to each member OIG's annual appropriation.

PERFORMANCE AND MANAGEMENT

For definitions of common acronyms used throughout NSF's FY 2023 Budget Request, see the NOTES found at the beginning of the entire document on pages iii-iv.

NSF PERFORMANCE FRAMEWORK

Per the Government Performance and Results Act (GPRA) Modernization Act of 2010,[1] this chapter, together with the Overview, contains basic information about the National Science Foundation's (NSF's) mission and Strategic Plan, as well as NSF's fiscal year (FY) 2023 Annual Performance Plan and FY 2021 Annual Performance Report. Information about NSF's performance can also be found on the NSF website in the FY 2021 Performance and Financial Highlights Report.[2]

FY 2022-2026 Strategic Plan Framework: Strategic Goals and Objectives

Alongside this FY 2023 Budget Request to Congress, NSF releases its new Strategic Plan for FYs 2022-2026: *Leading the World in Discovery and Innovation, STEM Talent Development, and the Delivery of Benefits from Research*. The four strategic goals in this plan are built upon four themes—Empower, Discover, Impact, and Excel—that form the core of the plan. These themes focus on expanding frontiers, engaging people, and delivering solutions. Under each goal are two Strategic Objectives, which together encompass all areas of agency activity. This goal structure enables NSF to link its investments to longer term outcomes.

FY 2022-2026 Strategic Framework, Strategic Goals, and Objectives

Strategic Goal	Strategic Objective
1. Empower: Empower STEM talent to fully participate in science and engineering	**1.1 Ensure accessibility and inclusivity –** Increase the involvement of communities underrepresented in STEM and enhance capacity throughout the nation.
	1.2 Unleash STEM talent for America – Grow a diverse STEM workforce to advance the progress of science and technology.
2. Discover: Create new knowledge about our universe, our world, and ourselves	**2.1 Advance the frontiers of research –** Accelerate discovery through strategic investments in ideas, people, and infrastructure
	2.2 Enhance research capacity – Advance the state of the art in research practice
3. Impact Benefit society by translating knowledge into solutions	**3.1 Deliver benefits from research –** Advance research and accelerate innovation that addresses societal challenges
	3.2 Lead globally – Cultivate a global science and engineering community based on shared values and strategic cooperation
4. Excel: Excel at NSF operations and management	**4.1 Strengthen at speed and scale –** Pursue innovative strategies to strengthen and expand the agency's capacity and capabilities
	4.2 Invest in people – Attract, empower, and retain a talented and diverse NSF workforce

[1] The GPRA Modernization Act of 2010 is Public Law 111-352 and is available at: www.congress.gov/111/plaws/publ352/PLAW-111publ352.pdf

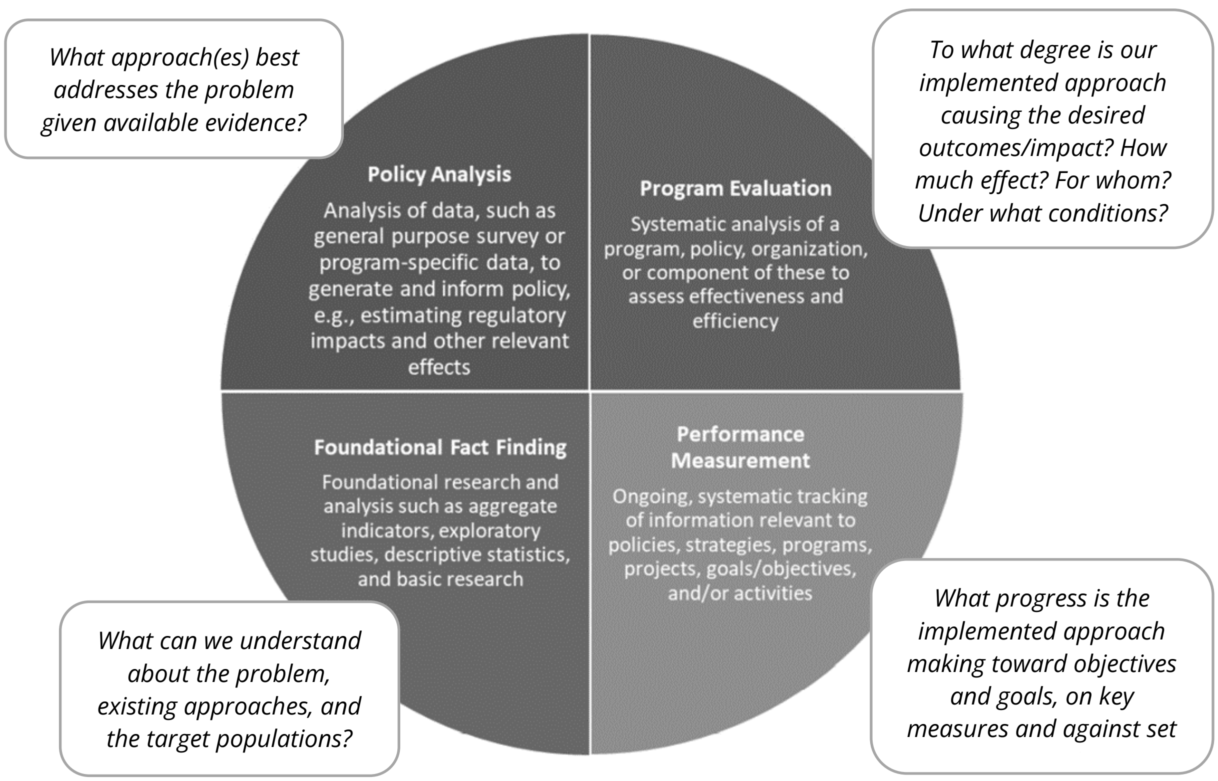
[2] FY 2021 Performance and Financial Highlights Report is available at www.nsf.gov/about/performance/annual.jsp

Integration of Performance and Evaluation

Throughout the development of this Strategic Plan, NSF has recognized that valuable synergies could be realized through greater integration of its assessment activities, such as its performance and evaluation assessment activities. NSF is now taking steps that build on the natural synergies in these areas and that capitalize on their relative strengths and complementary approaches. This is reflected in the FY 2022-2023 Annual Performance Plan, which outlines how NSF is expanding its view of performance to incorporate multiple types of evidence available at different timescales. Our approach leverages key aspects of the GPRA Modernization Act of 2010 (notably tools such as Agency Priority Goals and Strategic Reviews that enable agencies to think beyond annual output measures when designing performance targets) and the Evidence Act, which introduced a framework for types of evidence and placed performance monitoring as one of four components.

This framework incorporates the four evidence types described in OMB guidance on implementation of the Evidence Act.[3] This guidance defines four types of information used for Evidence Building: Foundational Fact Finding, Policy Analysis, Performance Measurement and Program Evaluation.

Components of Evidence[4]
(Presented in OMB M-19-23 and M-21-27)



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[3] OMB Memorandum M-21-27 "Evidence-Based Policymaking: Learning Agendas and Annual Evaluation Plans" may be accessed at www.whitehouse.gov/wp-content/uploads/2021/06/M-21-27.pdf;
OMB Memorandum M-19-23 "Phase 1 Implementation of the Foundations for Evidence-Based Policymaking Act of 2018: Learning Agendas, Personnel, and Planning Guidance" may be accessed at www.whitehouse.gov/wp-content/uploads/2019/07/M-19-23.pdf

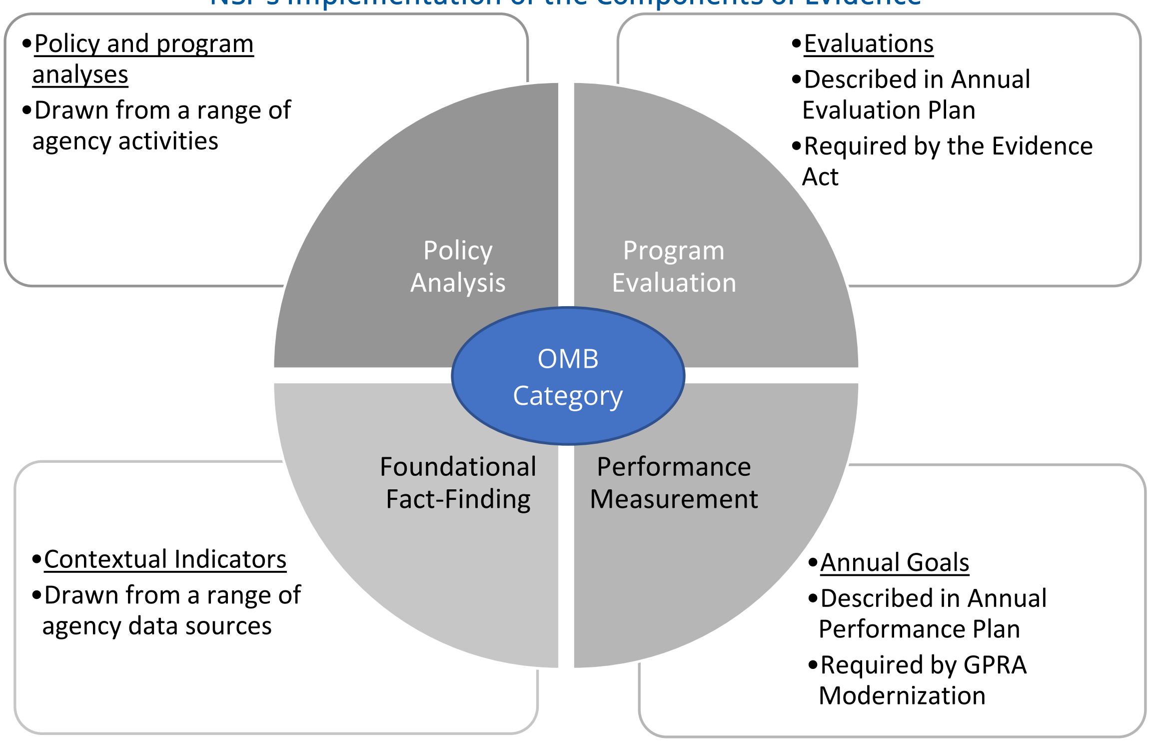
[4] OMB Memorandum M-21-27, www.whitehouse.gov/wp-content/uploads/2021/06/M-21-27.pdf

The Annual Performance Plan presented in this chapter includes goals, indicators, and other information that relate directly to these four categories:

- Annual Goals are included in the "Performance Measurement" category of evidence and answer the question, "What progress is the implemented approach making toward objectives and goals, on key measures and against set targets?"
- Contextual Indicators are included in the "Foundational Fact Finding" category of evidence and answer the question, "What can we understand about the problem, existing approaches, and the target populations?"
- Evaluations are included in the "Program Evaluation" category of evidence and answer the questions, "To what degree is our implemented approach causing the desired outcomes/impact? How much effect? For whom? Under what conditions?
- In the context of this Annual Performance Plan, Policy and Program Analysis reflect the "Policy Analysis" category of evidence, and answer the question, "What approach(es) best addresses the problem given available evidence?"

This multi-faceted framework will help to highlight how science and engineering research and education generate a dynamic set of impacts and benefits, and it will also provide valuable information and insights for strengthening NSF's programs and investments.

NSF's Implementation of the Components of Evidence



FY 2022-2023 ANNUAL PERFORMANCE PLAN

This Annual Performance Plan is the first under NSF's FY 2022-2026 Strategic Plan *Leading the World in Discovery and Innovation*, *STEM Talent Development, and the Delivery of Benefits from Research.*[1] The Strategic Plan presents NSF's overall strategies for achieving each Strategic Goal and Objective. The FY 2022-2023 Annual Performance Plan includes additional targeted goals and contextual indicators to assess performance against the FY 2022-2026 Strategic Plan and describes supporting or related activities and evaluations.[2]

Alignment of Annual Goals and Contextual Indicators with the FY 2022-2026 Strategic Plan

Vision	A nation that leads the world in science and engineering research and innovation, to the benefit of all, without barriers to participation.			
Strategic Goals	Empower	Discover	Impact	Excel
Strategic Objectives	Ensure Accessibility and Inclusivity	Advance the Frontiers of Research	Deliver Benefits from Research	Strengthen at Speed and Scale
	Unleash STEM Talent for America	Enhance Research Capability	Lead Globally	Invest in People
Annual Goals	• **Annual Goal 1:** Improve representation in the scientific enterprise (Agency Priority Goal)	• **Annual Goal 2:** Ensure that Major Facility Infrastructure Investments are on Track • **Annual Goal 3:** Ensure that Mid-Scale Infrastructure Investments are on Track	• **Annual Goal 4:** Grow Partnerships	• **Annual Goal 5:** Provide robust and reliable IT services • **Annual Goal 6:** Implement the Human Capital Operating Plan • **Annual Goal 7:** Foster a Culture of Inclusion
Cross Cutting Annual Goals	• **Annual Goal 8:** Make Timely Proposal Decisions • **Annual Goal 9:** Ensure Key Program Investments are on Track (ARP Funding)			
Contextual Indicators	Empower		Impact	
	• NSF funding to Minority Serving Institutions		• Number and diversity of entrepreneurs participating in I-Corps™ • Awards with international collaborations	
	• Ensure Key Program Investments are on Track (Budget Themes)			

With the FY 2022-2023 Annual Performance Plan, NSF is expanding its view of performance to incorporate multiple types of evidence available at different timescales. This approach is informed by

[1] NSF's FY 2022-2026 Strategic Plan is available at https://www.nsf.gov/about/performance/strategic_plan.jsp.

[2] The FY 2021 Annual Performance Report, which reports on goals and targets under the prior strategic plan, is presented separately in this chapter; future Annual Performance Reports will be combined with the Annual Performance Plan.

external NSF advisory panels that have suggested a more holistic approach, as well as:

- the GPRA Modernization Act of 2010, which created new tools such as Agency Priority Goals and Strategic Reviews that enable agencies to think beyond annual output measures when designing performance targets; and
- the Evidence Act of 2019, which introduced a framework for types of evidence and placed performance monitoring as one of four components.

As described in the Framework section of this chapter, this Plan focuses on four categories of evidence that are designed to gauge NSF's progress against the goals and objectives in the agency's strategic plan:

- Annual Goals: the ongoing monitoring and reporting of quantitative measures with defined targets.
- Contextual Indicators: quantitative data that describes what we know about a particular program, organization, policy, or population. Contextual indicators do not include targets for expected outputs or outcomes
- Evaluations: systematic analysis of a program, policy, organization, or component of these to assess effectiveness and efficiency.
- Policy and Program Analysis: analyses of data to generate and inform policy and decision-making.

The table below further describes these evidence categories and highlights how they are reflected in the framework for assessing progress against NSF's strategic goals and objectives.

Evidence Types for Measuring NSF Performance

Annual Goals: ongoing monitoring and reporting of quantitative measures with defined targets.
• Annual Goals focus on questions about the progress the implemented approach is making toward objectives and goals, on key measures, and against set targets. Examples of Annual Goals: • Output measures such as Annual Goal 8, "Make Timely Proposal Decisions," and Annual Goal 2, "Ensure that Major Facility Infrastructure Investments are on Track." • Quantitative elements and milestones related to information technology and human capital operating plans, such as those included in Annual Goals 5 and 6.
Contextual Indicators: quantitative data that describes what we know about a particular program, organization, policy, or population. Contextual indicators do not include targets for expected outputs or outcomes.
• Contextual Indicators are a valuable tool for foundational fact finding, and in this plan they enlighten our understanding of specific problems and challenges, target populations, and existing approaches to an area or issue of interest. Examples of Contextual Indicators: • NSF's Merit Review Reports, which include data on proposals and awards, including the number and funding rate for proposals, and demographic data on proposers and awardees, among other information on NSF's merit review process.[3] • Reports and analyses developed by The National Center for Science and Engineering Statistics,

[3] NSF's Merit Review Reports can be found at www.nsf.gov/nsb/publications/pubmeritreview.jsp

notably the biennial report, *Science and Engineering Indicators,* which includes data on the state [4]

Evaluations: systematic analysis of a program, policy, organization, or component of these to assess effectiveness and efficiency.

- This category of evidence incorporates structured approaches, notably NSF's Learning Agenda and Annual Evaluation Plan. These activities seek to answer questions such as: to what degree is our implemented approach causing the desired outcomes/impact? How much effect? For whom? Under what conditions?

Examples of Activities

- Examples of evaluations may be found in the Annual Evaluation Plan, which lists topics for evaluation intended to answer questions identified by NSF.[5] The Learning Agenda includes additional questions that may inform future evaluations.[6]
- The Learning Agenda includes *Guiding Questions* that apply to NSF's strategic goals and objectives, and these are highlighted throughout the APP.
- NSF's long-standing Committee of Visitors process, also applies to this category, as it assesses the quality and integrity of program operations.[7]

Policy and Program Analysis: analyses of data to generate and inform policy.

- In the context of this Annual Performance Plan, the Policy and Program Analysis category focuses on decision-making and on which approaches best address a given problem or challenge, given the available evidence.

Examples of Policy and Program Analysis

- Topical Reviews, a subset of Strategic Reviews that measure progress made toward Strategic Plan Goals and Objectives. Topical Reviews leverage cross-NSF teams to assess issues or problems and make recommendations for improvement.
- NSF reports progress made on Management Challenges identified by the Office of Inspector General (OIG) annually in the Agency Financial Report.[8] Teams of NSF staff use root cause analyses, risk management assessments, and other tools to develop action plans and direct efforts in these areas.

The Annual Performance Plan includes illustrative examples of each type of evidence under each Strategic Goal description, as well as the *Guiding Question* from NSF's Learning Agenda, to provide context beyond our targeted performance goals. NSF's Learning Agenda contains a set of specific questions to help NSF assess progress on the strategic objectives listed under each Strategic Goal. The plan does not contain an exhaustive list of all activities and evaluations NSF will use to assess performance in advancing the goals and objectives of the Strategic Plan.

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[4] *Science and Engineering Indicators* may be accessed at https://ncses.nsf.gov/indicators.
[5] NSF's Annual Evaluation Plan for FY 2022 can be found at www.evaluation.gov/agencies/national-science-foundation under "Annual Evaluation Plan."
[6] NSF's Learning Agenda is available at www.nsf.gov/od/oia/eac/products.jsp
[7] Information on NSF Committee of Visitors reviews is available at www.nsf.gov/od/oia/activities/cov/
[8] For more information on NSF's progress reports on OIG's Management Challenges, see Appendix 3 of the Agency Financial Report www.nsf.gov/pubs/2022/nsf22002/index.jsp

Strategic Goal 1, Empower

Empower STEM talent to fully participate in science and engineering

People are the core of America's scientific progress, and science and engineering are key to the nation's economic progress. To accelerate the advancement of discovery and learning, to prepare for a world in which work is increasingly reliant upon scientific and technological skills, and to ensure that all citizens share in the benefits that flow from research, we must promote inclusion in the research community and science, technology, engineering, and mathematics (STEM) workforce, access to STEM learning and training, and widespread STEM literacy.

Evidence Types for Strategic Goal 1, Empower

Annual Goal

- Annual Goal 1: Improve representation in the scientific enterprise **[Agency Priority Goal].**

Contextual Indicator

- NSF funding to Minority Serving Institutions (MSIs)

Evaluations

The Learning Agenda Guiding Question that will inform NSF's evidence strategy for Goal 1 is: "How can NSF grow STEM talent and opportunities for all Americans most equitably?" Specific questions to be address through studies described in the Learning Agenda include:

- How can NSF help increase the participation of underrepresented groups in the STEM workforce? [planned evaluation]
- In what ways did the COVID pandemic influence the participation of different groups in the NSF portfolio of programs and activities? [planned evaluation]
- How can NSF help reduce and ultimately eliminate harassment in federally funded research settings? [planned evaluation]
- How could the data system developed for the Research Experiences for Undergraduates (REU) Sites program be leveraged to improve prospective monitoring of characteristics of participants in research experiences supported by other NSF programs and study the impact of research experiences on STEM outcomes, such as educational attainment? [planned evaluation]

Policy and Program Analysis

- Topical Strategic Review of the STEM workforce which highlighted important steps NSF has taken to address longstanding disparities throughout the STEM enterprise and recognized continued challenges, as identified in recent Executive Orders and the National Science Board's *Vision 2030* report.[9] [FY 2021 activity]

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[9] Executive Order 13985 , "Advancing Racial Equity and Support for Underserved Communities Through the Federal Government," may be viewed at www.federalregister.gov/documents/2021/01/25/2021-

- NSF's response to the OIG's Management Challenge, "Increasing Diversity in Science and Engineering Education and Employment."[10] [FY 2021 and future activity]
- NSF is currently undertaking a pilot to improve its understanding of the demographics of principal investigators by requiring responses to demographic information questions on Research.gov; users have the ability to select "Do Not Wish to Provide" but may not opt out of answering.
- Analyses of data related to applications for, and participants in, the Research Experiences for Undergraduates (REU) program, including demographic, educational attainment, and attendance at a minority serving institution. These data will allow NSF to gauge its reach in providing opportunities across diverse populations.[11] [ongoing activity]

01753/advancing-racial-equity-and-support-for-underserved-communities-through-the-federal-government. Executive Order 14035, "Diversity, Equity, Inclusion, and Accessibility in the Federal Workforce," may be viewed at www.federalregister.gov/documents/2021/06/30/2021-14127/diversity-equity-inclusion-and-accessibility-in-the-federal-workforce. The National Science Board's *Vision 2030* report is available at www.nsf.gov/nsb/NSBActivities/vision-2030.jsp

[10] For more information on OIG's Management Challenge and NSF's response, see the FY 2021 Agency Financial Report www.nsf.gov/pubs/2022/nsf22002/toc.jsp Appendices (OI)-40.

[11] More information on the REU program can be found at www.nsf.gov/crssprgm/reu/.

Strategic Objective 1.1 – Ensure accessibility and inclusivity. Increase involvement of communities underrepresented in STEM and enhance capacity throughout the nation.

Annual Goal 1: Improve representation in the scientific enterprise **[Agency Priority Goal]**

Goal Statement**:** Increase both the number and proportion of proposals received from underrepresented and underserved 1) investigators and 2) institutions.

Target and Results:

	FY 2021	**FY 2022**	**FY 2023**
Target	N/A	Establish baseline	Increase by 10 percent over baseline.
Result			

Among the awards NSF makes annually, the proportion of awards to investigators from underrepresented groups is not on par with their representation in the STEM workforce, which in turn is below the relative proportions of the total population. Internal analyses indicate that investigators from underrepresented groups do well in the merit review process, and that this gap originates at the application level—proposals submitted to NSF do not reflect the diversity of the STEM workforce (let alone the population as a whole). The aim of this APG is to improve representation in the scientific enterprise by pursuing actions that will lead to an increase in proposal submissions from underrepresented and underserved applicants and communities, including both individual principal investigators and institutions.

Data Collection and Reporting: Data for this goal will be collected through the various administrative systems of record used to manage the receipt of project proposals.

Strategic Objective 1.2 – Unleash STEM talent for America. Grow a diverse STEM workforce to advance the progress of science and technology.

Contextual Indicator: NSF funding to Minority Serving Institutions (MSIs)

Metric Definition: The number and total funding amounts of new awards funded to MSIs.

Historical Actuals/Results:

Indicator	Prior Year Results (Actuals)[12] FY 2019	FY 2020	FY 2021
Number of new awards funded to MSIs	1,510	1,606	1,719
Percent of all new NSF awards	13.4%	13.2%	15.1%
Total funding for new awards to MSIs (millions)	$844	$894	$989
Percent of all new NSF funding (millions)	11.0%	11.5%	12.2%

MSIs are institutions of higher education enrolling populations with significant percentages of undergraduate minority students, or that serve certain populations of minority students under various programs created by Congress.[13] Many underrepresented minority undergraduates are the first in their families to attend college, and minority-serving academic institutions enroll a substantial fraction of these students.[14]

MSIs make considerable contributions to educating and training science leaders, contributing to U.S. economic growth and competitiveness, but NSF usually receives comparatively few grant proposals from, or involving, scholars at MSIs. NSF's FY 2023 Budget Request to Congress proposes a significant increase for investments in activities to grow the Nation's research capacity within underserved communities and institutions, which includes the majority of MSIs. These investments will bolster ongoing efforts such as NSF INCLUDES and the Science of Broadening Participation,[15] as well as the development of new initiatives such as Growing Research Access for Nationally Transformative Equity and Diversity (GRANTED). GRANTED aims to broaden the number and types of individuals who engage

[12] Results were generated using the MSI filter for the NSF by the Numbers dashboard as of February 8, 2022. The dashboard may be accessed at https://tableau.external.nsf.gov/views/NSFbyNumbers/NumbersbyState.

[13] MSIs are defined under Part F of the Higher Education Act (20 U.S. Code § 1067q – "Investment in historically Black colleges and universities and other minority serving institutions"). For more information see: www2.ed.gov/about/offices/list/ocr/edlite-minorityinst.html.

[14] National Center for Science and Engineering Statistics. 2021. Women, Minorities, and Persons with Disabilities in Science and Engineering: 2021. Special Report NSF 21-321. Alexandria, VA: National Science Foundation. https://ncses.nsf.gov/pubs/nsf21321/report/field-of-degree-minorities#blacks-or-african-americans

[15] NSF INCLUDES (Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science) is building the infrastructure for sustained broadening participation efforts across the Nation. The Science of Broadening Participation draws upon the theories, methods, and analytic techniques of the social, behavioral, economic, and learning sciences to better understand the factors that enhance as well as the barriers that hinder our ability to expand participation in education, the workforce, and major social institutions in society.

with NSF through listening sessions, research-coordination networks, research and implementation grants, partnerships with professional societies, and development of leadership in research administration.

Rationale for Contextual Indicator: NSF tracks and reviews the number of awards and funding provided to MSIs, as this portfolio is central to efforts to grow and sustain a diverse STEM workforce. Although the set of institutions identified as MSIs varies from year-to-year depending on which institutions meet the statutory criteria, it is a valuable contextual indicator for this strategic goal and objective.

Data Collection and Reporting: Data on NSF awards are captured in the administrative systems used to manage the award process, and publicly reported on an externally facing dashboard.[16] The dashboard displays award and funding amounts for all years based on the list of MSI in use at the time the data are queried.

[16] NSF by the Numbers Dashboard is available at https://tableau.external.nsf.gov/views/NSFbyNumbers/NumbersbyState

Strategic Goal 2, Discover

Create new knowledge about our universe, our world, and ourselves.

This goal furthers the NSF mission, "to promote the progress of science," pursuing the generation of new knowledge so that the Nation remains a global leader in expanding discovery in science, engineering, and learning. By generating knowledge, NSF-funded researchers provide the Nation with the capability to maintain scientific, technological, and economic leadership in a competitive world.

Evidence Types for Strategic Goal 2, Discover

Annual Goals

- Annual Goal 2: Ensure that Major Facility Infrastructure Investments are on Track
- Annual Goal 3: Ensure that Mid-Scale Infrastructure Investments are on Track

Evaluations

The Learning Agenda Guiding Question that will inform NSF's evidence strategy for Goal 2 is: "How can NSF fuel transformative discoveries most effectively?" Specific questions to be addressed through studies described in the Learning Agenda include:

- What are the characteristics of NSF's portfolio on climate change, and to what extent might this portfolio advance NSF's goals of equity, discovery, and impact? [planned evaluation]
- How do Established Program to Stimulate Competitive Research (EPSCoR) program funding strategies (infrastructure, co-funding, and outreach) contribute to increasing academic competitiveness across jurisdictions? [FY 2022 Evaluation Plan]

Policy and Program Analysis

- Process improvements in the major facilities portfolio to respond to various Government Accountability Office (GAO) and OIG reviews. Information on this work is summarized in NSF's response to the FY 2021 OIG Management Challenge, "Providing Oversight of Major Multi-User Research Facilities."[17] [Ongoing]
- Response to OIG's Management Challenge on, "Mitigating Threats Posed by Foreign Government Talent Recruitment Programs."[18] [Ongoing]

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[17] For the NSF response to OIG Management Challenge "Providing Oversight of Major Multi-User Research Facilities," see appendix 3 of the FY 2021 Agency Financial Report www.nsf.gov/pubs/2022/nsf22002/index.jsp p. (OI)-21

[18] For the NSF response to OIG Management Challenge on "Mitigating Threats Posed by Foreign Government Talent Recruitment Programs," see appendix 3 of the FY 2021 Agency Financial Report www.nsf.gov/pubs/2022/nsf22002/index.jsp p. (OI)-47

Strategic Objective 2.1 – Advance the frontiers of research. Accelerate discovery through strategic investments in ideas, people, and infrastructure.

Annual Goal 2: Ensure that Major Facility Infrastructure Investments are on Track

Goal Statement: Ensure program integrity and responsible stewardship of major research facilities and infrastructure.

Targets and Results**:** The percentage of all Major Facility projects under construction that are over 10% complete for which negative cost and schedule variance are both at or below 10%.

	FY 2021	FY 2022	FY 2023
Target	100% of facilities with negative **cost and schedule** variance at or below 10%.	100% of facilities with negative **cost and schedule** variance at or below 10%.	100% of facilities with negative **cost and schedule** variance at or below 10%.
Result	Target not achieved. 3 of 5 projects were behind **schedule** as of 9/30/2021. All 5 facilities did meet the target of negative **cost** variance at or below 10%.[19]		

Modern and effective research infrastructure is critical to maintaining U.S. international leadership in science and engineering. NSF's major multi-user research facilities (major facilities) are transformative in nature, with the potential to shift the paradigm in scientific understanding. Key to realizing the benefits of new major facility investments is ensuring their timely completion within budgeted resources. At a general level, cost and schedule variances are key indicators of whether a project is on track relative to the project plan. Although cost and schedule variances are a direct measure of the recipient's project management performance, NSF performs oversight activities that impact the measure results. The oversight activities serve to support the recipient's project management and maintain recipient accountability. Therefore, the measure results provide an indication of the effectiveness of NSF's oversight of major facility construction projects.

Data Collection and Reporting**:** Data for this goal are from the projects' earned value management systems, which may lag one and a half to two months depending on the project. Data are delivered to NSF monthly and are summarized quarterly for internal reporting. Public reporting occurs annually with the release of the President's Budget Request to Congress.

[19] For a full discussion of the results, see the Annual Performance Report, later in this chapter.

Strategic Objective 2.2 – Enhance research capability. Advance the state of the art in research practice.

Annual Goal 3: Ensure that Mid-Scale Infrastructure Investments are on Track

Goal Statement**:** Ensure program integrity and responsible stewardship of mid-scale research infrastructure.

Targets and Results**:** Track cost and schedule performance during project implementation for Mid-Scale Research Infrastructure projects with a Total Project Cost above $20.0 million that are over 10 percent complete and using Earned Value Management principles.

	FY 2021	FY 2022	FY 2023
Target	Track cost and schedule for all defined projects.	Track cost and schedule for all defined projects.	Track cost and schedule for all defined projects.
Result	Achieved.		

The Mid-Scale Research Infrastructure program is an NSF-wide effort to meet the research community's needs for modern research infrastructure at a scale that is otherwise difficult for individual institutions to acquire. The program's objectives are 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. Projects in this portfolio have costs that fall below the $100 million threshold for a major facility project, but exceed $4 million, so NSF oversight and tracking of performance measurements is crucial to ensuring stewardship of Federal funds.[20] Although the target for this goal reflects the relatively early stages of maturation for the Mid-Scale Research Infrastructure program, this goal serves as a marker of the importance the agency places on its stewardship responsibility, particularly for this new portfolio of investments.

Data Collection and Reporting: Reporting on this measure is provided in periodic progress reports, based on data from the projects' earned value management systems, and reviewed by the NSF staff overseeing these projects.

[20] Although Mid-Scale Research Infrastructure projects begin at the threshold of $4 million, this goal tracks those most likely to propose using Earned Value Management principles, with Total Project Costs of $20 million or more.

Strategic Goal 3, Impact

Benefit society by translating knowledge into solutions.

NSF has always been at the forefront of scientific discovery and technological advancements improving society. Appropriately translated, NSF-supported contributions to knowledge promote U.S. leadership in topics of strategic national interest. These contributions are captured and disseminated in research papers in journals and conferences, patents, new approaches to education and training, as start-up enterprises, and in technology licenses. Through partnerships among academia, government, non-profits, industry, civil society, and communities of practice, the exchange of knowledge and resources helps shape a vibrant research agenda in which research questions are inspired by practical challenges, and stronger connections between researchers and potential users speed results.

Evidence Types for Strategic Goal 3, Impact

Annual Goal

- Annual Goal 4: Grow Partnerships

Contextual Indicator

- Number and diversity of entrepreneurs participating in I-Corps™
- Awards with international collaborations

Evaluations

The Learning Agenda Guiding Question that will inform NSF's evidence strategy for Goal 3 is: "How can NSF mobilize knowledge most effectively to impact society?" Specific questions to be address through studies described in the Learning Agenda include:

- In what ways does the Convergence Accelerator Innovation Training contribute to the emergence of new capacities among participating researchers to meet pressing societal needs? [FY 2022 Evaluation Plan][21]
- What are the benefits of receiving an award from a program supported by a partnership? How do these differ from benefits associated with awards from programs not supported by a partnership? What outputs and outcomes are associated with partnership programs? To what extent can these be attributed to the partnership programs? What improvements could make partnership programs more effective or easier to implement? [FY 2022 Evaluation Plan]

[21] More information on the Convergence Accelerator and its innovation curriculum can be found at https://beta.nsf.gov/funding/initiatives/convergence-accelerator/program-model

Strategic Objective 3.1 – Deliver benefits from research. Advance research and accelerate innovation that addresses societal challenges.

Annual Goal 4: Grow Partnerships

Goal Statement**:** Increase opportunities for public and private partnerships that will address major scientific and technological goals while ensuring broad societal benefits.

Targets and Results**:** Tracking and improving upon partnerships among NSF, our awardees and other entities is an area of growing interest for the agency. For this reason, we intend to establish a baseline for performance in FY 2022. NSF will establish a performance goal target in future Annual Performance Plans.

	FY 2021	FY 2022	FY 2023
Target	N/A	Establish baseline	Set target
Result			

This is a new goal to support the FY 2022-2026 Strategic Plan that builds on prior efforts including the FY 2020-2021 Agency Priority Goal, “Strategic Engagement in Partnerships,” which sought to enhance the impact of NSF’s investments through engaging in public and private partnerships, as well as the FY 2018-2019 Agency Priority Goal to, “Expand Public and Private Partnerships.” The culmination of these Agency Priority Goals was an NSF-wide partnerships strategy, including outreach, process improvement, and communications aspects.

This new iteration of the goal focuses on partnerships that are shaping research directions, cultivating co-design and co-creation of research-based solutions, and accelerating piloting, prototyping, and eventual translation of knowledge gained through NSF’s research portfolio to address society’s most pressing needs. For example, the FY 2023 Budget Request invests in programs needed to catalyze these types of partnerships, such as the NSF Regional Innovation Engines. The NSF Regional Innovation Engines program aims to incentivize partnerships that bring together multiple disciplines, institutions, and sectors, to include academia, industry, nonprofits, state and local governments, and venture capital, for the purpose of advancing use-inspired, solutions-oriented research.

Data Collection and Reporting**:** NSF will rely on administrative data resulting from the funding opportunity and award process.

Strategic Objective 3.1 – Deliver benefits from research. Advance research and accelerate innovation that addresses societal challenges.

Contextual Indicator: Number and diversity of entrepreneurs participating in I-Corps™

Metric Definition: This metric tracks the number of unique individuals trained through NSF's Innovation Corps (I-Corps™) program, and the percentage of those trained who identified as being members of under-represented groups.[22]

Results/Historical Actuals

Indicator	Prior Year Results (Actuals) FY 2017-2018	FY 2019-2020
Total trained	1,628	1,928
Number (percentage) who identified as female	338 (21%)	411 (21%)
Number (percentage) who identified as a member of an underrepresented group	437 (27%)	568 (30%)

NSF I-Corps™ 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. Through I-Corps training, academic researchers can reduce the time needed to translate a promising idea from the laboratory to the marketplace or other relevant societal setting.

Rationale for Contextual Indicator: The I-Corps program is migrating to a new operational model based on expanded consortia, known as "Hubs," to develop and nurture a National Innovation Network. This new model will help NSF continue to expand the ability to teach researchers customer discovery skills and facilitate technology applications for solutions that benefit the Nation. NSF awarded the first round of I-Corps Hubs awards in FY 2020, and we anticipate that following conclusion of those first awards, more data will be available to inform meaningful targets for participation.

Data Collection and Reporting: Data for this metric will be collected from the participant information included in project proposals, as reported in the Innovation Corps (I-Corps™) Biennial Report for 2021.[23]

[22] Under-represented groups include individuals who identify as 1) female, 2) race as Black or African American, American Indian, Alaska Native, and/or Native Hawaiian or other Pacific Islander, 3) of Hispanic origin, and/or 4) having a disability on their I-Corps project proposals.
[23] NSF I-Corps™ Biennial Report 2021 www.nsf.gov/news/special_reports/i-corps/pdf/NSFI-Corps2021BiennialReport.pdf

Strategic Objective 3.2 – Lead globally. Cultivate a global science and engineering community based on shared values and strategic cooperation.

Contextual Indicator: Awards with international collaborations

Metric Definition: Number of NSF awards that include collaborations with international partners.

Historical Actuals/Results:

Indicator	Prior Year Results (Actuals) FY 2019	FY 2020	FY 2021
Actuals	1,368	1,330	1,398

The focus on international collaboration in science and engineering is based on discovery, learning, and research infrastructure to engage a diverse science community from different nations and cultural backgrounds. NSF develops international scientific collaborations on all seven continents and provides opportunities for researchers to enhance their work through international cooperation.

Rationale for Contextual Indicator: Monitoring the number of NSF awards that include international collaborations is only one of many ways the agency can gauge its reach and success in global leadership of science and engineering, though it is perhaps the most easily quantifiable. As efforts and strategies around this strategic objective mature, NSF will consider whether there are additional metrics that could be used to provide evidence of progress in this area.

Data Collection and Reporting: Data on international activities come from information collected on proposals at the time they are recommended for award. This metric monitors all proposals coded as "collaborative international activity" meaning that, for example, there was joint design or implementation of research, or foreign entities or personnel will be engaged in conducting the research. These data are updated and available on an ongoing basis.

Strategic Goal 4, Excel

Excel at NSF operations and management.

The first three strategic goals are associated with quickly evolving challenges. Meeting these and effectively fulfilling NSF's mission requires blending strong scientific leadership with robust organizational leadership. Both are characterized by vision and flexibility. NSF will reinforce its capacity to scale rapidly to advance an expanding portfolio that meets the growing need for breakthroughs in research and innovation.

Evidence Types for Strategic Goal 4, Excel

Annual Goals

- Annual Goal 5: Provide robust and reliable IT services
- Annual Goal 6: Implement the Human Capital Operating Plan
- Annual Goal 7: Foster a Culture of Inclusion

Evaluations

The Learning Agenda Guiding Question that will inform NSF's evidence strategy for Goal 4 is: "How can NSF excel at stewarding and realizing its vision?" Specific questions to be address through studies described in the Learning Agenda include:

- What are the characteristics of proposals evaluated through the merit review process? Are these characteristics (of individual investigators, teams, institutions, or proposed projects) associated with different review or funding outcomes? [planned evaluation]
- What outcomes are associated with the adoption of a no-deadlines proposal submission process? [planned evaluation]

Policy and Program Analysis

- Response to OIG's Management Challenge on, "Providing Oversight of Grants During a Pandemic."[24] [FY 2021 activity. Future activity on "Overseeing Grants in a Changing Environment"]
- Response to OIG Management Challenge, "Managing the Intergovernmental Personnel Act (IPA) Program."[25]

[24] For the NSF response to OIG Management Challenge on, "Providing Oversight of Grants During a Pandemic," see appendix 3 of the FY 2021 Agency Financial Report www.nsf.gov/pubs/2022/nsf22002/index.jsp p. (OI)-26

[25] For the NSF response to the OIG Management Challenge on, "Managing the Intergovernmental Personnel Act (IPA) Program," see appendix 3 of the FY 2021 Agency Financial Report www.nsf.gov/pubs/2022/nsf22002/index.jsp, p. (OI)-31

Strategic Objective 4.1 – Strengthen at speed and scale. Pursue innovative strategies to strengthen and expand the agency's capacity and capabilities.

Annual Goal 5: Provide robust and reliable IT services

Goal Statement: Ensure availability of IT resources for NSF staff and the broader research community.

Targets and Results: NSF IT systems will be available 99.6 percent of the time, excluding 469 hours of planned downtime.

	FY 2021	FY 2022	FY 2023
Target	99.6%	99.6%	99.6%
Result	Achieved. Result = 99.8%		

NSF prioritizes availability of IT services, and coordinates downtime for critical maintenance and service releases to minimize disruption. This goal supports the President's Management Agenda pillars of "Strengthening and empowering the Federal workforce," and, "Delivering excellent, equitable, and secure Federal services and customer experience," by ensuring that critical information and IT systems are available to support staff and our awardees in their pursuit of NSF's mission.

Data Collection and Reporting: IT system availability is monitored daily. This is appropriate as availability issues need to be addressed quickly and therefore current data are required. For Annual Goal 5, data are updated monthly and reported to the Division of Information Systems.

Strategic Objective 4.2 – Invest in people. Attract, empower, and retain a talented and diverse NSF workforce.

Annual Goal 6: Implement the Human Capital Operating Plan

Goal Statement: Track progress against NSF's Human Capital Operating Plan

Targets and Results: Targets will be determined in the first quarter of each fiscal year, based on the forthcoming Human Capital Operating Plan.

	FY 2021	FY 2022	FY 2023
Target	N/A	Submit draft FY 2022-2025 Human Capital Operating Plan to OPM.	To be determined following finalization of the FY 2022-2025 Human Capital Operating Plan.
Result			

NSF's Division of Human Resource Management prepares the NSF Human Capital Operating Plan, which outlines the agency's human capital strategies and actions that enable accomplishment of NSF's mission, its strategic plan, and its performance goals. The Human Capital Operating Plan is a tactical, dynamic plan that identifies the specific, near-term actions NSF will take to achieve the agency's human capital goals. It is a four-year plan updated regularly to reflect changes in the human capital strategies and actions needed to ensure the plan's continuous alignment with agency priorities. In FY 2022, NSF will finalize the Human Capital Operating Plan for FY 2022-2025. The human capital strategies and actions included in the plan will serve as the basis for evaluating progress on this goal.

Strategic Objective 4.2 – Invest in people. Attract, empower, and retain a talented and diverse NSF workforce.

Annual Goal 7: Foster a Culture of Inclusion

Goal Statement: Foster a culture of inclusion through change management efforts resulting in change leadership and accountability.

Targets and Results:

	FY 2021	FY 2022	FY 2023
Target	All NSF leaders will participate in culture change activities.	Increase agency-wide engagement in Special Emphasis Program observances and Diversity and Inclusion-related activities by 10% from 2021.	To be determined. Pending finalization of NSF's Diversity, Equity, Inclusion, and Accessibility Strategic Plan.
Result	Achieved. Result = 100%		

NSF values diversity and recognizes that a culture of inclusion is a critical driver in achieving our scientific mission. Fostering inclusive work environments and realizing the full potential of the workforce's diversity requires the implementation of thoughtful strategies focused on creating meaningful, sustainable, and measurable change. This holistic approach to diversity and inclusion is supported by Executive Order 14035, "Diversity, Equity, Inclusion, and Accessibility (DEIA) in the Federal Workplace," which requires that federal agencies develop DEIA Strategic Plans, and to regularly measure and report on the effectiveness of DEIA initiatives.[26] NSF's FY 2023 target will be directly related to the NSF DEIA Strategic Plan, which is currently under development.

NSF's FY 2022 target is focused on involving all of NSF's workforce in cultivating a healthy, inclusive workplace environment. The Office of Equity and Civil Rights, through the development of NSF's DEIA Strategic Plan, an expanded Diversity & Inclusion portfolio, and strong partnerships with all of NSF's Directorates and Offices, aims to increase agency-wide engagement in Special Emphasis Program observances, Employee Resource Groups, and other diversity and inclusion-related activities by 10 percent from 2021.

Data Collection and Reporting: Data for the FY 2022 target will be collected from Employee Resource Group membership rosters and event and activity participation logs.

[26] Executive Order 14035, "Diversity, Equity, Inclusion, and Accessibility in the Federal Workplace" www.federalregister.gov/documents/2021/06/30/2021-14127/diversity-equity-inclusion-and-accessibility-in-the-federal-workforce

Cross-cutting Areas

Annual Goals 8 and 9 are crosscutting in nature – supporting both the programmatic strategic objectives of NSF as well as the agency's aim to excel at operations and management of those programs.

Evidence Types for Cross-cutting Areas

Annual Goals

- Annual Goal 8: Make Timely Proposal Decisions
- Annual Goal 9: Ensure Key Program Investments are on Track (ARP Funding)

Contextual Indicator

- Ensure Key Program Investments are on Track (Budget Themes)

Evaluations

- What are the characteristics of NSF's portfolio on climate change, and to what extent might this portfolio advance NSF's goals of equity, discovery, and impact? [planned evaluation]

Policy and Program Analysis

- Proposal review quality. NSF previously reported on a goal to "Improve Review Quality" and although that goal has been retired in this version of the Annual Performance Plan, the work to improve review quality based on customer service feedback continues through activities that build upon the pilot efforts undertaken in FY 2021. [ongoing activity]

Cross-cutting Areas

Annual Goal 8: Make Timely Proposal Decisions

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.

Target and Results: The target reflects the percent of proposals for which a funding decision is communicated to the principal investigator for the proposal within 6 months of receipt.

	FY 2021	FY 2022	FY 2023
Target	75%	75%	75%
Result	65%		

Time to decision or "dwell time" is the amount of time that passes between receipt of a proposal and notification to the principal investigator 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 principal investigators for timely action, the need of NSF for a credible and efficient merit review system and postponing the finalization of some award or decline decisions until final appropriations and approval of NSF's operating plan have been received for the fiscal year. 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 much of the past two decades. NSF did not meet the target in FY 2021, due in part to prioritizing response to the pandemic among existing awardees and the activities required to plan, allocate, and distribute the relief funding made available through the American Rescue Plan.[27]

Data Collection and Reporting: Data for this goal are extracted from the NSF Enterprise Information System based on various systems that record date of proposal receipt and dates of funding decisions.

[27] The American Rescue Plan Act of 2021 (P.L. 117-2) provided $600 million for NSF to fund grants, scholarships, cooperative agreements, and other activities to respond to COVID-19.

Cross-cutting Areas

Annual Goal 9: Ensure Key Program Investments are on Track (ARP Funding)

Goal Statement: Ensure that key FY 2023 NSF-wide program investments are implemented and on track.

Targets and Results: Targets for this goal are developed on an annual basis to align with funding priorities of the year. In FY 2022, NSF will track obligations of remaining American Rescue Plan funding.

	FY 2021	FY 2022	FY 2023
Target	NSF will obligate 100 percent of designated funding targets for all identified NSF-wide priority investments.	NSF will obligate 100 percent of designated funding targets for all identified NSF-wide priority investments.	TBD
Result	Achieved.		

This measure looks at the extent to which NSF is able to meet its annual funding targets for key NSF-wide investments. The percentage of the annual targeted funding that is obligated by the end of the year is an indication of NSF's effectiveness in moving through the program investment process and ensuring that key investments are implemented and on track.

Contextual Indicator: Ensure Key Program Investments are on Track (Budget Themes)

Metric Definition: NSF will track obligations against key areas of focus in the budget (budget themes).

Historical Actuals/Results: These themes will be confirmed and tracked beginning in FY 2023.

The FY 2023 Budget Request to Congress proposes investments in several key areas of interest to NSF and the Administration, such as "emerging industries" and "research infrastructure." This measure looks at the extent to which NSF is able to meet its annual funding targets for key NSF-wide investments. The percentage of the annual targeted funding that is obligated by the end of the year is an indication of NSF's effectiveness in moving through the program investment process and ensuring that key investments are implemented and on track.

Data Collection and Reporting: Data for this goal are gathered from various systems of record, including the NSF financial system for funding amounts.

Retired measures

In the process of developing an Annual Performance Plan to align with the FY 2022-2026 Strategic Plan's goals and objectives, several goals reported under the prior Strategic Plan are being retired or modified to focus attention and efforts on new strategic priorities within these programmatic and operational areas. Historical information, including the FY 2021 results for these goals can be found in the Annual Performance Report later in this chapter. The retired goals include:

- **Strategic Engagement in Partnerships**: Strategically engage in public and private partnerships to enhance the impact of NSF's investments and contribute to American economic competitiveness and security. (Agency Priority Goal for FY 2020-21). This has been replaced by Annual Goal 4. "Grow Partnerships" in this Annual Performance Plan.
- **Improve Review Quality**: Improve the quality of written reviews of NSF proposals.
- **Align Job Requirements with Competencies**: Ensure that employee job requirements are aligned with competencies and skills needed for the future. NSF will focus efforts on implementation of its FY 2022-2025 Human Capital Operating Plan under Annual Goal 6 of this plan.
- **Improve User Interactions with IT Systems:** 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. NSF will retire the portions of this goal associated with consolidating interfaces to a single portal, due to reprioritization of IT resources. NSF will continue to report on IT system availability.

FY 2021 NSF STRATEGIC OBJECTIVE PROGRESS UPDATE

In FY 2021, NSF conducted the final set of Strategic Reviews 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). This information informed NSF's classification among three categories of the level of progress made towards each Objective: noteworthy progress, in need of focused improvement, or neither (making typical progress).

FY 2018-2022 Strategic Plan and Strategic Objectives

NSF's Strategic Plan for FYs 2018-2022, *Building the Future: Investing in Discovery and Innovation,* 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.

<table>
<tr><th colspan="2">Strategic Goal</th><th>Strategic Objective</th></tr>
<tr><td rowspan="2">1</td><td rowspan="2">Expand knowledge in science, engineering, and learning.</td><td>1.1 Knowledge
Advance knowledge through investments in ideas, people, and infrastructure.</td></tr>
<tr><td>1.2 Practice
Advance the practice of research.</td></tr>
<tr><td rowspan="2">2</td><td rowspan="2">Advance the capability of the Nation to meet current and future challenges.</td><td>2.1 Societal Impacts
Support research and promote partnerships to accelerate innovation and to provide new capabilities to meet pressing societal needs.</td></tr>
<tr><td>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.</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">Enhance NSF's performance of its mission.</td><td>3.1 Human Capital
Attract, retain, and empower a talented and diverse workforce.</td></tr>
<tr><td>3.2 Processes and Operations
Continually improve agency operations.</td></tr>
</table>

Two Components to NSF Strategic Reviews: Topic Reviews and Objective Rankings

NSF's Strategic Review process uses the results of existing assessments, evaluations, and reports as well as other sources of evidence. Dashboards for each of the Strategic Objectives in the NSF Strategic Plan are updated. These Objectives are crosscutting and do not mirror NSF's organizational structure, and the major strategic issues often facing NSF seldom fit within a single Objective, so NSF also scans the environment for topics and conducts crosscutting topical reviews as necessary. These are performed as a cross-NSF activity and are broader in scope than single organizational units or individual programs.

Both elements of the process draw upon comprehensive assessment processes that already are in use at NSF. For example, the annual Merit Review Report to the National Science Board describes all annual outputs.[1] The Committees of Visitors (COV) process, in which external experts assess NSF programmatic activities approximately every four years, is also comprehensive.[2] Instead of duplicating these efforts, the strategic review process at NSF complements them by making use of the information they generate when appropriate (e.g. reviewing their recommendations or using their data in a topic review, and using them as sources of evidence for a dashboard).

FY 2021 Objective Rankings

For the Objective rankings, NSF's Performance Improvement Officer (PIO) reviewed internal performance dashboards which contain information on relevant measures, recent evaluative activities, challenges, and risks in each Objective's domain. NSF is purposefully ranking its STEM Workforce Objective, 2.2, as demonstrating Noteworthy Progress and being a Focus Area for Improvement. This decision reflects the evolution and the elevation in the awareness and understanding of issues related to diversity, equity, and inclusion over the past year at a national level as well as at NSF and within the communities NSF serves. The ranking of Noteworthy Progress reflects the important steps NSF has taken over the past year to address longstanding disparities throughout the STEM enterprise, and the recognition of this as a Focus Area for Improvement parallels the import and the scope of the larger challenge, as identified most notably in the Administration's Executive Order on Racial Equity (EO 13985) and the National Science Board's *Vision 2030* report.

A few specific activities to advance diversity, equity, and inclusion are underway at NSF, and these reflect both NSF's longstanding leadership and commitment as well as its appreciation of the need for new approaches and an increased sense of urgency. (Note that this list excludes government-wide activities such as those in response to Executive Orders.)

- Racial Equity Task Force – established June 2020, the Racial Equity Task Force was charged to identify institutional and other barriers to full inclusion in STEM and to make recommendations to eliminate those barriers – both inside NSF and in the community it serves. Its two subgroups (Racial Equity Employment Working Group and Program Delivery Working Group) provided recommendations to the NSF Director in Spring 2021, and an action plan was released in December 2021. Implementation of that plan is ongoing.
- Management Challenge – In Fall 2020, the NSF Office Inspector General (OIG) identified "Increasing Diversity in Science & Engineering Education and Employment" as a Management Challenge for NSF. This challenge focuses on NSF's efforts to develop strategies and programs to increase diversity in science and engineering education and employment and to measure their effectiveness. NSF's response to this challenge was provided to OIG in the fall of 2021 and published as an appendix to the Annual Financial Report in November.[3]
- GAO Report – The 2020 report "Sexual Harassment in STEM Research: Agencies Have Taken Actions, but Need Complaint Procedures, Overall Plans, and Better Coordination" (GAO-20-187) recommended that the agency establish goals and an overall plan to assess its sexual harassment prevention efforts.[4] NSF implementation of this recommendation began in FY 2021 and is ongoing.
- Agency Priority Goal – NSF has established an Agency Priority Goal to, "increase both the number and proportion of proposals received from underrepresented and underserved 1) investigators, and 2) institutions by 10 percent over the FY 2020 baseline" by September 30, 2023.

[1] Merit Review Reports can be accessed at www.nsf.gov/nsb/publications/pubmeritreview.jsp
[2] More information on Committee of Visitors can be found at www.nsf.gov/od/oia/activities/cov/
[3] The NSF Agency Financial Report for FY 2021 is available at www.nsf.gov/pubs/2022/nsf22002/index.jsp
[4] GAO-20-187 is available at www.gao.gov/products/gao-20-187

- Change in Strategic Plan structure – Conversations throughout Spring 2021 about the Strategic Plan resulted in a change to the three-goal structure previously in use by NSF, with the addition of a new goal focused on the STEM workforce (which previously had been addressed at the Strategic Objective level). The change allows NSF to address some of the diversity, equity, and inclusion issues related to the STEM workforce in a more prominent manner.

2021 Process Adjustments

NSF used the topical review process to support the development of the next Strategic Plan and round of Agency Priority Goals, as well as to coordinate developing Evidence Act processes and products with performance processes and products. As in 2020, thanks in large part to the IT infrastructure and flexibilities afforded by NSF to all staff during the pandemic, all work was able to proceed in a fully remote setting.

FY 2021 ANNUAL PERFORMANCE REPORT

About this Report

For FY 2021, NSF issues three reports to provide financial management and program performance information to demonstrate accountability to our stakeholders and the American public. These reports are produced in accordance with the Office of Management and Budget (OMB) Circular A-136, *Financial Reporting Requirements,* and meet the requirements of the Chief Financial Officers Act, as amended by the Government Management Reform Act of 1994, the Federal Managers' Financial Integrity Act of 1982, the Reports Consolidation Act of 2000, and the Government Performance and Results Act Modernization Act of 2010.

- This report, the ***Annual Performance Report*** (APR), provides information on the progress NSF has made toward achieving its goals and objectives as described in the agency's strategic plan and Annual Performance Plan, including the strategic objectives, performance goals, and Agency Priority Goals. Most years, this report is published with the agency's Budget Request to Congress.
- In November 2021, NSF published the ***Agency Financial Report*** (AFR), which focuses on financial Report management and accountability.
- The third report is NSF's ***Performance and Financial Highlights*** report, which summarizes key financial and performance information from the *AFR* and *APR*.

All three reports are made available on NSF's website as they are completed at:
https://www.nsf.gov/about/performance/annual.jsp

We welcome your suggestions on how we can make these reports more informative. You can reach us at: accountability@nsf.gov or call (703) 292-8200.

FY 2021 Performance Framework

In FY 2018, NSF released its Strategic Plan for FYs 2018-2022: Building the Future: Investing in Discovery and Innovation. 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 (below) enables NSF to link its investments to longer-term outcomes.

NSF Strategic Goals and Objectives: FY 2018 to FY 2022

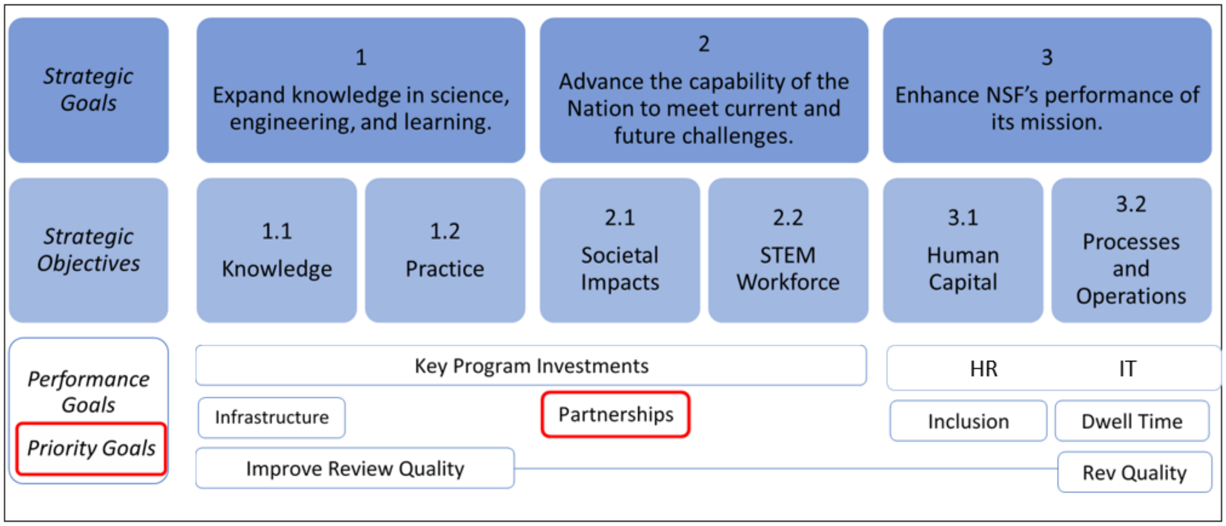
1. Expand knowledge in science, engineering, and learning.	**1.1 Knowledge:** Advance knowledge through investments in ideas, people, and infrastructure.
	1.2 Practice: Advance the practice of research.
2. Advance the capability of the Nation to meet current and future challenges.	**2.1 Societal Impacts:** 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.

FY 2021 Performance and Results

In this FY 2021 APR, 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, as shown below. In FY 2021, NSF tracked progress toward its three strategic goals using eight performance goals, one of which was a 2-year Agency Priority Goal in its second and final year of activity.

Overall, seven of the eight goals achieved all or some of their targets. As is detailed below, NSF partially achieved two goals.

- For the major facilities and infrastructure goal (Goal 3), one of two targets was achieved: the target for mid-scale investments was achieved, but for major construction projects, three of five projects experienced schedule delays (largely due to pandemic-related factors).
- For the IT systems goal (Goal 8), of its three targets, the one for streamlining externally facing merit review systems was not achieved. This area was affected by key decisions to reprioritize IT investments to focus on external customer experience enhancements, such as developing a demonstration and training environment for the research community, and to improve the collection of data needed to inform strategies for improving equity and inclusion among principal investigators.
- The goal for timely award decisions (Goal 4) was also not achieved due in part to the need to focus the NSF response to the pandemic among existing awardees and the activities required to plan, allocate, and distribute the relief funding made available through the American Rescue Plan. Consistent with previous years, when unique events such as the agency's FY 2017 relocation disrupted normal operations, agency leadership determined that meeting this goal should be considered secondary to meeting more mission-critical responsibilities in the wake of the pandemic.



FY 2021 PERFORMANCE GOAL	RESULT
1. Agency Priority Goal: Developing an Agency-Wide Partnerships Strategy. (Partnerships)	Achieved
2. Ensure that key NSF-wide program investments are implemented and on track. (Key Program Investments)	Achieved
3. Ensure program integrity and responsible stewardship of major research facilities and infrastructure. (Infrastructure)	Partially Achieved
4. Divisions and Offices will make timely proposal decisions. (Dwell Time)	Not Achieved
5. Improve the quality of written reviews of NSF proposals. (Improve Review Quality)	Achieved
6. Foster a culture of inclusion through change management efforts resulting in change leadership and accountability. (Inclusion)	Achieved
7. Ensure that employee job requirements are aligned with competencies and skills needed for the future. (HR)	Achieved
8. 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. (IT)	Partially Achieved

Goal 1, Agency Priority Goal (APG): Strategic Engagement in Partnerships

Lead Organizations: Directorate for Computer and Information Science and Engineering, Directorate for Education and Human Resources, Directorate for Geosciences.

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

Reporting Year		
FY	**Target Summary**	**Result**
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.	Achieved. Established and accomplished 14 milestones in the development of NSF's agency-wide partnership strategy.
Previous Years		
FY	**Target Summary**	**Result**
2018-2019	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.

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 OMB Memorandum M-17-22, "Comprehensive Plan for Reforming the Federal Government."[1]

Private industry, foundations, and non-profits, together with other federal agencies and international

[1] OMB Memorandum M-17-22 www.whitehouse.gov/sites/whitehouse.gov/files/omb/memoranda/2017/M-17-22.pdf

funding organizations, bring additional expertise, resources, and capacity to NSF-funded research. NSF is a sought-after partner, and the range of partnership opportunities present different needs, goals, and priorities. Developing partnerships requires significant time and intellectual capital, as well as strategic foresight.

Assessing and prioritizing partnership opportunities often happens at the directorate or office level. Efficiencies could be better realized through greater harmonization across the agency. Consequently, pursuing partnership opportunities in a strategic and coordinated manner will allow NSF to accelerate discovery and translation of research to products and services, and enhances preparation of the future workforce to benefit society and grow the American economy.
Developing a consistent agency-wide partnerships strategy and improving internal processes will result in partnerships that will allow NSF to maximize the scientific, economic, and societal impacts of its investments.

Discussion of FY 2021 Results
Over FY 2020 and FY 2021, this APG established and accomplished 14 milestones in the development of NSF's agency-wide partnership strategy. This effort focused agency-wide attention on identifying the intellectual foundations of partnerships, standardizing, and streamlining the business processes for partnership activities, and creating tools for agency-wide communications.[2]

[2] For more information, see:
https://trumpadministration.archives.performance.gov/NSF/APG_nsf_1.html

Goal 2, Ensure that Key Program Investments are on Track

Lead Organization: Office of Budget, Finance, and Award Management.

<u>Goal Statement</u>
Ensure that key NSF-wide program investments are implemented and on track.

<u>Measure, Milestone, or Deliverable</u>

Reporting Year		
FY	**Target Summary**	**Result**
2021	NSF will obligate 100 percent of designated funding targets for all identified NSF-wide priority investments.	Achieved
Previous Years		
FY	**Target Summary**	**Result**
2020	NSF will obligate 100 percent of designated funding targets for all identified NSF-wide priority investments.	Achieved
2019	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.	Achieved
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

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 several 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 2021 Results

Beginning in FY 2020, and on the recommendation of NSF's independent verification and validation team, the unit of measurement was adjusted to simplify quarterly tracking and the determination of achievement (from a qualitative approach, where the unit of analysis was a program, to a quantitative approach that tracks spending against a target). The goal now tracks the extent to which funding is obligated in accordance with the annual operating plan, and the percentages, by program, are reported to leadership each quarter.

In FY 2021, the targets for this goal focused on 1) continued monitoring of the NSF-wide priorities known as the Big Ideas and 2) funding provided through the American Rescue Plan, in keeping with the Administration's commitment to the effective implementation and stewardship of ARP funds, as outlined in M-20-21, issued by OMB on March 19, 2021. Internally, tracking of ARP began in FY 2021, but the 100 percent funding target will not be applied until FY 2022 since these funds have a 2-year period of availability for obligation. For the Big Ideas, total obligations for the year exceeded the target by 4 percent; funding above the target was obligated in three areas: Convergence Accelerator, Navigating the New Artic, and Quantum Information Science.

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. Starting in FY 2019 NSF has monitored the Big Ideas as the "key NSF-wide program investments" of this goal, and 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 makes the goal more quantifiable and meaningful.

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 2020/FY 2021: Ensure that key NSF-wide program investments are implemented and on track.
- 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	CEMMS	SaTC	CIF21	SEES	UtB	INFEWS	NSF INCLUDES	Risk and Resilience
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

Goal 3, Ensure that Infrastructure Investments are on Track

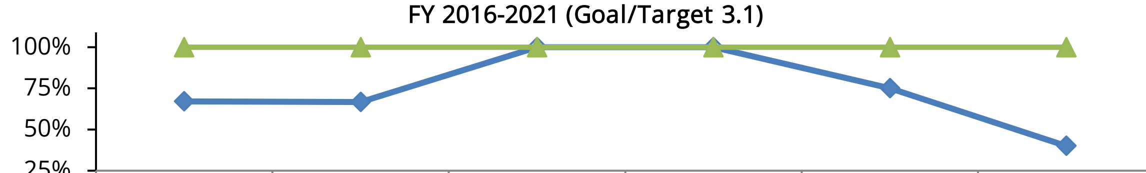
Lead Organization: Large Facilities Office, Office of Budget, Finance, and Award Management.

Goal Statement
Ensure program integrity and responsible stewardship of major research facilities and infrastructure.

Measure, Milestone, or Deliverable

Reporting Year		
FY	**Target**	**Result**
2021	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 above $20.0 million that are over 10 percent complete and using Earned Value Management (EVM) principles.	Not Achieved. 3 of 5 projects were behind schedule as of 9/30/2021. Achieved. Of the 5 ongoing projects, 3 are above the reporting threshold and all 3 are reporting cost/schedule data using EVM principles.
Measure Information for All Years		

Major Facility Construction Projects: Percent Meeting Cost & Schedule Targets
FY 2016-2021 (Goal/Target 3.1)



	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Result	67%	67%	100%	100%	75%	40%
Target	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 Major Research Equipment and Facilities Construction (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 major facility 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.

A second element for this goal was added in FY 2020 to track mid-scale research infrastructure projects and monitor whether these projects are tracking cost and schedule performance using EVM principles.

For both targets, projects that are under 10 percent complete are not considered eligible because EVM data is less meaningful statistically in the very early stages of a project.

<u>Discussion of FY 2021 Results and Explanation of Unmet Goal</u>
For the tracking of major facility construction projects (Target 3.1), five projects[3] were tracked in FY 2021: the Vera C. Rubin Observatory (Rubin), Regional Class Research Vessels (RCRV), Antarctic Infrastructure and Modernization for Science (AIMS), Compact Muon Solenoid (CMS), and A Toroidal LHC Apparatus (ATLAS).[4] As of September 30, all five reported being on-track for cost performance, and two (ATLAS and Rubin) reported also being on-track for schedule performance. Three projects reported not being on-track for schedule performance (RCRV, AIMS, and CMS), largely due to pandemic-related delays, and expect to see improved performance in FY 2022 and future years. (For additional information, please see the MREFC chapter.)

For the tracking of mid-scale infrastructure projects (Target 3.2), five projects over $20 million and using EVM were underway in FY 2021; three were more than 10 percent complete and therefore constitute the FY 2021 portfolio for this target: the Ice Cube Neutrino Observatory Upgrade (ICNO-U), the Laser Interferometer Gravitational-Wave Observatory A+ Upgrade (LIGO A+), and the High Magnetic Field Beamline (HMF). All three projects reported cost and schedule performance using EVM principles.

[3] The sixth project in this portfolio, the Daniel K. Inouye Solar Telescope (DKIST), was near completion in FY21 and was no longer reporting EVM metrics. NSF tracked final progress against milestones. DKIST completion was in first quarter FY22.
[4] CMS and Atlas are two projects with separate awards within the Large Hadron Collider High Luminosity Upgrade program. The EVM metrics are tracked separately for each project within this program.

Goal 4, Make Timely Proposal Decisions

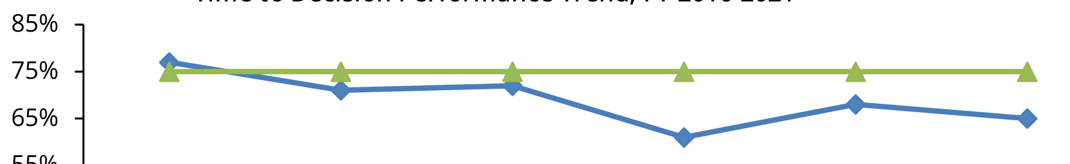
Lead Organization: Office of Integrative Activities.

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

Reporting Year		
FY	Target	Result
2021	75 percent.	Not Achieved. Result = 65 percent.
Measure Information for All Years		

Time to Decision Performance Trend, FY 2016-2021



	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Result	77%	71%	72%	61%	68%	65%
Target	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 inhibits the progress of research as it delays the funding process, but too short a time 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, with over 70 percent of proposals receiving responses in under 6 months for much of the past two decades. Years in which the target was missed were affected by significant external factors.[5] More recent surveys have shown that this is now the second most common concern mentioned by PIs (see Goal 5, Improve Review Quality, for more recent survey results).

[5] As discussed below, the agency's response to the COVID-19 pandemic has affected the timeliness of proposal decisions. In FY 2019, this goal was affected by a 35-day lapse in appropriations that shut down most of NSF's operations.

Discussion of FY 2021 Results and Explanation of Unmet Goal

The major factors that led to NSF missing this goal in FY 2021 included the need to focus the NSF response to the pandemic among existing awardees and the activities required to plan, allocate, and distribute the relief funding made available through the American Rescue Plan. Consistent with previous years, when unique events such as the agency's FY 2017 relocation disrupted normal operations, agency leadership determined that meeting this goal should be considered secondary to meeting more mission-critical responsibilities in the wake of the pandemic.

Goal 5, Improve Review Quality

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

Reporting Year		
FY	**Target**	**Result**
2021	In FY 2021, assess the feasibility of and develop the strategy and plan for measuring and piloting activities to improve the quality of written reviews.	Achieved. 5 of 5 milestones met.
Previous Years		
FY	**Target**	**Result**
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.	1. Achieved. Result = 313 programs. 2. Achieved. Result = 14,434 reviewers.
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. a. 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. b. 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.	Achieved. Achieved. Achieved.
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.	Achieved. Not achieved.

Strategic Alignment

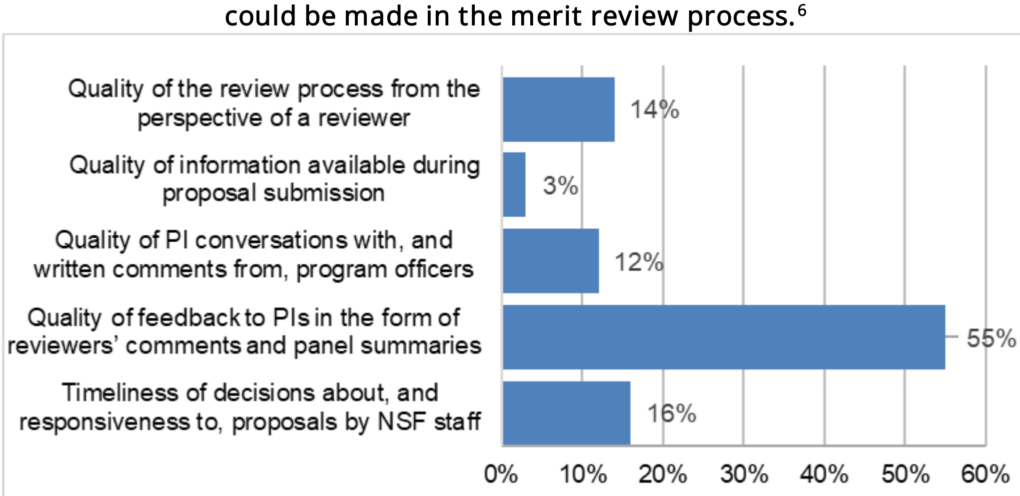
- Strategic Goal 1: Expand knowledge in science, engineering, and learning (all Objectives)
- Strategic Goal 3: Enhance NSF's performance of its mission. Objective 3.2, Processes and Operations: Continually improve agency operations.

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 highlights steps NSF has taken to improve the quality of written reviews. In previous years, it has focused on the implementation of a pilot program, initiated in December 2016, to improve the quality of written reviews of NSF proposals. That pilot encouraged 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. In FY 2021, activities associated with this goal focused on assessing and piloting a range of activities to improve the quality of written reviews, such as automated scoring of review quality. This work will inform the development of a new target in future years, ensuring that the new target is aligned with the agency's new strategic plan.

Percentage of respondents identifying each item as the most significant improvement that could be made in the merit review process.[6]



Discussion of FY 2021 Results

The FY 2021 target for this goal encompassed five milestones that broke down into three sub-initiatives: management and governance of the proposal review process (Milestone 1), piloting a new panel review system (Milestones 2 & 3), and implementing improvements to an experimental automated process to assess review quality (Milestones 4 & 5). All five milestones were achieved during FY 2021.

[6] FY 2015 Merit Review Report, p.126. www.nsf.gov/nsb/publications/2016/nsb201641.pdf

Goal 6, Foster a Culture of Inclusion

Lead Organization: Office of Equity and Civil Rights (OECR), Office of the Director.[7]

<u>Goal Statement</u>
Foster a culture of inclusion through change management efforts resulting in change leadership and accountability.

<u>Measure, Milestone, or Deliverable</u>

Reporting Year		
FY	**Target**	**Result**
2021	All NSF leaders will participate in culture change activities.	Achieved. Result = 100 percent.
Reporting Year		
FY	**Target**	**Result**
2020/ 2021	All NSF leaders will participate in culture change activities.	Not Achieved. Result = 96.2 percent.
2019	In FY 2019, 100 percent of NSF leaders will participate in culture change activities.	Not Achieved
2018	By September 30, 2018, the Office of Diversity and Inclusion (ODI) will conduct the New Inclusion Quotient (New IQ) process with four organizational units. Improve the four NSF organizational units' New IQ Self-Survey Scores by five percent above established baseline.	Achieved. Achieved.
2017	By September 30, 2017, ODI will conduct the New IQ process with three additional organizational units. Improve the three NSF organizational units' New IQ Self-Survey Scores by seven percent above established baseline.	No targets achieved.
2016	By September 30, 2016, ODI will conduct the New IQ process with two NSF organizational units. 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 Equal Employment Opportunity (EEO) agency and perform two compliance desk reviews under antidiscrimination laws.	Not Achieved

[7] During FY 2021, the ODI changed its name to the Office of Equity and Civil Rights; this change does not signify a change in goal ownership.

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 OMB Memorandum 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 ensuring 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 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.

Beginning in 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 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.

Discussion of FY 2021 Results
In FY 2021, NSF maintained the same framework for this goal and target as in FY 2020: "culture change activities" are defined as participation in anti-harassment and anti-bullying training; and the target requires that all managers and executives on board more than 30 days complete the training by the end of the fiscal year. For this year, the target population of managers and executives totaled 248 people, and all of them completed the required training before September 30, 2021.

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" status. Starting in FY 2016, this goal focused on inclusion,

and New IQ workshops were made available to NSF staff. The focus on leadership represented another new direction for this goal in FY 2019, when 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.

For more information on the Model EEO Agency formulation of this goal, refer to the FY 2015 Annual Performance Report in the FY 2017 NSF Budget Request:
(www.nsf.gov/about/budget/fy2017/pdf/56_fy2017.pdf).

For more information on the New IQ formulation of this goal, refer to the FY 2018/FY 2020 APPR in the FY 2020 NSF Budget Request (www.nsf.gov/about/budget/fy2020/pdf/67_fy2020.pdf).

Goal 7, Align Job Requirements with Competencies

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

Reporting Year		
FY	**Target Summary**	**Result**
2021	Eliminate 100 obsolete position descriptions in FY 2021.	Achieved. Result = 1,742 PDs eliminated.
Previous Year		
FY	**Target Summary**	**Result**
2020	In FY 2020, the Division of Human Resource Management will review, modernize, or eliminate 10 percent of the existing position descriptions requiring review.	Not applicable.
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.
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 OMB Memorandum 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. Further, NSF is promoting transdisciplinary and convergent research and will need to ensure its current and future workforce can adapt to this convergent approach. As technological systems increase in complexity, greater support is needed in data processing, data mining, analytics, and use of automated processes. 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 that are outdated or do not reflect current and future work responsibilities. This position description 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.

<u>Goal Change History</u>
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 in the IT and HR domains.

In FY 2019, NSF had identified a pool of 400 position descriptions that had the potential for being either updated or eliminated, based on vacancy rate or consolidation with other types of positions. The 10 percent target was measured against that denominator in FY 2019. In mid-FY 2020, NSF revisited this limitation and determined that limiting the review to 400 predefined position descriptions no longer effectively supported the goal (Ensure that employee job requirements are aligned with competencies and skills needed for the future) or the priority from the Renewing NSF effort that motivated the goal (Adapting the NSF Workforce to the Work). Rather than continue tracking and reporting against the previous measure, NSF switched to a broader review of several thousand NSF position descriptions. This rendered the 10 percent target inapplicable since it was devised in relation to a smaller denominator, and the target of 100 PDs was established for FY 2021.

<u>Discussion of FY 2021 Result</u>
As is noted above, FY 2021 was the first year where the focus of this goal was the broader review of several thousand position descriptions. The target of 100 PDs eliminated was therefore set conservatively in recognition of the general uncertainty associated with the resources required to implement this process. The result achieved for FY 2021 (1,742 PDs retired) reflects efficiencies that were achieved during the year.

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

Reporting Year		
FY	**Target Summary**	**Result**
2021	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. 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.	1. Achieved. Result = 99.8 percent. 2. Achieved. Result = 86 percent. 3. Not Achieved. Result = 41 percent.
Previous Year		
FY	**Target**	**Result**
2020	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.	Achieved. Result = 99.8 percent . Not Achieved. Result = 79 percent. Not Achieved. Result = 41 percent
2019	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.	1. Achieved 2. Achieved 3. Achieved
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 3.2, 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 OMB Memorandum 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 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 2021 Result
Target 1, measuring system uptime, was exceeded. Targets 2 and 3 encompass a multi-year effort to establish single portals for NSF's internal and external merit review functions, to streamline and simplify user interactions with systems supporting the NSF mission. The effort began in FY 2017, and multi-year targets were set for 86% (25 of 29) of internal merit review functions and 64% (14 of 22) of external merit review functions to be accessible via single portals by the end of FY 2021. Intervening-year targets were established to monitor the overall progress of the effort and ensure it remained on track. In FY 2021, of its three targets, the one for streamlining externally facing merit review systems was not achieved. This area was affected by key decisions to reprioritize IT investments to focus on external customer experience enhancements, such as developing a demonstration and training environment for the research community, and to improve the collection of data needed to inform strategies for improving equity and inclusion among principal investigators.

FY 2021 MANAGEMENT CHALLENGE PROGRESS REPORT

Background

Under the Reports Consolidation Act of 2000, NSF's Inspector General is required to submit a memo to the NSF Director summarizing what it considers to be the most significant management and performance challenges facing NSF in the coming fiscal year. In response, the Director provides a report on NSF's progress and achievements made over the prior year in relation to each management challenge.

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 published in November.[1] This section is a republication of NSF's summary of the FY 2021 OIG Management Challenge progress reports, which appeared in the Management Discussion and Analysis section of the FY 2021 Agency Financial Report.[2] It highlights the significant actions taken in FY 2021 on the management challenges identified by NSF's Inspector General at the beginning of that fiscal year. The FY 2022 Progress Update will be published in November 2022.

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 key actions NSF has already taken to address those risks.

FY 2021 Management Challenges

In October 2020, the OIG identified six areas representing challenges for the agency for FY 2021: (1) Providing Oversight of Major Multi-User Research Facilities, (2) Providing Oversight of Grants During a Pandemic, (3) Managing the Intergovernmental Personnel Act Program, (4) Providing Oversight of the Antarctic Infrastructure Modernization for Science (AIMS) Project, (5) Increasing Diversity in Science & Engineering Education and Employment, and (6) Mitigating Threats Posted by Foreign Government Talent Recruitment Programs.[3] Some of the agency's significant actions and planned next steps to address the challenges are highlighted below.

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[1] Prior year Agency Financial Reports are available at www.nsf.gov/about/performance/annual.jsp

[2] The summary of the FY 2021 Management Challenges is included in the FY 2021 Agency Financial Report on p. MD&A-12. The full progress reports are included in Appendix 3 of that document on p. Appendices (OI)-21. www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf22002.

[3] The Inspector General's Memorandum on Management Challenges for NSF in FY 2021 is in NSF's *FY 2020 Agency Financial Report, Appendix 2A.* www.nsf.gov/pubs/2021/nsf21002/pdf/08-chap3-appendices.pdf

Providing Oversight of Major Multi-User Research Facilities

NSF understands the importance of its role in overseeing current award recipients' on-going management of major facilities, and of assessing prospective recipients' capabilities for managing major facilities prior to award. Over the past several years, NSF has greatly strengthened its oversight policies and procedures in response to prior OIG audits and four Government Accountability Office (GAO) reviews related to its oversight of projects funded from the Major Research Equipment and Facilities Construction account.

NSF leadership continues to show its commitment to major facilities oversight through appointment of the Chief Officer for Research Facilities and through the annual Major Facilities Portfolio Risk Assessment process. Further, NSF has taken significant actions in recent years to mitigate the risks inherent in the major facilities portfolio, including the unprecedented degree of complexity and uncertainty resulting from the COVID-19 pandemic. Such actions include, but are not limited to: (1) completing the major facilities portfolio workforce gap analysis and beginning development of a training plan tied specifically to the major facility oversight competency model, (2) producing a regular report on COVID-19 impacts on major facilities in both the operations and construction stages, and (3) revising standard operating guidance for NSF grants and agreements officers on the pre-award review process, which includes business and financial reviews, in line with GAO guidance. In addition, NSF took action to address the unique risks presented by the COVID-19 pandemic, including potential improper use of budget contingency funds, by developing internal and external guidance for major facility programs and recipients. The controls developed in response to the pandemic will be more widely applicable to other unforeseen events, such as when the shipyard constructing the Regional Class Research Vessels experienced significant damage from Hurricane Ida in August 2021. NSF is confident that its current and planned controls related to major facility oversight adequately consider and balance risk, resources, benefit to the science community, and stewardship of federal funds.

Going forward, NSF will finalize the *Major Facilities Oversight Reviews* standard operating guidance and provide it to OIG and GAO for consideration in closing remaining recommendations. NSF will also complete development and implementation of the training plan for the major facilities oversight workforce and monitor progress through periodic self-assessment surveys or other means.

Providing Oversight of Grants During a Pandemic

Throughout the COVID-19 pandemic, the research community has faced unprecedented challenges that have tested the people and infrastructure that make up the U.S. scientific research enterprise. Given these challenges, NSF recognized there may be heightened risk in grants programs compared to prior years, and that existing oversight processes may not align with challenges presented by the pandemic. In response to these risks, NSF has demonstrated strong commitment to ensuring continued operations and maintenance of oversight functions, including ensuring sufficient people and resources to operate in a pandemic, and has established processes to monitor spending of pandemic-related funding. NSF was able to maintain advanced monitoring and oversight activities through virtual site visits, desk reviews, targeted assessments, audit resolution, and new analytic approaches focused on the grant and cooperative agreement award portfolio.

In FY 2021, NSF demonstrated progress in addressing the challenges created by the COVID-19 pandemic in the following areas: (1) policy and outreach, including disseminating new guidance on the NSF Coronavirus webpage for the grants community to address emerging NSF and government-wide COVID-19 policies; (2) grants oversight, including implementation of internal NSF dashboards to monitor potential grant risk factors around expenditure patterns and post-award adjustments; and (3) risk management and internal controls, including conducting annual testing of grant award expenditures covering April 2020 through March 2021 to update the improper payment risk baseline, which indicated a similarly low risk level as in prior year testing results.

Going forward, NSF will continue to assess and minimize risk through activities such as issuing updated guidance as necessary, monitoring compliance through site visits and desk reviews, updating and enhancing financial reporting, and issuing a final improper payment risk assessment report.

Managing the Intergovernmental Personnel Act (IPA) Program

NSF provides the opportunity for scientists, engineers, and educators to rotate into the Foundation on a temporary basis, bringing fresh perspectives from across all fields of science and engineering supported by the agency. OIG has noted risks related to these rotators remaining involved in their professional research and development activities while working at NSF; and the COVID-19 pandemic has brought new and unique challenges to this program, including recruiting, onboarding, and managing IPAs in a remote work environment. NSF takes a proactive approach to the management of the IPA Program to appropriately consider and mitigate inherent risks associated with its execution, including through an IPA Steering Committee that advises the Foundation's senior leadership on matters that directly concern policy on the use of the IPA Program. NSF engages in continuous improvement of its management of the IPA Program, addressing the management challenges identified by the OIG as well as other agency-identified risks and challenges.

In recent years, NSF has completed numerous actions to address the management challenges identified by the OIG related to the IPA program. Through these actions, NSF is confident it has reduced the inherent risk substantially and that the benefits of the program outweigh the residual risk. Specific accomplishments in FY 2021 include (1) migrating Program Director and Executive IPAs to the USA Performance system for managing performance plans, (2) facilitating a focus group of IPAs who onboarded during the pandemic, to help identify new and unique challenges associated with onboarding in a remote work environment, and (3) establishing a plan to collect and analyze FY 2021 data on IPA recruiting, onboarding, and costs attributed to the COVID-19 pandemic to be included in the FY 2021 IPA Annual Report.

Going forward, NSF will continue to monitor risk and manage the IPA program through actions such as providing annual training for independent research/development (IR/D) experts; collecting quarterly data on IR/D time and travel by both permanent and rotating staff for oversight by NSF senior management; and using the Federal Employee Viewpoint Survey and other mechanisms to help identify challenges to the program, including recruiting, onboarding, and managing IPAs in a remote work environment.

Providing Oversight of the Antarctic Infrastructure Modernization for Science (AIMS) Project

NSF—through the Office of Polar Programs in the Directorate for Geosciences—funds and manages the U.S. Antarctic Program which supports the United States' research and national policy goals in the Antarctic. The U.S. Antarctic Program has two major construction projects to replace multiple outdated structures and consolidate key functions for more streamlined and efficient operations, one of which is the Antarctic Infrastructure Modernization for Science (AIMS) project. The OIG identified the AIMS project as one that will require continued vigilance, as it will stretch agency resources and may present additional challenges. While NSF agrees there are inherent risks associated with Antarctica's remote location, extreme environment, and the short period of time during which the continent is accessible, NSF has mitigated risk through actions such as extensive planning and coordination to meet equipment delivery dates.

The global pandemic associated with COVID-19 resulted in significant changes to program and construction project plans as deployed construction crews were brought home due to health and safety concerns. In accordance with NSF policy, the magnitude of these impacts will require re-baselining of the AIMS project and the Office of Polar Programs is actively engaged with the contractor; the Office of Budget, Finance, and Award Management; and the Office of the Director for that purpose. In FY 2021, NSF acquired no-cost access to long-term storage for materials, and convened NSF leadership to evaluate options for project re-baselining and to develop a new path forward that transitions AIMS to a long-term Antarctic Infrastructure Recapitalization program.

Going forward, NSF will continue to monitor and oversee AIMS, under established internal management and project execution plans, while working to re-baseline the project cost and schedule. NSF will also conduct quarterly NSF integrated project team meetings to ensure the status of AIMS developments is communicated and to solicit expert feedback.

Increasing Diversity in Science & Engineering Education and Employment

Efforts to increase diversity in science and engineering (S&E) education and employment have been a hallmark of NSF since its founding, and throughout its history. The agency has pursued a variety of program and policy approaches to increasing diversity in S&E. Broadening participation is the focus or emphasis of a number of programs, and this emphasis is demonstrated within the entire NSF portfolio through the broader impacts criterion used in the merit review process. This challenge remains a priority for NSF: while there have been noteworthy areas of progress, such as increases in the shares of individuals in S&E occupations from racial and ethnic groups historically underrepresented in STEM,[4] the groups and communities that have been underrepresented and underserved in the STEM arena for decades remain so today.

NSF fully recognizes that its efforts to advance diversity and promote inclusion warrant unprecedented urgency, in keeping with the national imperative outlined by the Administration and its Racial Equity Executive Order (Executive Order 13985)[5] and also the global trends in science and outlined by the NSB in the *Vision 2030* report.[6] Efforts to address this challenge span across every NSF Directorate and Office. Specific actions in FY 2021 to increase diversity in S&E education and employment included (1) release of the 2021 Women, Minorities, and Persons with Disabilities in Science and Engineering report, providing data on participation of these groups in S&E education and

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[4] National Center for Science and Engineering Statistics data on underrepresented minorities in science and engineering occupations, by broad occupational category: 2003 and 2017 https://ncses.nsf.gov/pubs/nsb20201/figure/8

[5] Executive Order 13985, www.whitehouse.gov/briefing-room/presidential-actions/2021/01/20/executive-order-advancing-racial-equity-and-support-for-underserved-communities-through-the-federal-government/

[6] The NSB's *Vision 2030* report is available at www.nsf.gov/nsb/publications/2020/nsb202015.pdf

employment, (2) organizational changes within NSF to streamline processes and procedures related to equity and civil rights issues, and (3) releasing new funding opportunities related to broadening participation and to assessing the impacts of COVID-19 on students from groups historically underrepresented in STEM.[7]

Going forward, NSF will focus attention on milestones in line with its operational and strategic objectives in the area of increasing diversity, including: (1) continuing implementation work to strengthen the engagement of historically Black colleges and universities (HBCUs) in NSF's programs, in line with Executive Order 13985, (2) continuing to examine the challenges of the availability of limited data on certain groups of individuals known to be underrepresented in STEM, and (3) in keeping with the agency's response to Executive Order 13985, finalizing the strategic framing of efforts to ensure accessibility and inclusivity in the NSF Strategic Plan for FY 2022-2026, and its associated performance activities, with public release scheduled for February 2022.

Mitigating Threats Posted by Foreign Government Talent Recruitment Programs

The National Science Foundation seeks to maintain a vibrant science and engineering community for the benefit of the Nation. Participation in this community relies on individuals to uphold core principles and values such as openness, transparency, reciprocity, collaboration, and integrity. However, open scientific exchange and research face a challenge from some foreign governments through the use of talent recruitment programs. Some of these programs deliberately disregard these core principles and incentivize participants to misappropriate U.S.-funded scientific research prior to its open publication. These programs target scientists, engineers, and educators of all nationalities working or educated in the United States.

In FY 2021, NSF took multiple actions to demonstrate progress on this issue, including (1) release of a new training for NSF staff on assessing disclosures required as part of the proposal process, (2) outreach to the academic community through numerous meetings and conferences to raise awareness of the risks posed by foreign government talent recruitment programs, and (3) collaborating with OIG to address threats posed by foreign government talent recruitment programs, including recouping or preventing the loss of millions of taxpayer dollars through actions to suspend or terminate awards.

Going forward, NSF will continue to work diligently to address the risks of foreign government interference in NSF-funded research. This work will include development of a comprehensive plan of additional actions to address threats from foreign government interference, and evaluation of recommendations related to (1) enhancing awareness of research security risks and protections, (2) strengthening disclosure requirements, (3) information sharing across U.S. government agencies, including OIG, and (4) risk identification and analysis.

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[7] The 2021 *Women, Minorities, and Persons with Disabilities in Science and Engineering* report is available at https://ncses.nsf.gov/pubs/nsf21321

GAO-IG ACT EXHIBITS

Pursuant to P.L. 115-414, the Good Accounting Obligation in Government Act (GAO-IG Act), the following three tables report on unresolved NSF OIG and the U.S. Government Accountability Office (GAO) recommendations open for more than one year and their associated statuses as of March 1, 2022.

Open OIG Recommendations – Internal Audits

OIG Number	Audit Report Title	OIG Recommendation – Internal Audit	Date of Audit Report Issued	Status as of March 1, 2022[1]
17-2-009	Audit of Preservation of Electronic Records and Cooperation with Congressional Requests	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.	7/6/2017	Recommendation Resolved and Open
19-2-003	NSF Could Improve its Controls to Prevent Inappropriate Use of Electronic Devices	4. Ensure that all existing NSF-owned mobile devices (iPhones and iPads) are enrolled in AirWatch.	12/21/2018	Recommendation Resolved and Open
19-2-005	Performance Audit over the Improper Payments Elimination and Recovery Act	Update its risk assessment (i.e., Survey, ICQA risk assessment) to include all relevant leadership and key personnel of the program and activities (e.g., OPP), regardless of whether they are under BFA, to strengthen the thoroughness and quality of information gathered and evaluated to obtain adequate risk assessment results	5/10/2019	Recommendation Resolved and Open
19-2-005	Performance Audit over the Improper Payments Elimination and Recovery Act	Develop policies and procedures (i.e., SOPs) to provide formal instructions on the Recapture Table development process and ensure consistency on how the various sets of documentation and reports are used to identify recapture amounts within the Recapture Table.	5/10/2019	Recommendation Resolved and Open

[1] Resolved recommendations reflect those where OIG and NSF agree on corrective actions, but the implementation of those corrective actions is ongoing.

OIG Number	Audit Report Title	OIG Recommendation – Internal Audit	Date of Audit Report Issued	Status as of March 1, 2022[1]
19-2-005	Performance Audit over the Improper Payments Elimination and Recovery Act	Strengthen communication between DFM and RAM to ensure that complete and accurate reports (e.g., PAAR report) are used to develop the Recapture Table Amounts.	5/10/2019	Recommendation Resolved and Open
19-2-005	Performance Audit over the Improper Payments Elimination and Recovery Act	Update the process to identify contract-related overpayments by DFM, to include consideration of payment credits processed via IPP, to ensure complete and accurate information is used to develop its Recapture Table amounts.	5/10/2019	Recommendation Resolved and Open
19-2-006	Audit of NSF's Controls to Prevent Misallocation of Major Facility Expenses	6. Require an independent panel to review construction completion and facility readiness prior to the acceptance of a major facility.	6/21/2019	Recommendation Resolved and Open
20-2-002	FISMA Audit for FY19	5. NSF Screening Process 5.2. Implement procedures, including a formal monitoring program, to ensure that the screening process and all associated documentation is completed for full-time and seasonal individuals before access is granted to the USAP network.	11/22/2019	Recommendation Resolved and Open
20-2-002	FISMA Audit for FY19	6. Authentication and Identification 6.3. Perform a risk assessment to determine what is required to implement PIV authentication, including documenting any circumstances that would not allow a successful implementation in all operating locations. NSF should prioritize the HSPD-12 implementation for USAP users and deploy necessary resources to fully implement PIV authentication for regular user and privileged/administrator-level access to the USAP network.	11/22/2019	Recommendation Resolved and Open

OIG Number	Audit Report Title	OIG Recommendation – Internal Audit	Date of Audit Report Issued	Status as of March 1, 2022[1]
20-2-002	FISMA Audit for FY19	7. Incident Response Tool Develop a plan and obtain and deploy necessary resources to implement monitoring and alerting tools such as a Security Information and Event Management (SIEM) tool into the USAP IT environment.	11/22/2019	Recommendation Resolved and Open
20-2-004	Audit of WHOI-NSF Review of WHOI Cost Containment Measures	3. NSF should develop internal and external guidance to ensure all operations proposals include an evaluation of key operational risks, their potential cost and scientific impacts, and mitigation strategies. The guidance should include instructions on determining whether to conduct a risk and uncertainty analysis or a sensitivity analysis, and how to document that analysis.	4/14/2020	Recommendation Resolved and Open
20-6-003	Management Notification re SSN Access in Report Database	3. Take steps to regularly remove or recertify access to sensitive information, including SSNs, in the Report Database to ensure only individuals with continuing business need may view this sensitive information.	9/16/2020	Recommendation Resolved and Open

Open OIG Recommendation – External Audits

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
19-1-008	University of Utah (4/17/2019)	1.1) Resolve the $21,286 in questioned costs for unsupported stipend costs	Unresolved	TBD	$21,286	TBD	TBD	4/30/22
19-1-008	University of Utah (4/17/2019)	1.2) Direct Utah to ensure that policies and procedures are in place for charging only appropriate expenses to participant support costs	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-008	University of Utah (4/17/2019)	2.1) Resolve the $13,147 in questioned costs for indirect costs inappropriately applied to capital equipment on IGERT award	Unresolved	TBD	$13,147	TBD	TBD	4/30/22
19-1-008	University of Utah (4/17/2019)	2.2) Direct Utah to develop new policies and procedures to ensure the application of indirect costs on capital equipment is properly recorded in acct system	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-008	University of Utah (4/17/2019)	2.3) Direct Utah to develop new policies and procedures that require Utah to periodically review expenses, and other budget categories.	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-008	University of Utah (4/17/2019)	3.1) Resolve the $7,724 in questioned costs for unallocable and/or unreasonable expenses near award expiration	Unresolved	TBD	$7,724	TBD	TBD	4/30/22
19-1-008	University of Utah (4/17/2019)	3.2) Direct Utah to develop policies and procedures to ensure purchases are made timely within the award period of performance to support the award.	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-008	University of Utah (4/17/2019)	4.1) Direct Utah to develop new policies and procedures to strengthen controls over expense classifications.	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-008	University of Utah (4/17/2019)	5.1) Direct Utah to review guidance on PSCs and determine if strengthening controls over payroll and PSC expense classifications are necessary.	Unresolved	TBD	$0	TBD	TBD	4/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
19-1-008	University of Utah (4/17/2019)	5.2) Direct Utah to enhance enforcement of policies and procedures that require Utah to periodically review payroll expenses to ensure transactions are posted accurately.	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-008	University of Utah (4/17/2019)	6.1) Direct Utah to develop new policies and procedures to strengthen controls over the petty cash policy and ensure cash does not exceed the total authorized amount.	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-008	University of Utah (4/17/2019)	7.1) Direct Utah to review policies and procedures to ensure that Utah has adequate controls over the NICRA rates and uses the rates in effect at the time of the initial award.	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-010	University of Maryland College Park (5/2/2019)	1.1) Resolve the $101,937 in questioned costs related to unreasonable and unallocable payroll transfers near award expiration.	Unresolved	TBD	$101,937	TBD	TBD	4/30/22
19-1-010	University of Maryland College Park (5/2/2019)	1.2) Direct UMD to strengthen administrative and management controls and processes over payroll expenditures.	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-010	University of Maryland College Park (5/2/2019)	2.1) Resolve the $79,956 in questioned costs for equipment purchases near award expiration.	Unresolved	TBD	$79,956	TBD	TBD	4/30/22
19-1-010	University of Maryland College Park (5/2/2019)	2.2) Direct UMD to strengthen admin and mang controls and processes related to the review of expenditures charged to Federal awards.	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-010	University of Maryland College Park (5/2/2019)	3.1) Resolve the $43,710 in questioned costs for unsupported charges for data collection services, conference fees, & equipment purchases.	Unresolved	TBD	$43,710	TBD	TBD	4/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
19-1-010	University of Maryland College Park (5/2/2019)	3.2) Direct UMD to provide support that it has repaid the $1,918 of unsupported questioned costs for equipment purchased.	Unresolved	TBD	$1,918	TBD	TBD	4/30/22
19-1-010	University of Maryland College Park (5/2/2019)	3.3) Direct UMD to implement policies and procedures to ensure NSF approves changes to the scope of work regarding subcontractors, and, maintain source documentation to properly support charges to Federal awards.	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-010	University of Maryland College Park (5/2/2019)	4.1) Resolve the $37,812 in questioned costs for equipment and supply purchases near or after award expiration date, and direct UMD to repay or otherwise remove the sustained questioned costs from its NSF awards	Unresolved	TBD	$37,812	TBD	TBD	4/30/22
19-1-010	University of Maryland College Park (5/2/2019)	4.2) Direct UMD to strengthen admin and mgt controls and processes over equipment & supply expenditures near the end of an award.	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-010	University of Maryland College Park (5/2/2019)	5.1) Resolve the $31,697 in questioned costs for lab & computer equipment allocations, and direct UMD to repay or otherwise remove the sustained questioned costs from its NSF awards.	Unresolved	TBD	$31,697	TBD	TBD	4/30/22
19-1-010	University of Maryland College Park (5/2/2019)	5.2) Direct UMD to strengthen admin and mgt controls over allocation of lab & computer equipment costs benefitting multiple awards or projects.	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-010	University of Maryland College Park (5/2/2019)	6.1) Resolve the $24,559 in questioned travel costs, and direct UMD to repay or otherwise remove the sustained questioned costs from its NSF awards.	Unresolved	TBD	$24,559	TBD	TBD	4/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
19-1-010	University of Maryland College Park (5/2/2019)	6.2) Direct UMD to strengthen admin and mgt controls and processes over travel costs, including identifying guidelines for determining reasonableness of lodging costs	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-010	University of Maryland College Park (5/2/2019)	7.1) Resolve the $13,905 in questioned costs for unreasonable travel and equipment cost transfers	Unresolved	TBD	$13,905	TBD	TBD	4/30/22
19-1-010	University of Maryland College Park (5/2/2019)	7.2) Direct UMD to strengthen administrative and management policies and procedures relating to travel & equipment cost transfers .	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-010	University of Maryland College Park (5/2/2019)	8.1) Direct UMD to provide support that is has repaid the $12,659 of questioned indirect costs	Unresolved	TBD	$12,659	TBD	TBD	4/30/22
19-1-010	University of Maryland College Park (5/2/2019)	8.2) Direct UMD to strengthen admin and mgt controls and processes for reviewing and approving indirect costs for equipment purchases charged to NSF awards	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-010	University of Maryland College Park (5/2/2019)	9.1) Resolve the $8,955 in questioned costs for unallowable public relation costs	Unresolved	TBD	$8,955	TBD	TBD	4/30/22
19-1-010	University of Maryland College Park (5/2/2019)	9.2) Strengthen admin and mgt controls and processes to ensure unallowable public relation cost are not charged to NSF awards	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-011	University of Delaware (4/29/2019)	1.1) Resolve the $233,075 in questioned inadequately supported costs	Unresolved	TBD	$233,075	TBD	TBD	4/30/22
19-1-011	University of Delaware (4/29/2019)	1.2) Direct UD to strengthen controls and implement policies related to source documentation.	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-011	University of Delaware (4/29/2019)	2.1) Resolve the $125,458 in questioned equipment costs	Unresolved	TBD	$125,458	TBD	TBD	4/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
19-1-011	University of Delaware (4/29/2019)	2.2) Direct UD to strengthen its administrative and management controls and processes	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-011	University of Delaware (4/29/2019)	3.1) Resolve the $44,469 in questioned travel costs	Unresolved	TBD	$44,469	TBD	TBD	4/30/22
19-1-011	University of Delaware (4/29/2019)	3.2) Direct UD to develop and implement travel policies and procedures	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-011	University of Delaware (4/29/2019)	4.1) Resolve the $19,208 in questioned material and supply costs	Unresolved	TBD	$19,208	TBD	TBD	4/30/22
19-1-011	University of Delaware (4/29/2019)	4.2) Direct UD to develop and implement policies and procedures over material and supply purchases.	Unresolved	TBD	$0	TBD	TBD	3/31/22
19-1-011	University of Delaware (4/29/2019)	5.1) Resolve the $2,465 in questioned indirect costs	Unresolved	TBD	$2,465	TBD	TBD	3/31/22
19-1-011	University of Delaware (4/29/2019)	5.2) Direct UD to strengthen its administrative and management controls and processes related to indirect costs.	Unresolved	TBD	$0	TBD	TBD	3/31/22
19-1-011	University of Delaware (4/29/2019)	6.1) Resolve the $1,992 in questioned payroll costs	Unresolved	TBD	$1,992	TBD	TBD	3/31/22
19-1-011	University of Delaware (4/29/2019)	6.2) Direct UD to strengthen its administrative and management controls over payroll transfers	Unresolved	TBD	$0	TBD	TBD	3/31/22
19-1-016	Ohio State University (8/8/2019)	1.1) Resolve the $304,977 questioned equipment, materials/supplies, consulting/services, travel and other costs	Unresolved	TBD	$304,977	TBD	TBD	9/30/22
19-1-016	Ohio State University (8/8/2019)	1.2) Direct OSU to strengthen the administrative and management controls and processes over allocating expenses	Unresolved	TBD	$0	TBD	TBD	9/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
19-1-016	Ohio State University (8/8/2019)	1.3) Direct OSU to strengthen the administrative and management controls and processes over purchasing equipment and materials/supplies at the end of a project's POP	Unresolved	TBD	$0	TBD	TBD	9/30/22
19-1-016	Ohio State University (8/8/2019)	2.1) Resolve the $76,822 questioned subaward costs	Unresolved	TBD	$76,822	TBD	TBD	9/30/22
19-1-016	Ohio State University (8/8/2019)	2.2) Direct OSU to strengthen the administrative and management controls and processes over transferring significant parts of federally funded research	Unresolved	TBD	$0	TBD	TBD	9/30/22
19-1-016	Ohio State University (8/8/2019)	3.1) Resolve the $67,006 questioned software, salary, and travel costs	Unresolved	TBD	$67,006	TBD	TBD	9/30/22
19-1-016	Ohio State University (8/8/2019)	3.2) Direct OSU to strengthen the administrative and management controls and processes over obtaining and maintaining sufficient supporting documentation	Unresolved	TBD	$0	TBD	TBD	9/30/22
19-1-016	Ohio State University (8/8/2019)	4.1) Resolve the $46,178 questioned salary, travel, participant support, pre-award, promotional, and foreign currency costs	Unresolved	TBD	$46,178	TBD	TBD	9/30/22
19-1-016	Ohio State University (8/8/2019)	4.2) Direct OSU to strengthen the administrative and management procedures over allocating salary expenses	Unresolved	TBD	$0	TBD	TBD	9/30/22
19-1-016	Ohio State University (8/8/2019)	4.3) Direct OSU to strengthen the administrative and management procedures over allocating travel expenses	Unresolved	TBD	$0	TBD	TBD	9/30/22
19-1-016	Ohio State University (8/8/2019)	4.4) Direct OSU to strengthen the administrative and management procedures over allocating PSCs	Unresolved	TBD	$0	TBD	TBD	9/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
19-1-016	Ohio State University (8/8/2019)	4.5) Direct OSU to strengthen the administrative and management procedures over allocating pre-award expenses	Unresolved	TBD	$0	TBD	TBD	9/30/22
19-1-016	Ohio State University (8/8/2019)	4.6) Direct OSU to strengthen the administrative and management procedures over allocating promotion-related expenses	Unresolved	TBD	$0	TBD	TBD	9/30/22
19-1-016	Ohio State University (8/8/2019)	4.7) Direct OSU to strengthen the administrative and management procedures over allocating expenses involving foreign currency	Unresolved	TBD	$0	TBD	TBD	9/30/22
19-1-016	Ohio State University (8/8/2019)	5.1) Resolve the $7,604 questioned indirect costs	Unresolved	TBD	$7,604	TBD	TBD	9/30/22
19-1-016	Ohio State University (8/8/2019)	5.2) Direct OSU to strengthen the administrative and management controls and processes over applying indirect costs	Unresolved	TBD	$0	TBD	TBD	9/30/22
19-1-016	Ohio State University (8/8/2019)	6.1) Direct OSU to clarify its existing policies surrounding payments to human research subjects to establish a formal process/procedure and reasonable deadline(s)	Unresolved	TBD	$0	TBD	TBD	9/30/22
19-1-016	Ohio State University (8/8/2019)	6.2) Direct OSU to strengthen the administrative and management procedures in place surrounding payments to human research subjects	Unresolved	TBD	$0	TBD	TBD	9/30/22
19-1-016	Ohio State University (8/8/2019)	7.1) Direct OSU to strengthen the administrative and management controls and processes over establishing indirect cost rates	Unresolved	TBD	$0	TBD	TBD	9/30/22
19-1-016	Ohio State University (8/8/2019)	8.1) Direct OSU to strengthen the administrative and management procedures over procurement and travel	Unresolved	TBD	$0	TBD	TBD	9/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
19-1-016	Ohio State University (8/8/2019)	9.1) Direct OSU to update its accounting system to ensure that it correctly applies and removes fringe benefits using the fringe benefit rates	Unresolved	TBD	$0	TBD	TBD	9/30/22
19-1-016	Ohio State University (8/8/2019)	10.1) Direct OSU to strengthen the administrative and management procedures in place surrounding student employment agreements	Unresolved	TBD	$0	TBD	TBD	9/30/22
19-1-017	Oregon State University (9/13/2019)	1.1) Resolve the $169,950 in questioned consulting and subaward costs and direct OSU to repay or otherwise remove the sustained questioned costs from its NSF awards.	Unresolved	TBD	$169,950	TBD	TBD	4/30/22
19-1-017	Oregon State University (9/13/2019)	1.2) Direct OSU to establish a policy to ensure that OSU employees are not paid as both employees and independent contractors.	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-017	Oregon State University (9/13/2019)	1.3) Direct OSU to strengthen its administrative and management procedures over awarding subawards	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-017	Oregon State University (9/13/2019)	2.1) Resolve the $78,153 in questioned costs	Unresolved	TBD	$78,153	TBD	TBD	4/30/22
19-1-017	Oregon State University (9/13/2019)	2.2) Direct OSU to strengthen its administrative and management procedures for obtaining NSF's approval	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-017	Oregon State University (9/13/2019)	2.3) Direct OSU to strengthen its administrative and management procedures for allocating salary expenses to sponsored projects.	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-017	Oregon State University (9/13/2019)	2.4) Direct OSU to strengthen its administrative and management procedures for allocating travel expenses to sponsored projects.	Unresolved	TBD	$0	TBD	TBD	4/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
19-1-017	Oregon State University (9/13/2019)	2.5) Direct OSU to strengthen its administrative and management procedures for allocating equipment to sponsored projects.	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-017	Oregon State University (9/13/2019)	2.6) Direct OSU to strengthen its administrative and management procedures over use of PSC funding under NSF awards.	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-017	Oregon State University (9/13/2019)	3.1) Resolve the $65,153 in questioned indirect costs	Unresolved	TBD	$65,153	TBD	TBD	4/30/22
19-1-017	Oregon State University (9/13/2019)	3.2) Direct OSU to strengthen its administrative and management procedures for applying indirect costs to Federal awards.	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-017	Oregon State University (9/13/2019)	4.1) Resolve $31,319 in questioned supplies, equipment, and travel costs	Unresolved	TBD	$31,319	TBD	TBD	4/30/22
19-1-017	Oregon State University (9/13/2019)	4.2) Direct OSU to strengthen its administrative and management procedures for purchases at end of a project's POP	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-017	Oregon State University (9/13/2019)	4.3) Direct OSU to strengthen its administrative and management procedures for travel taken within the final 90 days of an award's POP.	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-017	Oregon State University (9/13/2019)	5.1) Resolve $10,574 in Questioned Unallocable Costs	Unresolved	TBD	$10,574	TBD	TBD	4/30/22
19-1-017	Oregon State University (9/13/2019)	5.2) Direct OSU to strengthen its administrative and management procedures for allocating expenses to sponsored projects.	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-017	Oregon State University (9/13/2019)	5.3) Direct OSU to encourage PIs to identify all award participants.	Unresolved	TBD	$0	TBD	TBD	4/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
19-1-017	Oregon State University (9/13/2019)	6.1) Resolve the $8,820 in questioned costs.	Unresolved	TBD	$8,820	TBD	TBD	4/30/22
19-1-017	Oregon State University (9/13/2019)	6.2) Direct OSU to strengthen its administrative and management procedures for honorarium payments.	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-017	Oregon State University (9/13/2019)	7.1) Resolve $5,563 in questioned lodging and M&IE costs.	Unresolved	TBD	$5,563	TBD	TBD	4/30/22
19-1-017	Oregon State University (9/13/2019)	7.2) Direct OSU to strengthen its administrative and management procedures for reimbursing M&IE expenses.	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-017	Oregon State University (9/13/2019)	7.3) Direct OSU to strengthen its administrative and management procedures for reimbursing lodging expenses.	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-017	Oregon State University (9/13/2019)	8.1) Direct OSU to strengthen its administrative and management procedures for travel, procurement, PSCs, effort certifications, cost transfers, fellowship appointments, and currency conversions.	Unresolved	TBD	$0	TBD	TBD	4/30/22
19-1-017	Oregon State University (9/13/2019)	9.1) Direct OSU to strengthen its administrative and management procedures for establishing indirect cost rates for Federal awards.	Unresolved	TBD	$0	TBD	TBD	4/30/22
20-1-001	University of Colorado Boulder (1/10/2020)	1.1) Resolve the $25,902 of questioned material, supply. and, equipment expenditures;	Unresolved	TBD	$25,902	TBD	TBD	6/30/22
20-1-001	University of Colorado Boulder (1/10/2020)	1.2) Direct CU Boulder to provide support that it has repaid the $7,621 of questioned equipment costs.	Unresolved	TBD	$7,621	TBD	TBD	6/30/22
20-1-001	University of Colorado Boulder (1/10/2020)	1.3) Direct CU Boulder to strengthen the administrative and management procedures over expenditures near the end of an award	Unresolved	TBD	$0	TBD	TBD	6/30/22

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20-1-001	University of Colorado Boulder (1/10/2020)	2.1) Resolve the $20,575 of questioned publication costs	Unresolved	TBD	$20,575	TBD	TBD	6/30/22
20-1-001	University of Colorado Boulder (1/10/2020)	2.2) Direct CU Boulder to provide support that it has repaid the $78 of questioned material and supplies costs.	Unresolved	TBD	$78	TBD	TBD	6/30/22
20-1-001	University of Colorado Boulder (1/10/2020)	2.3) Direct CU Boulder to strengthen the admin and management controls and processes over applying the appropriate criteria to Fed and NSF award expenditures.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-001	University of Colorado Boulder (1/10/2020)	2.4) Direct CU Boulder to strengthen the admin and management controls and processes over expenditures charged to awards after the award expiration.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-001	University of Colorado Boulder (1/10/2020)	3.1) Direct CU Boulder to provide support that it has repaid the $15,785 of questioned travel costs.	Unresolved	TBD	$15,785	TBD	TBD	6/30/22
20-1-001	University of Colorado Boulder (1/10/2020)	3.2) Direct CU Boulder to strengthen the admin and management procedures over travel expenditures charged to NSF awards.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-001	University of Colorado Boulder (1/10/2020)	4.1) Direct CU Boulder to provide support that it has repaid the $4,597 of questioned participant support costs.	Unresolved	TBD	$4,597	TBD	TBD	6/30/22
20-1-001	University of Colorado Boulder (1/10/2020)	4.2) Direct CU Boulder to strengthen the admin and management procedures over allocating participant support costs to sponsored projects.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-001	University of Colorado Boulder (1/10/2020)	5.1) Direct CU Boulder to provide support that it has repaid the $2,728 of questioned salary and wages costs.	Unresolved	TBD	$2,728	TBD	TBD	6/30/22

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20-1-001	University of Colorado Boulder (1/10/2020)	5.2) Direct CU Boulder to strengthen the admin and management procedures over employee terminations.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-001	University of Colorado Boulder (1/10/2020)	6.1) Direct CU Boulder to provide support that it has repaid the $2,545 of questioned costs that did not have adequate documentation to support the expenses charged	Unresolved	TBD	$2,545	TBD	TBD	6/30/22
20-1-001	University of Colorado Boulder (1/10/2020)	6.2) Direct CU Boulder to strengthen the admin and management controls, training, processes, and procedures related to document retention.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	1.1) Resolve the $136,024 in questioned conference, travel, and AURA service costs and direct UNC to repay or otherwise remove the sustained questioned costs from its NSF awards.	Unresolved	TBD	$136,024	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	1.2) Direct UNC to provide support verifying that it has repaid or otherwise credited the $39,389 of questioned equipment, internal service center, salary, and other direct costs for which it has agreed to reimburse NSF.	Unresolved	TBD	$39,389	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	1.3) Direct UNC to strengthen its policies and procedures related to the creation and retention of documentation.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	1.4) Direct UNC to strengthen its administrative and management processes and procedures surrounding the approval of travel expense reports.	Unresolved	TBD	$0	TBD	TBD	6/30/22

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20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	1.5) Direct UNC to strengthen its administrative and management processes and procedures surrounding the approval of vendor and service provider invoices.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	1.6) Direct UNC to strengthen its administrative and management processes and procedures surrounding the internal service center billing process.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	1.7) Direct UNC to strengthen its administrative and management processes and procedures surrounding the reconciliation and tracking of gift cards or other prepaid cards.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	2.1) Resolve the $164,313 in questioned subaward costs and direct UNC to repay or otherwise remove the sustained questioned costs from its NSF awards.	Unresolved	TBD	$164,313	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	2.2) Direct UNC to strengthen the administrative and management controls and processes over transferring significant parts of federally funded research to other organizations.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	3.1) Direct UNC to provide support verifying that it has repaid or otherwise credited the $103,250 of questioned unsupported ACM$ cash drawdowns for which it has agreed to reimburse NSF.	Unresolved	TBD	$103,250	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	3.2) Direct UNC to strengthen the administrative and management controls and processes over its ACM$ reconciliation process.	Unresolved	TBD	$0	TBD	TBD	6/30/22

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20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	4.1)Resolve the $26,505 in inappropriately allocated materials and supplies, travel, and equipment costs for which UNC has not agreed to reimburse NSF and direct UNC to repay or otherwise remove the sustained questioned costs from its NSF awards.	Unresolved	TBD	$26,505	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	4.2) Direct UNC to provide support verifying that it has repaid or otherwise credited the $61,496 of questioned materials and supplies, travel, equipment, and other direct costs for which it has agreed to reimburse NSF.	Unresolved	TBD	$61,496	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	4.3) Direct UNC to strengthen its administrative and management processes and procedures surrounding the approval of materials and supplies, travel, equipment, and other direct costs.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	4.4) Direct UNC to strengthen its administrative and management processes and procedures surrounding the approval of travel expense reports.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	4.5) Direct UNC to strengthen its administrative and management processes and procedures surrounding the allocation of equipment expenses to NSF awards.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	4.6) Direct UNC to strengthen its administrative and management processes and procedures surrounding the allocation of publication expenses.	Unresolved	TBD	$0	TBD	TBD	6/30/22

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20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	3.1) Direct UNC to provide support verifying that it has repaid or otherwise credited the $103,250 of questioned unsupported ACM$ cash drawdowns for which it has agreed to reimburse NSF.	Unresolved	TBD	$103,250	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	3.2) Direct UNC to strengthen the administrative and management controls and processes over its ACM$ reconciliation process.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	4.1) Resolve the $26,505 in inappropriately allocated materials and supplies, travel, and equipment costs for which UNC has not agreed to reimburse NSF.	Unresolved	TBD	$26,505	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	4.2) Direct UNC to provide support verifying that it has repaid or otherwise credited the $61,496 of questioned materials and supplies, travel, equipment, and other direct costs for which it has agreed to reimburse NSF.	Unresolved	TBD	$61,496	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	4.3) Direct UNC to strengthen its administrative and management processes and procedures surrounding the approval of materials and supplies, travel, equipment, and other direct costs charged or transferred to an NSF award near the award's expiration date.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	4.4) Direct UNC to strengthen its administrative and management processes and procedures surrounding the approval of travel expense reports.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	4.5) Direct UNC to strengthen its administrative and management processes and procedures surrounding the allocation of equipment and publication expenses to NSF awards	Unresolved	TBD	$0	TBD	TBD	6/30/22

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20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	4.6) Direct UNC to strengthen its administrative and management processes and procedures surrounding the allocation of publication expenses.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	5.1) Resolve the $11,542 in meal and lodging per diem expenses for which UNC has not agreed to reimburse NSF and direct UNC to repay or otherwise remove the sustained questioned costs from its NSF awards.	Unresolved	TBD	$11,542	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	5.2) Direct UNC to provide support verifying that it has repaid or otherwise credited the $75,065 in questioned pre-award, PSC, airfare, and other direct cost expenses for which it has agreed to reimburse NSF.	Unresolved	TBD	$75,065	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	5.3) Direct UNC to strengthen its administrative and management processes and procedures surrounding the review of pre-award travel expenses.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	5.4) Direct UNC to update its meal and lodging per diem policies to comply with Federal regulations.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	5.5) Direct UNC to strengthen its administrative and management processes and procedures surrounding the use of PSC funding.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	5.6) Direct UNC to strengthen its administrative and management processes and procedures surrounding the approval of airfare expenses.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	5.7) Direct UNC to strengthen its administrative processes surrounding the approval of other direct costs charged to Federal awards.	Unresolved	TBD	$0	TBD	TBD	6/30/22

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20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	6.1) Direct UNC to provide support verifying that it has repaid or otherwise credited the $65,314 of questioned indirect costs for which it has agreed to reimburse NSF.	Unresolved	TBD	$65,314	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	6.2) Direct UNC to strengthen its administrative and management procedures for applying indirect costs to Federal awards.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	7.1) Resolve the $30,435 in questioned costs related to inappropriately procured equipment and services for which UNC has not agreed to reimburse NSF and direct UNC to repay or otherwise remove the sustained questioned costs from its NSF awards.	Unresolved	TBD	$30,435	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	7.2) Direct UNC to provide support verifying that it has repaid or otherwise credited the $5,143 in server costs for which it has agreed to reimburse NSF.	Unresolved	TBD	$5,143	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	7.3) Direct UNC to strengthen its administrative and management procedures related to competitive bidding.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	8.1) Direct UNC to provide support to verify that it has repaid or otherwise credited the $17,136 of questioned costs caused by accounting issues for which it has agreed to reimburse NSF.	Unresolved	TBD	$17,136	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	8.2) Direct UNC to strengthen its administrative and management procedures related to handling NSF awards.	Unresolved	TBD	$0	TBD	TBD	6/30/22

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20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	9.1) Direct UNC to provide support to verify that it has repaid or otherwise credited the $9,059 of questioned costs in inappropriately treated GRFP expenses for which it has agreed to reimburse NSF.	Unresolved	TBD	$9,059	TBD	TBD	6/30/22
20-1-004	University of North Carolina at Chapel Hill (7/13/2020)	9.2) Direct UNC to update its current practices for award set-up to ensure that personnel working on the award, directly or indirectly, have knowledge of specific NSF terms and conditions that apply to special types of NSF awards.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-005	University of Houston (7/23/2020)	1.1) Resolve the $32,153 in questioned unallocable software, tuition remission, stipend, supply, and travel costs for which UH has not agreed to reimburse NSF and direct UH to repay or otherwise remove the sustained questioned costs from its NSF awards.	Unresolved	TBD	$32,153	TBD	TBD	9/30/22
20-1-005	University of Houston (7/23/2020)	1.2) Direct UH to provide documentation that it has repaid or otherwise credited the $21,513 in questioned conference, travel, and workshop costs for which it has agreed to reimburse NSF.	Unresolved	TBD	$21,513	TBD	TBD	9/30/22
20-1-005	University of Houston (7/23/2020)	1.3) Direct UH to strengthen its administrative and management controls and processes for allocating expenses to sponsored projects.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-005	University of Houston (7/23/2020)	1.4) Direct UH to encourage PIs to identify all award participants and report all award-related travel in the annual reports submitted to NSF.	Unresolved	TBD	$0	TBD	TBD	9/30/22

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20-1-005	University of Houston (7/23/2020)	2.1) Resolve the $17,787 in questioned conference, supply, currency conversion, and publication expenses for which UH has not agreed to reimburse NSF and direct UH to repay or otherwise remove the sustained questioned costs from its NSF awards.	Unresolved	TBD	$17,787	TBD	TBD	9/30/22
20-1-005	University of Houston (7/23/2020)	2.2) Direct UH to provide documentation that it has repaid or otherwise credited the $19,790 in questioned fringe, conference, airfare, parking, and lodging costs for which it has agreed to reimburse NSF.	Unresolved	TBD	$19,790	TBD	TBD	9/30/22
20-1-005	University of Houston (7/23/2020)	2.3) Direct UH to strengthen its policies and procedures related to the creation and retention of documentation	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-005	University of Houston (7/23/2020)	2.4) Direct UH to strengthen its administrative and management processes and procedures surrounding the approval of travel expense reports.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-005	University of Houston (7/23/2020)	2.5) Direct UH to strengthen its administrative and management procedures surrounding expenses charged to NSF awards after the award has expired.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-005	University of Houston (7/23/2020)	2.6) Direct UH to strengthen its administrative and management procedures surrounding the processing of invoices to ensure that it pays all invoices in a timely manner.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-005	University of Houston (7/23/2020)	2.7) Direct UH to ensure that it only applies fringe benefits based on eligible employee salary costs, as outlined in its Negotiated Indirect Cost Rate Agreement .	Unresolved	TBD	$0	TBD	TBD	9/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
20-1-005	University of Houston (7/23/2020)	2.8) Direct UH to establish clear guidance regarding the allowability of publication expenses.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-005	University of Houston (7/23/2020)	2.9) Direct UH to establish clear guidance regarding the allowability of participant expenses.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-005	University of Houston (7/23/2020)	3.1) Direct UH to provide documentation that it has repaid or otherwise credited the $19,445 in questioned indirect costs for which it has agreed to reimburse NSF.	Unresolved	TBD	$19,445	TBD	TBD	9/30/22
20-1-005	University of Houston (7/23/2020)	3.2) Direct UH to strengthen its administrative and management procedures for applying indirect costs to Federal awards.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-005	University of Houston (7/23/2020)	4.1) Resolve the $7,650 in questioned inappropriately procured goods and services for which UH has not agreed to reimburse NSF and direct UH to repay or otherwise remove the sustained questioned costs from its NSF awards.	Unresolved	TBD	$7,650	TBD	TBD	9/30/22
20-1-005	University of Houston (7/23/2020)	4.2) Direct UH to provide documentation that it has repaid or otherwise credited the $3,306 of questioned costs that it has agreed to reimburse.	Unresolved	TBD	$3,306	TBD	TBD	9/30/22
20-1-005	University of Houston (7/23/2020)	4.3) Direct UH to strengthen its administrative and management controls and processes for procuring goods and services that it will charge to NSF awards.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-005	University of Houston (7/23/2020)	5.1) Direct UH to provide documentation that it has repaid or otherwise credited the $9,954 in questioned costs for which it has agreed to reimburse NSF.	Unresolved	TBD	$9,954	TBD	TBD	9/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
20-1-005	University of Houston (7/23/2020)	5.2) Direct UH to strengthen its policies and procedures related to the creation and retention of documentation	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-005	University of Houston (7/23/2020)	5.3) Direct UH to strengthen its administrative and management processes and procedures surrounding the approval of travel expense reports.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-005	University of Houston (7/23/2020)	6.1) Direct UH to provide documentation that it has repaid or otherwise credited the $1,707 of questioned costs for which it has agreed to reimburse NSF.	Unresolved	TBD	$1,707	TBD	TBD	9/30/22
20-1-005	University of Houston (7/23/2020)	6.2) Direct UH to update its current practices for award set-up to ensure that it appropriately communicates all NSF award terms and conditions.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-005	University of Houston (7/23/2020)	7.1) Direct UH to strengthen its administrative and management procedures for approving consultant and independent contractor payments.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-005	University of Houston (7/23/2020)	7.2) Direct UH to strengthen its administrative and management procedures for incurring travel costs related to sponsored projects.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-005	University of Houston (7/23/2020)	7.3) Direct UH to strengthen its administrative and management procedures surrounding effort reporting.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-005	University of Houston (7/23/2020)	7.4) Direct UH to issue specific guidance regarding when UH can pay individuals through participant support stipends.	Unresolved	TBD	$0	TBD	TBD	9/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
20-1-005	University of Houston (7/23/2020)	7.5) Direct UH to strengthen its administrative and management procedures for equipment expenditures in the final 6 months of a grant's POP to ensure that personnel obtain the Office of Contracts and Grants' approval before purchasing equipment.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-005	University of Houston (7/23/2020)	8.1) Direct UH to update its current award set-up practices to ensure that it sets up accounts for NSF awards such that the account applies indirect costs at the rates established in the NICRA that was in effect as of the date of grant award.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-005	University of Houston (7/23/2020)	9.1) Direct UH to update its current practices for specialized service facilities to ensure that it complies with all of the Federal requirements for these facilities, as outlined in 2 CFR §200.468, Specialized service facilities.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-006	Temple University (8/15/2020)	1.1) Direct Temple to provide support that it has credited or repaid the $4,524 of questioned material and supply costs.	Unresolved	TBD	$4,254	TBD	TBD	3/31/22
20-1-006	Temple University (8/15/2020)	1.2) Direct Temple to strengthen the administrative and management procedures over expenditures near the end of an award.	Unresolved	TBD	$0	TBD	TBD	3/31/22
20-1-006	Temple University (8/15/2020)	2.1) Direct Temple to provide support that it has credited or repaid the $1,445 of questioned travel costs.	Unresolved	TBD	$1,445	TBD	TBD	3/31/22
20-1-006	Temple University (8/15/2020)	2.2) Direct Temple to strengthen the administrative and management procedures over travel expenditures.	Unresolved	TBD	$0	TBD	TBD	3/31/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
20-1-007	Yale University (8/11/2020)	1.1) Resolve the $26,151 in salary, promotional, and airfare expenses for which Yale has not agreed to reimburse NSF and direct Yale to repay or otherwise remove the sustained questioned costs from its NSF awards.	Unresolved	TBD	$26,151	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	1.10) Direct Yale to strengthen its administrative processes surrounding the approval of publication costs charged to Federal awards.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	1.2) Direct Yale to provide documentation supporting that it has repaid or otherwise credited the $81,993 in questioned participant support costs, salary, duplicate charges, airfare, travel, and other expenses for which it has agreed to reimburse NSF.	Unresolved	TBD	$81,993	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	1.3) Direct Yale to strengthen its administrative and management processes and procedures surrounding the use of participant support cost funding.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	1.4) Direct Yale to strengthen its policies and procedures surrounding the approval of summer effort commitments on sponsored projects.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	1.5) Direct Yale to strengthen its administrative and management processes and procedures surrounding the approval of expenses to ensure that it does not approve duplicate expenses submitted by subawardees, vendors, and employees.	Unresolved	TBD	$0	TBD	TBD	9/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
20-1-007	Yale University (8/11/2020)	1.6) Direct Yale to implement a control that flags potential duplicate payments for additional review.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	1.7) Direct Yale to strengthen its administrative and management processes and procedures surrounding the approval of travel expense reports.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	1.8) Direct Yale to update its travel policies and procedures to include specific guidance regarding how to identify and appropriately account for expenses associated with cancelled or unused airfare.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	1.9) Direct Yale to strengthen its administrative processes surrounding the approval of other direct costs charged to Federal awards.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	2.1) Resolve the $58,577 in questioned unallocable equipment costs for which Yale has not agreed to reimburse NSF and direct Yale to repay or otherwise remove the sustained questioned costs from its NSF awards.	Unresolved	TBD	$58,577	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	2.2) Direct Yale to provide documentation supporting that it has repaid or otherwise credited the $24,732 of questioned materials, publication, travel, and other direct costs for which it has agreed to reimburse NSF.	Unresolved	TBD	$24,732	TBD	TBD	9/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
20-1-007	Yale University (8/11/2020)	2.3) Direct Yale to strengthen its administrative and management processes and procedures surrounding the approval of equipment and materials charged to an NSF award near the award's expiration date.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	2.4) Direct Yale to strengthen its administrative and management processes and procedures surrounding the allocation methodology used to charge equipment, materials/supplies, travel, and other direct costs to sponsored awards.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	2.5) Direct Yale to strengthen its administrative processes surrounding the approval of publication costs charged to Federal awards.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	2.6) Direct Yale to strengthen its administrative and management processes and procedures surrounding the approval of travel expense reports.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	3.1) Resolve the $39,850 in questioned professional services agreement costs for which Yale has not agreed to reimburse NSF and direct Yale to repay or otherwise remove the sustained questioned costs from its NSF award.	Unresolved	TBD	$39,850	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	3.2) Review Yale's re-charging of the questioned cost amounts for compliance with Federal, NSF, and Yale regulations and policies.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	3.3) Direct Yale to strengthen its administrative and management controls and processes surrounding the execution of professional services and consulting agreements.	Unresolved	TBD	$0	TBD	TBD	9/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
20-1-007	Yale University (8/11/2020)	4.1) Resolve the $12,855 in questioned internal service provider expenses for which Yale has not agreed to reimburse NSF and direct Yale to repay or otherwise remove the sustained questioned costs from its NSF awards.	Unresolved	TBD	$12,855	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	4.2) Direct Yale to provide documentation supporting that it has repaid or otherwise credited the $2,397 in inappropriately billed internal service provider expenses for which it has agreed to reimburse NSF.	Unresolved	TBD	$2,397	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	4.3) Direct Yale to strengthen its administrative and management processes and procedures surrounding internal service provider billings.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	4.4) Direct Yale to strengthen its administrative and management processes and procedures surrounding the development of internal service provider rate sheets.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	4.5) Direct Yale to update its invoicing process for the CINSTR, ISP011, ISP043, ISP058, ISP455, and YRISPS internal service providers to require that invoices identify the number of unit(s) or hour(s) billed, as well as the rate(s) used to calculate the	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	5.1) Direct Yale to provide documentation supporting that it has repaid or otherwise credited the $5,418 of questioned indirect costs for which it has agreed to reimburse NSF.	Unresolved	TBD	$0	TBD	TBD	9/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
20-1-007	Yale University (8/11/2020)	5.2) Direct Yale to strengthen its oversight procedures surrounding the charging of, or transferring of, expenses related to rearrangement, alteration, and other capital expenditures.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	5.3) Direct Yale to perform periodic reviews of expenditures charged to its facilities accounts to ensure rearrangement and alteration costs are not inappropriately charged to accounts that accumulate modified total direct costs to which Yale applies its	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	6.1) Direct Yale personnel who are independent from the monthly NSF cash draw down process to perform periodic Award Cash Management $ervice reconciliations	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	7.1) Direct Yale to update its current practices for establishing indirect cost rates to apply to sponsored projects awarded during provisional rate periods	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	8.1) Direct Yale to publish specific guidance regarding how travelers should document travel that includes both personal and business travel.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	8.2) Direct Yale to strengthen its policies and procedures surrounding the creation and retention of documentation	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	8.3) Direct Yale to strengthen its administrative and management procedures related to the effort certification process.	Unresolved	TBD	$0	TBD	TBD	9/30/22

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20-1-007	Yale University (8/11/2020)	8.4) Direct Yale to strengthen its administrative and management procedures surrounding the establishment of temporary appointments.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	8.5) Verify that Yale has updated its subaward invoicing payment procedures within the Workday system to ensure that personnel review and approve all subaward invoices within 30 days of receipt	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	8.6) Direct Yale to strengthen its administrative and management procedures surrounding the procurement of consulting services.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-007	Yale University (8/11/2020)	8.7) Direct Yale to strengthen its administrative and management processes surrounding the payment of invoices submitted by new vendors.	Unresolved	TBD	$0	TBD	TBD	9/30/22
20-1-008	Duke University (8/31/2020)	1.1) Resolve the $164,022 in questioned administrative salary and airfare expenses for which Duke has not agreed to reimburse NSF and direct Duke to repay or otherwise remove the sustained questioned costs from its NSF awards.	Unresolved	TBD	$164,022	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	1.10) Direct Duke to strengthen its policies and procedures related to approving travel expense reports.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	1.11) Direct Duke to establish additional controls to help ensure that it appropriately creates and retains all documentation necessary to support the allowability of expenses charged to sponsored programs.	Unresolved	TBD	$0	TBD	TBD	6/30/22

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20-1-008	Duke University (8/31/2020)	1.12) Direct Duke to implement a control to flag any charges against an NSF award when the purchaser incurs the expense more than 90 days before the effective date of an award.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	1.2) Direct Duke to provide documentation to support that it has repaid or otherwise credited the $106,386 of questioned airfare, entertainment, participant support costs, visiting scholar, & other expenses for which it has agreed to reimburse NSF.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	1.3) Direct Duke to strengthen its policies and procedures related to charging project coordinator time directly to NSF awards.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	1.4) Direct Duke to strengthen its policies and procedures related to purchasing airfare that will be charged to a Federal project.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	1.5) Direct Duke to strengthen its controls surrounding spending on NSF awards for which the sponsor has denied no-cost extension requests.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	1.6) Direct Duke to strengthen its conference hosting policies and procedures to ensure that it does not charge Federal awards for unallowable entertainment expenses.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	1.7) Direct Duke to strengthen its administrative and management processes and procedures related to the use of, and the re-budgeting of, participant support cost funding.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	1.8) Direct Duke to strengthen its policies and procedures related to providing salary and stipend payments to visiting scholars.	Unresolved	TBD	$0	TBD	TBD	6/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
20-1-008	Duke University (8/31/2020)	1.9) Direct Duke to perform periodic reviews of costs accumulated within its general ledger to identify and remove any duplicate expenses charged against Federal awards.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	1.10) Direct Duke to strengthen its policies and procedures related to approving travel expense reports.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	1.11) Direct Duke to establish additional controls to help ensure that it appropriately creates and retains all documentation necessary to support the allowability of expenses charged to sponsored programs.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	1.12)Direct Duke to implement a control to flag any charges against an NSF award when the purchaser incurs the expense more than 90 days before the effective date of an award.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	2.1) Resolve the $237,141 in questioned Office of Information Technology, participant support, and travel expenses for which Duke has not agreed to reimburse NSF.	Unresolved	TBD	$237,141	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	2.2) Direct Duke to provide documentation to support that it has repaid or otherwise credited the $9,494 in questioned participant support, travel, and other direct costs for which it has agreed to reimburse NSF.	Unresolved	TBD	$9,494	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	2.3) Direct Duke to strengthen its policies and procedures related to creating and retaining documentation.	Unresolved	TBD	$0	TBD	TBD	6/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
20-1-008	Duke University (8/31/2020)	2.4) Direct Duke to strengthen its policies and procedures related to internal specialized service center billings.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	2.5) Direct Duke to strengthen its policies and procedures related to participant support cost payments.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	2.6) Direct Duke to strengthen its policies and procedures surrounding participation incentive payments.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	2.7) Direct Duke to issue guidance regarding how to appropriately document the allowability of medical expense reimbursements for individuals performing fieldwork on Duke's behalf.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	2.8) Direct Duke to strengthen its administrative and management processes and procedures surrounding the approval of travel expenses.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	3.1) Resolve the $77,923 in questioned salary expenses for which Duke has not agreed to reimburse NSF and direct Duke to repay or otherwise remove the sustained questioned costs from its NSF awards.	Unresolved	TBD	$77,923	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	3.2) Direct Duke to strengthen its administrative and management processes and procedures related to establishing supplemental pay appointments.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	3.3) Direct Duke to strengthen its administrative and management processes and procedures related to rehiring former employees as adjunct faculty.	Unresolved	TBD	$0	TBD	TBD	6/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
20-1-008	Duke University (8/31/2020)	4.1) Resolve the $29,892 in questioned Award Cash Management $ervice drawdowns for which Duke has not agreed to reimburse NSF and direct Duke to repay or otherwise remove the sustained questioned costs from its NSF awards.	Unresolved	TBD	$29,892	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	4.2) Direct Duke to strengthen its administrative and management processes and procedures surrounding the drawing-down of funding from the Award Cash Management $ervice system on awards with expiring appropriations.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	4.3) Direct Duke to strengthen its award set-up processes and procedures to ensure it cannot charge costs to active awards if the Federal appropriations have expired.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	5.1) Resolve the $9,137 in questioned unallocable chemical analysis costs for which Duke has not agreed to reimburse NSF and direct Duke to repay or otherwise remove the sustained questioned costs from its NSF awards.	Unresolved	TBD	$9,137	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	5.2) Direct Duke to provide documentation to support that it has repaid or otherwise credited the $19,582 in questioned unallocable travel, publication, supply, and participant support espenses for which it has agreed to reimburse NSF.	Unresolved	TBD	$19,582	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	5.3) Direct Duke to strengthen its administrative and management controls and processes related to allocating expenses to sponsored projects.	Unresolved	TBD	$0	TBD	TBD	6/30/22

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20-1-008	Duke University (8/31/2020)	5.4) Direct Duke to encourage Principal Investigators to identify all award participants and report all award-related travel in the annual reports submitted to NSF.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	6.1) Resolve the $23,406 in questioned costs incurred for inappropriately procured supplies and services for which Duke has not agreed to reimburse NSF and direct Duke to repay or otherwise remove the sustained questioned costs from its NSF awards.	Unresolved	TBD	$23,406	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	6.2) Direct Duke to strengthen its administrative and management procedures related to procuring consultant services.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	6.3) Direct Duke to strengthen its administrative and management procedures related to performing competitive bidding activities.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	7.1) Resolve the $1,672 in questioned Organization for Tropical Studies costs for which Duke has not agreed to reimburse NSF and direct Duke to repay or otherwise remove the sustained questioned costs from its NSF awards.	Unresolved	TBD	$1,672	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	7.2) Direct Duke to provide documentation to support that it has repaid or otherwise credited the $10,854 of questioned Organization for Tropical Studies expenses for which it has agreed to reimburse NSF.	Unresolved	TBD	$10,854	TBD	TBD	6/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
20-1-008	Duke University (8/31/2020)	7.3) Direct Duke to strengthen its administrative and management processes and procedures related to creating contractual relationships with organizations for which it will serve as a legal or fiscal agent.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	8.1) Resolve the $10,000 in questioned non-compliant Graduate Research Internship Program costs for which Duke has not agreed to reimburse NSF and direct Duke to repay or otherwise remove the sustained questioned costs from its NSF awards.	Unresolved	TBD	$10,000	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	8.2) Direct Duke to strengthen its controls related to award set-up to ensure that personnel working on the award, either directly or indirectly, are aware of the specific NSF terms and conditions that apply to special types of NSF awards.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	9.1) Direct Duke to provide documentation to support that it has repaid or otherwise credited the $9,397 of questioned indirect costs.	Unresolved	TBD	$9,397	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	9.2) Direct Duke to strengthen its administrative and management procedures related accounting for participant support costs.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	10.1) Direct Duke to strengthen its controls related to award set-up.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	11.1) Direct Duke to strengthen its administrative and management procedures related to procuring consultant services.	Unresolved	TBD	$0	TBD	TBD	6/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
20-1-008	Duke University (8/31/2020)	11.2) Direct Duke to strengthen its policies and procedures related to its subaward payment approval process.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	11.3) Direct Duke to strengthen its procedures for approving cost transfers that involve equipment purchases.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	11.4) Direct Duke to update its current effort reporting processes to ensure that personnel certify their effort in compliance with Duke's internal policies.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	11.5) Direct Duke to strengthen its administrative and management procedures related to its competitive bidding process.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	11.6) Direct Duke to strengthen its policies and procedures surrounding corporate purchase cards.	Unresolved	TBD	$0	TBD	TBD	6/30/22
20-1-008	Duke University (8/31/2020)	11.7) Direct Duke to strengthen its administrative and management procedures related to internal service provider billings.	Unresolved	TBD	$0	TBD	TBD	6/30/22
21-1-001	Univ of Kansas Ctr for Research (EPSCoR) (1/7/2021)	1.1) Resolve the $625,532 in subrecipient indirect costs retained by KUCR and direct KUCR to repay or otherwise remove the sustained questioned costs from its NSF awards	Unresolved	TBD	$625,532	TBD	TBD	7/31/22
21-1-001	Univ of Kansas Ctr for Research (EPSCoR) (1/7/2021)	1.2) Confirm that KUCR has ended the practice of retaining a portion of allowable subrecipient indirect costs charged to EPSCoR awards.	Unresolved	TBD	$0	TBD	TBD	7/31/22
21-1-001	Univ of Kansas Ctr for Research (EPSCoR) (1/7/2021)	2.1) Resolve the $15,854 in indirect costs charged, and direct KUCR to repay or otherwise remove the sustained questioned costs from its NSF award.	Unresolved	TBD	$15,854	TBD	TBD	7/31/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
21-1-001	Univ of Kansas Ctr for Research (EPSCoR) (1/7/2021)	3.1) Resolve the $569,477 in questioned unsupported subaward costs	Unresolved	TBD	$569,477	TBD	TBD	7/31/22
21-1-001	Univ of Kansas Ctr for Research (EPSCoR) (1/7/2021)	3.2) Direct KUCR to provide oversight that Haskell is charging actual costs and develops processes to appropriately account for salary and fringe benefit charges	Unresolved	TBD	$0	TBD	TBD	7/31/22
21-1-001	Univ of Kansas Ctr for Research (EPSCoR) (1/7/2021)	3.3) Direct KUCR to strengthen its administrative and management controls and processes related to subaward risk assessment and oversight.	Unresolved	TBD	$0	TBD	TBD	7/31/22
21-1-001	Univ of Kansas Ctr for Research (EPSCoR) (1/7/2021)	3.4) Direct KUCR to strengthen its administrative and management controls and processes related to record retention.	Unresolved	TBD	$0	TBD	TBD	7/31/22
21-1-001	Univ of Kansas Ctr for Research (EPSCoR) (1/7/2021)	4.1) Resolve the $328,494 in questioned cost share costs	Unresolved	TBD	$328,494	TBD	TBD	7/31/22
21-1-001	Univ of Kansas Ctr for Research (EPSCoR) (1/7/2021)	5.1) Resolve the $10,697 in questioned costs	Unresolved	TBD	$10,697	TBD	TBD	7/31/22
21-1-001	Univ of Kansas Ctr for Research (EPSCoR) (1/7/2021)	5.2) Direct KUCR to provide training on Federal requirements prohibiting alcoholic beverages and requiring expenses to be necessary and reasonable	Unresolved	TBD	$0	TBD	TBD	7/31/22
21-1-001	Univ of Kansas Ctr for Research (EPSCoR) (1/7/2021)	5.3) Direct KUCR to strengthen its administrative and management controls and processes related to participant support costs	Unresolved	TBD	$0	TBD	TBD	7/31/22
21-1-002	Texas A&M University (12/17/2020)	1.1) Resolve the $33,575 in questioned service and airfare expenses for which TAMU has not agreed to reimburse NSF and direct TAMU to repay or otherwise remove the sustained questioned costs from its NSF awards.	Unresolved	TBD	$33,575	TBD	TBD	10/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
21-1-002	Texas A&M University (12/17/2020)	1.2) Direct TAMU to provide documentation supporting that it has repaid or otherwise credited the $16,864 in questioned salary, airfare, and publication costs for which it has agreed to reimburse NSF.	Unresolved	TBD	$16,864	TBD	TBD	10/30/22
21-1-002	Texas A&M University (12/17/2020)	1.3) Direct TAMU to strengthen its policies and procedures related to creating and retaining documentation.	Unresolved	TBD	$0	TBD	TBD	10/30/22
21-1-002	Texas A&M University (12/17/2020)	1.4) Direct TAMU to verify that services provided under service and subaward agreements occurred during the agreement's period of performance prior to reimbursing costs.	Unresolved	TBD	$0	TBD	TBD	10/30/22
21-1-002	Texas A&M University (12/17/2020)	1.5) Direct TAMU to strengthen its administrative and management procedures and internal controls surrounding retroactive salary payments charged to sponsored projects.	Unresolved	TBD	$0	TBD	TBD	10/30/22
21-1-002	Texas A&M University (12/17/2020)	1.6) Direct TAMU to strengthen its administrative and management procedures and internal controls surrounding the purchase of airfare and the approval of travel expense reports.	Unresolved	TBD	$0	TBD	TBD	10/30/22
21-1-002	Texas A&M University (12/17/2020)	1.7) Direct TAMU to establish clear guidance regarding the allowability of publication expenses, including the need to acknowledge NSF funding sources.	Unresolved	TBD	$0	TBD	TBD	10/30/22
21-1-002	Texas A&M University (12/17/2020)	2.1) Resolve the $49,218 in questioned service and travel expenses for which TAMU has not agreed to reimburse NSF.	Unresolved	TBD	$49,218	TBD	TBD	10/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
21-1-002	Texas A&M University (12/17/2020)	2.2) Direct TAMU to provide documentation supporting that it has repaid or otherwise credited the $1,191 in questioned additional salary costs for which it has agreed to reimburse NSF.	Unresolved	TBD	$1,191	TBD	TBD	10/30/22
21-1-002	Texas A&M University (12/17/2020)	2.3) Direct TAMU to strengthen its policies and procedures related to creating and retaining documentation.	Unresolved	TBD	$0	TBD	TBD	10/30/22
21-1-002	Texas A&M University (12/17/2020)	2.4) Direct TAMU to strengthen its administrative and management procedures and internal controls surrounding the retention of documentation to support that personnel purchased airfare in compliance with Federal and NSF guidance.	Unresolved	TBD	$0	TBD	TBD	10/30/22
21-1-002	Texas A&M University (12/17/2020)	2.5) Direct TAMU to strengthen its administrative and management processes and internal controls related to establishing and documenting compensation rates for individuals who perform additional work outside the scope of their regular duties.	Unresolved	TBD	$0	TBD	TBD	10/30/22
21-1-002	Texas A&M University (12/17/2020)	3.1) Resolve the $15,757 in questioned unallocable materials and software costs for which TAMU has not agreed to reimburse NSF and direct TAMU to repay or otherwise remove the sustained questioned costs from its NSF awards.	Unresolved	TBD	$15,757	TBD	TBD	10/30/22
21-1-002	Texas A&M University (12/17/2020)	3.2) Direct TAMU to provide documentation supporting that it has repaid or otherwise credited the $4,982 in questioned publication and one-time salary payments for which it has agreed to reimburse NSF.	Unresolved	TBD	$4,982	TBD	TBD	10/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
21-1-002	Texas A&M University (12/17/2020)	3.3) Direct TAMU to strengthen its administrative and management procedures and internal controls for allocating expenses to sponsored projects.	Unresolved	TBD	$0	TBD	TBD	10/30/22
21-1-002	Texas A&M University (12/17/2020)	4.1) Resolve the $1,950 in questioned indirect costs for which TAMU has not agreed to reimburse NSF and direct TAMU to repay or otherwise remove the sustained questioned costs from its NSF award.	Unresolved	TBD	$1,950	TBD	TBD	10/30/22
21-1-002	Texas A&M University (12/17/2020)	4.2) Direct TAMU to provide documentation supporting that it has repaid or otherwise credited the $13,362 of questioned indirect costs for which it has agreed to reimburse NSF.	Unresolved	TBD	$13,362	TBD	TBD	10/30/22
21-1-002	Texas A&M University (12/17/2020)	4.3) Direct TAMU to strengthen its administrative and management processes and internal controls for applying indirect costs to Federal awards.	Unresolved	TBD	$0	TBD	TBD	10/30/22
21-1-002	Texas A&M University (12/17/2020)	5.1) Direct TAMU to provide documentation supporting that it has repaid or otherwise credited the $659 of questioned Award Cash Management $ervice drawdowns for which it has agreed to reimburse NSF.	Unresolved	TBD	$659	TBD	TBD	10/30/22
21-1-002	Texas A&M University (12/17/2020)	5.2) Direct TAMU to strengthen the administrative and management internal controls and processes over its Award Cash Management $ervice reconciliation process.	Unresolved	TBD	$0	TBD	TBD	10/30/22
21-1-002	Texas A&M University (12/17/2020)	6.1) Direct TAMU to strengthen its administrative and management procedures and internal controls for incurring travel costs charged to sponsored projects.	Unresolved	TBD	$0	TBD	TBD	10/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
21-1-002	Texas A&M University (12/17/2020)	6.2) Direct TAMU to strengthen its administrative and management procedures and internal controls related to the effort certification process.	Unresolved	TBD	$0	TBD	TBD	10/30/22
21-1-002	Texas A&M University (12/17/2020)	6.3) Direct TAMU to strengthen its administrative and management procedures and internal controls related to procurement processes.	Unresolved	TBD	$0	TBD	TBD	10/30/22
21-1-002	Texas A&M University (12/17/2020)	7.1) Direct TAMU to update its current award set-up practices to require that, when setting up accounts established for NSF awards, personnel ensure that the accounts apply indirect costs using the rates that were established in the NICRA at award date.	Unresolved	TBD	$0	TBD	TBD	10/30/22
21-1-003	University of Wyoming (EPSCoR) (1/13/2021)	1.1) Resolve the $90,000 in questioned cost share	Unresolved	TBD	$90,000	TBD	TBD	5/30/22
21-1-003	University of Wyoming (EPSCoR) (1/13/2021)	1.2) Direct UW to strengthen its administrative and management controls and processes related to cost transfers	Unresolved	TBD	$0	TBD	TBD	5/30/22
21-1-003	University of Wyoming (EPSCoR) (1/13/2021)	2.1) Resolve the $7,908 in questioned commercial printing costs	Unresolved	TBD	$7,908	TBD	TBD	5/30/22
21-1-003	University of Wyoming (EPSCoR) (1/13/2021)	2.2) Direct UW to strengthen its administrative and management controls and processes related to cost transfers.	Unresolved	TBD	$0	TBD	TBD	5/30/22
21-1-003	University of Wyoming (EPSCoR) (1/13/2021)	3.1) Resolve the $15,207 in questioned entertainment costs	Unresolved	TBD	$15,207	TBD	TBD	5/30/22
21-1-003	University of Wyoming (EPSCoR) (1/13/2021)	3.2) Direct UW to provide NSF additional detail for proposed SRAP entertainment activities annually so NSF can assess the allowability of the proposed activities.	Unresolved	TBD	$0	TBD	TBD	5/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
21-1-003	University of Wyoming (EPSCoR) (1/13/2021)	3.3) Direct UW to strengthen its administrative and management controls and processes related to documenting SRAP activity attendees and programmatic purposes.	Unresolved	TBD	$0	TBD	TBD	5/30/22
21-1-003	University of Wyoming (EPSCoR) (1/13/2021)	4.1) Resolve the $24,773 in questioned indirect costs	Unresolved	TBD	$24,773	TBD	TBD	5/30/22
21-1-003	University of Wyoming (EPSCoR) (1/13/2021)	4.2) Direct UW to strengthen its policies and controls over identification of participant support costs.	Unresolved	TBD	$0	TBD	TBD	5/30/22
21-1-003	University of Wyoming (EPSCoR) (1/13/2021)	5.1) Resolve the $864 in questioned meal costs	Unresolved	TBD	$864	TBD	TBD	5/30/22
21-1-003	University of Wyoming (EPSCoR) (1/13/2021)	5.2) Direct UW to develop policy and training on the allowability and reasonableness of meal costs.	Unresolved	TBD	$0	TBD	TBD	5/30/22
21-1-003	University of Wyoming (EPSCoR) (1/13/2021)	6.1) Resolve the $117,599 in questioned costs	Unresolved	TBD	$117,599	TBD	TBD	5/30/22
21-1-003	University of Wyoming (EPSCoR) (1/13/2021)	6.2) Direct UW to augment its policy on subrecipient monitoring and develop training to ensure that subrecipients comply with requirements for award management.	Unresolved	TBD	$412,363	TBD	TBD	5/30/22
21-1-003	University of Wyoming (EPSCoR) (1/13/2021)	6.3) Direct UW to not provide future funding to WRNAC until UW confirms WRNAC has the controls to ensure compliance with Federal regulations and NSF award terms and conditions.	Unresolved	TBD	$0	TBD	TBD	5/30/22
21-1-003	University of Wyoming (EPSCoR) (1/13/2021)	6.4) Direct UW to work with WRNAC to ensure adequate controls are in place to ensure that the risk of conflicts of interest are mitigated and unmanageable conflicts are reported	Unresolved	TBD	$0	TBD	TBD	5/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
21-1-004	University of Florida (1/15/2021)	1.1) Resolve the $412,363 in questioned subaward costs	Unresolved	TBD	$0	TBD	TBD	10/30/22
21-1-004	University of Florida (1/15/2021)	1.2) Direct UF to strengthen the administrative and management internal controls and processes over transferring significant parts of NSF funded research to other organizations	Unresolved	TBD	$0	TBD	TBD	10/30/22
21-1-004	University of Florida (1/15/2021)	2.1) Resolve the $47,226 in questioned participant support, travel, and publication expenses for which UF has not agreed to reimburse NSF	Unresolved	TBD	$47,226	TBD	TBD	10/30/22
21-1-004	University of Florida (1/15/2021)	2.2) Direct UF to provide documentation that it has repaid or otherwise credited the $66,590	Unresolved	TBD	$66,590	TBD	TBD	10/30/22
21-1-004	University of Florida (1/15/2021)	2.3) Direct UF to establish clear guidance regarding the use of participant support cost funding	Unresolved	TBD	$0	TBD	TBD	10/30/22
21-1-004	University of Florida (1/15/2021)	2.4) Direct UF to strengthen its administrative and management procedures and internal controls surrounding the purchase of airfare and the approval of travel expense reports	Unresolved	TBD	$0	TBD	TBD	10/30/22
21-1-004	University of Florida (1/15/2021)	2.5) Direct UF to strengthen its administrative and management procedures and internal controls	Unresolved	TBD	$0	TBD	TBD	10/30/22
21-1-004	University of Florida (1/15/2021)	2.6) Direct UF to establish clear guidance regarding the allowability of publication expenses	Unresolved	TBD	$0	TBD	TBD	10/30/22
21-1-004	University of Florida (1/15/2021)	3.1) Resolve the $83,227 in questioned supplies, software, severance and publication costs	Unresolved	TBD	$83,227	TBD	TBD	10/30/22
21-1-004	University of Florida (1/15/2021)	3.2) Direct UF to provide documentation that it has repaid or otherwise credited the $29,600	Unresolved	TBD	$29,600	TBD	TBD	10/30/22

OIG Number	Title (Final Audit Report Date)	OIG Recommendation - External Audit	Status	Date Resolved	Costs Questioned	Costs Disallowed	Costs Allowed	Timeline for Final Implem-entation
21-1-004	University of Florida (1/15/2021)	3.3) Direct UF to strengthen its administrative and management procedures, internal controls, and processes for allocating salary, publication, material and supply, travel, and tuition expenses	Unresolved	TBD	$0	TBD	TBD	10/30/22
21-1-004	University of Florida (1/15/2021)	4.1) Direct UF to provide documentation that it has repaid or otherwise credited the $1,717	Unresolved	TBD	$0	TBD	TBD	10/30/22
21-1-004	University of Florida (1/15/2021)	4.2) Direct UF to update its current procedures and internal controls for reviewing stipend costs charged to Graduate Research Fellowship Program awards	Unresolved	TBD	$0	TBD	TBD	10/30/22
21-1-004	University of Florida (1/15/2021)	5.1) Direct UF to strengthen its directives/procedures and internal controls for procuring goods and services	Unresolved	TBD	$0	TBD	TBD	10/30/22
21-1-004	University of Florida (1/15/2021)	5.2) Direct UF to strengthen its directives/procedures and internal controls surrounding the completion of Cost Accounting Standards exemptions	Unresolved	TBD	$0	TBD	TBD	10/30/22
21-1-004	University of Florida (1/15/2021)	5.3) Direct UF to strengthen its directives/procedures and internal controls for incurring travel costs	Unresolved	TBD	$0	TBD	TBD	10/30/22
21-1-004	University of Florida (1/15/2021)	6.1) Direct UF to update its current award set-up practices	Unresolved	TBD	$0	TBD	TBD	10/30/22

GAO Open Recommendations

GAO Report Number	Title	GAO Recommendation	Status of Recommendation[2]	Timeline for Final Implementation
GAO-21-130	Federal Research: Agencies Need to Enhance Policies to Address Foreign Influence	The Director of the National Science Foundation should include a definition on non-financial conflicts in their agency policies, such as the one developed by OSTP, and address these conflicts, both foreign and domestic. (Recommendation 9)	Fully Implemented	The National Science Foundation (NSF) has had well-defined conflict of interest policies for many years and the agency does not differentiate between foreign and domestic conflicts of interest. However, NSF committed to communication to the community by the NSF Director and Chief of Research Security Strategy and Policy (CRSSP) regarding research security risks including concerns about malign foreign talent recruitment programs. The NSF Director and CRSSP have communicated frequently over the past year with groups such as APLU, AAU, and COGR regarding such risks. Additionally, NSF co-chaired the NSTC research security subcommittee that released NSPM-33 Implementation Guidance in January 2022 to harmonize disclosure requirements on potential conflicts of interest and commitment with other federal agencies. NSF considers this recommendation fully implemented.
GAO-21-152	Data Governance: Agencies Made Progress in Establishing Governance, but Need to Address Key Milestones	The Director of the National Science Foundation should direct the Chief Data Officer to conduct a gap analysis between the current staff's skills and the skills the agency requires, and establish a baseline performance plan to close the identified data skills and literacy gaps. (Recommendation 9)	Open	NSF is making progress to complete this action by Q3 FY22.

[2] Fully implemented signifies that NSF has completed all actions to address the recommendation and is awaiting GAO review and closure.

GAO Report Number	Title	GAO Recommendation	Status of Recommendation[2]	Timeline for Final Implementation
GAO-20-187	Sexual Harassment in STEM Research: Agencies Have Taken Actions, but Need Complaint Procedures, Overall Plans, and Better Collaboration	Recommendation 15: The Director of NSF should establish goals and an overall plan to assess all of the agency's sexual harassment prevention efforts for their university grantees, including methods to regularly monitor and evaluate its sexual harassment prevention policies and communication mechanisms (e.g. Title IX or sex discrimination websites).	Open	The evaluation of NSF's harassment prevention efforts focused on the Harassment Notification Term and Condition and the conference policy. Currently, under review (a draft of the first phase of the evaluation was completed in the first quarter of FY 22 and is expected to be finalized in the second quarter of FY22), preliminary findings provide useful information for the next steps in NSF efforts to dismantle barriers to the participation of underrepresented groups (URGs) in STEM. For example, the analysis of communications shows that, on average, universities submitting proposals to NSF have adopted an anti-harassment policy and disseminated it through their websites. The analysis also shows that NSF's conference policy had a positive impact on adherence to the guidance provided by NSF. This finding holds overall and by type of institution (R1 versus R2), but not for all types of Minority Serving Institutions (MSIs). These and other findings will inform ongoing NSF efforts to develop targeted approaches to accelerate the impact of harassment prevention efforts, particularly given NSF's Strategic Goal of increasing participation in the STEM enterprise and the Strategic Plan's focus on private sector partnerships and MSIs. Findings will also inform the next steps and subsequent phases of monitoring and evaluation activities, which may begin in FY 23. A timeline for the implementation of subsequent phases may be developed in the second half of FY22.
GAO-20-59	Information Management: Selected Agencies Need to Fully	Recommendation 18: The Director of the National Science Foundation should establish a time frame to ensure all records schedules are up-	Fully Implemented	NSF has implemented this recommendation and does not plan further actions in this area.

GAO Report Number	Title	GAO Recommendation	Status of Recommendation[2]	Timeline for Final Implementation
	Address Federal Electronic Recordkeeping Requirements	to-date and submitted to NARA. The schedules should include all required information, including when eligible temporary records must be destroyed or deleted and when permanent records are to be transferred to NARA.		
GAO-20-59	Information Management: Selected Agencies Need to Fully Address Federal Electronic Recordkeeping Requirements	Recommendation 19: The Director of the National Science Foundation should establish a time frame to update the agency's electronic information system inventory to include the following characteristics: technical characteristics of the systems, identify inputs and outputs, and describe update cycles.	Fully Implemented	NSF has implemented this recommendation and does not plan further actions in this area.
GAO-20-59	Information Management: Selected Agencies Need to Fully Address Federal Electronic Recordkeeping Requirements	Recommendation 20: The Director of the National Science Foundation should establish a time frame to update the agency's policies and procedures to include all of the records management controls required for electronic information systems and the required preservation mechanisms to ensure that records in its electronic recordkeeping system will be retrievable and useable.	Fully Implemented	NSF has implemented this recommendation and does not plan further actions in this area.

GAO Report Number	Title	GAO Recommendation	Status of Recommendation[2]	Timeline for Final Implementation
GAO-20-59	Information Management: Selected Agencies Need to Fully Address Federal Electronic Recordkeeping Requirements	Recommendation 21: The Director of the National Science Foundation should develop policies and procedures for the required retention and management requirements for email, including instructions to staff to ensure that the names and addresses of the sender, date of message, attachments, calendars, and draft documents will be retained.	Fully Implemented	NSF has implemented this recommendation and does not plan further actions in this area.
GAO-20-81	Federal Research: Additional Actions Needed to Improve Public Access to Research Results	Recommendation 7: The Director of the National Science Foundation should fully implement plans to ensure appropriate agency-funded research data are readily findable and accessible to the public.	Open	In December 2021, NSF implemented NSF-PAR version 2.0 which enables the system to accept dataset records and ensure agency-funded research data are readily findable and accessible to the public. This process is continuing to evolve and NSF-PAR 2.5 is being planned.
GAO-20-81	Federal Research: Additional Actions Needed to Improve Public Access to Research Results	Recommendation 37: As the Subcommittee on Open Science moves forward, the National Science Foundation co-chair, in coordination with other co-chairs and participating agencies, should take steps to fully implement leading practices that enhance and sustain collaboration.	Open	Following the GAO recommendations, the NSF co-chair in coordination with the other co-chairs and participating agencies, rebuilt and restructure the subcommittee's workplan. The new workplan highlighted high-value action categories and clarified relationships between actions and deliverables. The subcommittee used the workplan to organize its activities in calendar years 2020 and 2021, and the SOS continues to move forward with a newly organized workplan that advances updates in CY 2022 to OSTP's goals (advance equity, maximize accessebilty and utility, revolutionize infrstucture, enhance ease and rewards) for open science.

GAO Report Number	Title	GAO Recommendation	Status of Recommendation[2]	Timeline for Final Implementation
GAO-20-129	Information Technology: Agencies Need to Fully Implement Key Workforce Planning Activities	Recommendation 13: The Director of the National Science Foundation should ensure that the agency fully implements each of the eight key IT workforce planning activities it did not fully implement.	Open	NSF has made significant progress implementing the eight workforce planning activities identified in GAO's review. NSF is preparing a package for GAO as evidence of completion for the remaining engagement items.
GAO-19-241	Data Center Optimization: Additional Agency Actions Needed to Meet OMB Goals	Recommendation 29: The Director of the National Science Foundation should take action to meet the data center optimization metric targets established under DCOI by OMB.	Open	NSF has implemented this recommendation and does not plan further actions in this area.
GAO-19-227	National Science Foundation: Cost and Schedule Performance of Large Facilities Construction Projects and Opportunities to Improve Project Management	Recommendation 1: The Director of NSF should assess the agency's large facilities oversight workforce to identify any project management competency gaps, develop a plan to address any gaps and time frames for doing so, and monitor progress in closing them.	Open	As part of the implementation of the Program Management Improvement and Accountability Act (PMIAA), NSF has developed a competency model for staff overseeing major facilities, completed a gap analysis through self-assessment and supervisor surveys, evaluated available training options to identify gaps, and revised position descriptions. A new Training Plan specific to staff involved in major facilities oversight is under development. GAO will continue to monitor NSF's progress on PMIAA implementation during their 2022 engagement of this recommendation. NSF will consider this recommendation sufficiently implemented to close once the PMIAA Training Plan is available to NSF staff in 2022.

GAO Report Number	Title	GAO Recommendation	Status of Recommendation[2]	Timeline for Final Implementation
GAO-19-227	National Science Foundation: Cost and Schedule Performance of Large Facilities Construction Projects and Opportunities to Improve Project Management	Recommendation 2: The Director of NSF should establish criteria for the project management expertise of award recipients for large facilities projects and incorporate the criteria in project requirements and external panel reviews.	Open	Section 4.6.6 of the Research Infrastructure Guide (RIG) on Recipient project team competencies was finalized and posted in December 2021. NSF also intends to incorporate review of Recipient project team competencies against these new guidelines into NSF internal standard operating guidance. NSF considers this recommendation partially implemented. Once the new internal guidance is finalized (planned for March 31, 2022), GAO will determine if this recommendation can be closed.
GAO-19-227	National Science Foundation: Cost and Schedule Performance of Large Facilities Construction Projects and Opportunities to Improve Project Management	Recommendation 3: The Director of NSF should ensure, through a requirement or other means, that award recipients for large facilities projects provide information to NSF on any lessons learned or best practices.	Fully Implemented	In October 2020, NSF implemented new award terms and conditions that encourage major facility award Recipients to participate in NSF's Knowledge Management Program by a variety of means. GAO considers this recommendation fully implemented as stated in GAO-21-417.

GAO Report Number	Title	GAO Recommendation	Status of Recommendation[2]	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	Due to a delay in the formation of the NQI-authorized Advisory Committee, the Subcommittee on Quantum Information Science is continuing to follow the guidance provided in the "National Strategic Overview of Quantum Information Science", which outlined six key policy opportunities. With advice and coordination from the Subcommittee the NSTC has now released reports from working groups representing all agencies in three areas with recommendations for possible actions: "A Coordinated Approach to Quantum Networking Research", "The Role of International Talent in Quantum Information Science", and a "QIST Workforce Development National Strategic Plan". The full complement of NSF and DOE centers called for in the NQI is now complete. Progress reviews held by the two agencies reveal considerable cross-fertilization between the members of these centers.
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.	Fully Implemented	NSF has implemented this recommendation through their ongoing leadership of the Interagency Synthetic Biology Work as a forum for sustained collaboration across agencies. NSF considers this recommendation closed

GAO Report Number	Title	GAO Recommendation	Status of Recommendation[2]	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 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.	Fully Implemented	NSF's Office of Human Resource Management (HRM) has successfully implemented the agency-wide use of a 'Staffing Planning Tool' to capture staffing plans for each directorate and office for a fiscal year. This tool provides projections for FTE and IPA resources based on staffing trend data. HRM has formed a Community of Practice around best practices for use of the tool and HRM provides support on the strategic use of the tool to match anticipated changes in organization workload and mission, with existing staffing levels. HRM continues to work closely with Budget to use the tools to gather FTE and IPA projections which inform the Office of the Director decisions on resource allocation.
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 will provide a status report by March 31, 2022.
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.	Fully Implemented	NSF has implemented this recommendation and does not plan further actions in this area.

GAO Report Number	Title	GAO Recommendation	Status of Recommendation[2]	Timeline for Final Implementation
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.	Fully Implemented	Section 4.3 – *Schedule Estimating and Evaluation* has been finalized and published in the 2021 *Research Infrastructure Guide* (RIG; NSF 21-107), formerly the *Major Facilities Guide*. To implement the 2021 RIG, NSF has already updated SOG2020-03; *Pre-Award Review Process* to require inclusion of an analysis of the proposed schedule in NSF's Decision Memo prior to award.

PROGRAM EVALUATION AND MONITORING INFORMATION

Evaluations at NSF are currently performed at the discretion of the individual directorate, office, or program being evaluated. This section provides information for each program directorate and office on three principal types of evaluation activities:

- Major external evaluations completed in FY 2021,
- Advisory Committees and Committees of Visitors, and
- Significant workshops related to NSF programs in these areas.

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 2021

<u>CISE</u>

Evaluation is a key part of all CISE's education programs. For example, 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 to track program-level progress. CISE expects to continue these evaluation activities in FY 2023.

<u>EDU</u>

- An evaluation contract for NSF INCLUDES was awarded in September 2021 to assess progress toward leveraging collaborative change strategies to increase diversity and inclusion and broaden participation in STEM fields. The evaluation will identify evidence of successful and promising programmatic efforts and generate recommendations to the program for enhancing measurement and reporting to demonstrate progress. NSF INCLUDES learning agenda questions provided the framework for the evaluation. This evaluation will be extensive and will include specific metrics for assessment of program impacts. While interim deliverables will provide NSF INCLUDES with formative evaluation findings in the base year - and option years, if exercised, final results are expected by end date of FY 2026.
- In FY 2022, the Louis Stokes Alliances for Minority Participation program (LSAMP) will initiate a program evaluation. Evaluation questions will (1) investigate the impact of LSAMP strategies to strengthen STEM pathways and increase undergraduate and graduate STEM degrees from African-Americans, Hispanic-Americans, American Indians, Alaska Natives, Native Hawaiians, and Native Pacific Islanders, students historically underrepresented in STEM, at all educational levels; (2) identify and characterize the organizational structure, governance, and institutional transformation of LSAMP alliances; and, (3) examine the strength of the knowledge base of evidence-based practices and models implemented by LSAMP grantees. Results are expected to be used to assess program impacts and equity gaps at the undergraduate and graduate STEM pathways to contribute to the diversity of the nation's STEM workforce. Final results from this study are expected in FY 2026.
- The LSAMP program conducted a descriptive study (or analytical study) using data collected from the LSAMP monitoring system. The study focused on student participants in the Bridge to the Baccalaureate activity of the LSAMP program and their transfer rate to 4-year institutions and

completion rate of baccalaureate degrees were compared with non-LSAMP students in the same institutions. Final results from this study are expected in FY 2022.

- In FY 2022, the Robert Noyce Teacher Scholarship Program is developing a comprehensive external evaluation plan to assess the efficacy of the program as it relates to the short-term, medium-term, and long-term programmatic outcomes consistent with the Congressional legislation that undergirds the Robert Noyce Teacher Scholarship program. The evaluation will be launched in FY 2023. Results from the study are expected in FY 2025 and will be used to inform solicitation revisions and new track development (as needed).
- In FY 2022, the Improving Undergraduate STEM Education: EDU program is developing a comprehensive external evaluation plan to assess the efficacy of the program as it relates to the short-term, medium-term, and long-term programmatic outcomes. The evaluation will be launched in FY 2023. Results from the study are expected in FY 2025 and will be used to inform solicitation revisions and new track development (as needed).
- In FY 2023 or FY 2024, the National Science Foundation Research Traineeship program plans to initiate a program evaluation. Findings will be used to inform NSF leadership and other stakeholders of progress towards achievement of the program's long-term goals and to inform decision-making related to program development and management.
- In FY 2023, the Innovations in Graduate Education Program plans to initiate a formative and/or developmental evaluation. Results are expected to be used to inform program planning and development.
- An evaluation of the ADVANCE: Organizational Change for Gender Equity in STEM Academic Professions program was performed to investigate the sustainability of ADVANCE grants beyond NSF funding and the diffusion of ADVANCE generated ideas. The report was delivered to the ADVANCE program in FY 2022. The evaluation found that former ADVANCE grantees have had success in sustaining policy changes and institutional structural changes to make the institution more equitable. This report will help determine the next steps that will be taken by the Division.

<u>ENG</u>

- In FY 2019, the Division of Chemical, Bioengineering, Environmental, and Transport Systems (CBET) co-funded a three-year study on "New Directions for Chemical Engineering" by the National Academies of Sciences, Engineering, and Medicine (the National Academies). With the goal of identifying opportunities for the profession over the next 10-30 years, the study examines the role chemical engineering will play in the decarbonization of the chemical industries, development of personalized medicines, and creation of a circular economy for plastics and other materials. The final report[1], issued in 2022, will inform investment in chemical engineering research and education.
- In July 2019, NSF initiated an assessment of the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs as required by Congress. An ad hoc committee of the National Academies is conducting the study of the economic and non-economic impacts of the NSF SBIR and STTR programs, drawing on published research and existing data.[2] The committee is also providing guidance to NSF on its outreach strategy to potential SBIR and STTR applicants. The committee's report is anticipated by the end of FY 2022.

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[1] https://doi.org/10.17226/26342, National Academies of Sciences, Engineering, and Medicine. 2022. *New Directions for Chemical Engineering*. Washington, DC: The National Academies Press.

[2] www.nationalacademies.org/our-work/review-of-the-small-business-innovation-research-and-small-business-technology-transfer-programs-at-the-national-science-foundation

- In March 2019, NSF made a significant change to the SBIR/STTR proposal submission process, requiring that small businesses or entrepreneurs submit a three-page Project Pitch prior to submitting a full proposal. Pitch submitters learn within a month if their idea aligns with program objectives and receive program guidance. NSF has taken steps to assess the Project Pitch approach relative to the original goals, i.e., to offer real-time assistance to startups, advance the funding process, and accelerate the development of new ventures.
- In FY 2022, the Division of Civil, Mechanical, and Manufacturing Innovation (CMMI) has begun planning for an external study of future needs for the NSF Natural Hazards Engineering Research Infrastructure (NHERI) program after the current round of NHERI facility awards end. The study is intended to be completed in FY 2023 and will inform CMMI decisions on future directions for natural hazards engineering.
- In FY 2023, the Division of Engineering Education and Centers (EEC) is planning to initiate an external evaluation to examine aspects of the Engineering Research Centers program, such as the effectiveness of ERC graduates in industry and the benefits of ERC membership to industry. Findings are expected to help EEC understand the effectiveness of the ERC model in academic environments. Results from this study are expected in FY 2024.

MPS

MPS is leveraging several National Academies surveys and studies in support of program evaluations and studies, including:

- Division of Astronomical Sciences: In late October 2021, "Astro2020" the decadal survey on astronomy and astrophysics was published. The National Academies report "Pathways to Discovery in Astronomy and Astrophysics for the 2020s"[3], spells out the key scientific challenges for the next decade and proposes an ambitious program of ground-based and space-based activities for future investment. It also recommends near-term actions to support the foundations of the profession as well as technologies and tools to carry out the science.

The Division of Physics has two evaluations underway:

- Sponsored by NSF, the "Biological Physics/Physics of Living Systems: A Decadal Survey" is the first National Academies decadal survey of this field. It will survey developments in the field and identify new opportunities to use the tools and techniques of physics to address fundamental questions in living systems. The report[4] is expected to be completed in FY 2022.
- The "Elementary Particle Physics: Progress and Promise" decadal survey[5] will identify the fundamental scientific questions in particle physics that are expected to motivate research in the next decade along with potential new tools and techniques to address them. Jointly sponsored by the NSF and DOE, the survey is expected to be completed in FY 2024.

The Division of Materials Research (DMR) has three evaluations underway:

- In FY 2021, MPS/DMR commissioned a National Academies study[6] of the Designing Materials to Revolutionize and Engineer our Future (DMREF) program to examine its impact on the national Materials Genome Initiative. The study will evaluate the goals, progress, and scientific achievements of the DMREF program within the context of similar efforts both within the United

[3] www.nationalacademies.org/our-work/decadal-survey-on-astronomy-and-astrophysics-2020-astro2020
[4] www.nationalacademies.org/our-work/biological-physicsphysics-of-living-systems-a-decadal-survey
[5] www.nationalacademies.org/our-work/elementary-particle-physics-progress-and-promise
[6] www8.nationalacademies.org/pa/projectview.aspx?key=52250

States and abroad, and it will provide high-level strategic recommendations for DMREF to take full advantage of opportunities for accelerating the progression of materials research.

- In FY 2022, MPS/DMR plans to commission a National Academies study of ultra-high-field magnet technology and the associated science drivers of the future. The study will be carried out jointly by the Board on Physics and Astronomy and National Materials and Manufacturing Board.
- In FY 2023, MPS/DMR plans to commission a National Academies study of the Materials Research Science and Engineering Centers (MRSEC) Program. Results are expected to inform future directions and the format of the program.

<u>SBE</u>

- In FY 2022, the National Center for Science and Engineering Statistics (NCSES) sponsored a consensus study[7] with the National Academy of Sciences Committee on National Statistics (CNSTAT) related to transparency and reproducibility. NCSES intends to use the recommendations of this study to help shape the Federal Statistical System's approach to transparency and to ultimately strengthen public trust in federal statistics.
- Over FY 2022, NCSES is sponsoring and leading a project[8] 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, provide training on those linked data sets—while building capacity for researchers and analysts inside and outside the Federal Statistical System.
- Over FY 2022, NCSES is continuing to develop and refine its data governance efforts as outlined in the Evidence Act, the President's Management Agenda, the Federal Data Strategy, and recent OMB guidance.

<u>OIA</u>

In FY 2021 and FY 2022, the following studies and statistics reports were completed:

- *A Comparative Analysis of the International Research Experiences for Undergraduates (IRES) and the Research Experiences for Undergraduates (REU) Programs.* The analysis indicates that both programs contribute to building and diversifying the scientific workforce, varying in the types of activities in which students engage and the types of institutions they attend. The study provided several considerations for strategic decisions to build efficiencies, capitalize knowledge, and further increase the participation of underrepresented groups in STEM.[9]
- *Merit Review Process: Fiscal Year 2020 Digest.*[10] The report's summary statistics are used as indicators of the performance of the merit review process. In FY 2020, NSF saw an increase in proposals, awards, and funding rate, likely driven by the response to the COVID-19 pandemic. When adjusted for inflation, research award sizes across NSF have largely been flat since FY 2011.
- NSF's Evaluation and Assessment Capability group is pursuing evaluations of the Convergence Accelerator (CA) as well as NSF's direct partnerships with the private sector. In the case of the CA evaluation, the goal is to establish and operationalize a thorough set of metrics for grantee selection, training, progress, and outcomes for the full three-year lifecycle of a team progressing through the two phases of the CA. This effort will provide a set of instruments and infrastructure

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[7] www.nationalacademies.org/our-work/transparency-and-reproducibility-of-federal-statistics-for-the-national-center-for-science-and-engineering-statistics

[8] https://github.com/Coleridge-Initiative/ada-2021-ncses

[9] This study is expected to be released to the public in March 2022.

[10] www.nsf.gov/nsb/publications/2021/merit_review/FY-2020/nsb202145.pdf

to facilitate detailed and customized evaluation on a consistent basis going forward.

In FY 2022, the following studies are underway and are expected to be influential for decision making:

- *Education and Training Application.*[11] NSF is scaling up testing and adoption of this application that collects robust, high-quality data on applicants and participants in NSF programs. These data are vital for use in monitoring, research, and evaluation, and to promote equity and effectiveness in achieving NSF's mission. Findings are expected in FY 2022.
- *No deadlines literature review and descriptive analyses.* This study will enable NSF to assess the feasibility of conducting a rigorous evaluation of programs that removed proposal submission deadlines and inform decisions regarding next steps in removing deadlines more widely. Findings are expected in FY 2022.
- *Anti-harassment policies.* NSF designed and supported the implementation of an evaluation of its anti-harassment policies to inform learning about their efficacy and consider next steps in expanding the reach of these policies. Preliminary findings were included in NSF's Agency Equity Action Plan (January 2022). Final findings are expected in FY 2022.

<u>OISE</u>

- In FY 2022, OISE will initiate an assessment of the MULTIPLIER program.[12] Results are expected to determine the effectiveness of the MULTIPLIERs as a permanent mechanism for international engagement.
- An evaluation of the IRES was performed by Mathematica to assess participant demographic and background characteristics, program experiences, perceptions of the programs' impact on their professional careers and educational and employment outcomes. The final analysis, delivered to OISE in FY 2021, suggested the IRES program is well aligned with OISE's mission of leveraging international collaborations to advance science. The evaluation concluded with recommendations to encourage participation among underrepresented groups, stimulate participation from institutions with limited research opportunities, and to create a community of practice to promote best practices. The results from this evaluation will inform the next IRES solicitation for release in FY 2022.

<u>OPP</u>

In FY 2022 the National Academies released a Mid-Term Assessment of Progress on the *2015 Strategic Vision for Antarctic and Southern Ocean Research*. The report highlights progress in each of the three priority research areas: changing Antarctic ice sheets, biota evolution and adaption through genomic studies, and the origins of the universe. Opportunities identified in the next five years include greater progress in studying past ice sheet fluctuations, fostering community development to advance understanding of biological adaptations, and strive for improved communication between NSF and the scientific community.

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

[11] nsfetap.org

[12] More information on NSF's Multiplier Program available at www.nsf.gov/od/oise/multiplier.jsp

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: biological infrastructure; human resource development; earth sciences; geosciences education programs; and social and economic sciences.

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.[13]

In FY 2021, four directorates convened five COVs, covering five divisions. A table of the COVs performed in recent years and planned through FY 2023 is provided on the next page. This chapter also contains information on these COVs, as well as information on *ad hoc* reports.

[13] www.nsf.gov/od/oia/activities/cov/covs.jsp

Table 1 of 2, List of Committees of Visitors Meetings, FY 2016-FY 2023

All: all programs within the division were covered. Some COVs cover only some of a division's programs; these are noted under the FY.

Proj: projected to be completed in the designated FY.

DIR	DIV	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
BIO	Biological Infrastructure					All		
	Environmental Biology			All				Proj
	Integrative Organismal Systems		All				Proj	
	Molecular and Cellular Biosciences		All				Proj	
CISE	Advanced Cyberinfrastructure		All				Proj	
	Computing and Communication Foundations				All			
	Computer and Network Systems				All			
	Information and Intelligent Systems				All			
EDU	EDU Core Research	All						
	Graduate Education						Proj	
	Human Resource Development					All		
	Research on Learning in Formal and Informal Settings				All			
	Undergraduate Education	TUES STEP WIDER IUSE					Proj	
ENG	Chemical, Bioengineering, Environmental and Transport Systems			All				Proj
	Civil, Mechanical and Manufacturing Innovations			All				Proj
	Electrical, Communications and Cyber Systems		All					Proj
	Emerging Frontiers and Multidisciplinary Activities		All				Proj	
	Engineering, Education and Centers				All			
	Industrial Innovation and Partnerships				All			

Table 2 of 2, List of Committees of Visitors Meetings, FY 2016-FY 2023

All: all programs within the division were covered. Some COVs cover only some of a division's programs; these are noted under the FY.

Proj: projected to be completed in the designated FY.

DIR	DIV	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
GEO	Atmospheric and Geospace Sciences		Geospace Section		All			
	Earth Sciences	All				All		
	Ocean Sciences: Integrative		All	All			Proj	
	Ocean Sciences: Research							
	Education and Diversity Programs	All				All		
MPS	Astronomy			All				Proj
	Chemistry				All			
	Materials Research			All	All			Proj
	Mathematical Sciences							
	Physics			All				Proj
SBE	Behavioral and Cognitive Sciences			All				
	Office of Multidisciplinary Activities				All			
	Social and Economic Sciences					All		
OIA	Major Research Infrastructure						Proj	
	Established Program to Stimulate Competitive Research				All			
	STC						Proj	
OISE			All (2)				Proj	
OPP	Antarctic Sciences (ANT)				All			
	Arctic Sciences (ARC)				All			

Committees of Visitors (COV)[14]

BIO: In FY 2021, the Division of Biological Infrastructure COV convened December 15-17 and reviewed division operations and the programmatic portfolio for the five-year period spanning FY 2016 – FY 2020. BIO is evaluating all the COV recommendations and working to include them in future planning activities.

EDU: In November 2020, a COV reviewed the Division of Human Resource Development, (to be renamed the Division of Equity for Excellence in STEM, EES, in FY 2023). The chair of the COV presented the report to the EDU Advisory Committee, which met virtually in May 2021. The COV commended the division for many aspects of its merit review process and program management, including its diverse reviewer pool; high standards regarding the selection of reviewers, conflict-of-interest considerations, confidentiality, and procedures; generally thorough review analyses and panel summaries; and well-balanced award portfolio across disciplines and geography. The COV recommended that the division increase the number of reviewers with experience in evaluation, educational psychology, and related areas; expand efforts to recruit early-career investigators and reviewers; provide additional guidance to reviewers to promote consistency in format and quality throughout reviews and panel summaries; support mentoring and outreach to prospective and active investigators to foster more transformative research and education projects; support research to clearly articulate the role of, and intersectionality between, multiple identities (including race, ethnicity, gender, and disability) in students' STEM success; develop rigorous evidentiary bases and analytic frameworks for evaluation across all division programs; align logic models across programs; and clearly communicate how individual division programs align with the division's strategic plan. The division is addressing the recommendations as it plans future revisions of solicitations and future reviews of proposals in the programs.

GEO: On May 12-13, 2021, a COV reviewed GEO-wide education programs and on June 21-24 a COV reviewed programs in EAR. The COVs presented their reports to the GEO Advisory Committee, which convened in October of 2021. The COVs made a number of observations about the positive impact of the programs under review and made suggestions to improve the utility of program documentation for future committees as well as to broaden the impact of the programs.

SBE: In 2021, a COV assessed the Division of Social and Economic Sciences division's merit review process and presented their report to the SBE Advisory Committee in December 2021. Based on recommendations from the COV regarding the proposal success rate of underrepresented investigator coupled with addressing NSF's goals of diversity, equity, and inclusion; the directorate is evaluating best practices for helping researchers improve their proposals. In addition, the directorate will continue to support SBE's Build and Broaden (B2) program. B2 is designed to increase proposal submissions, advance research collaborations and networks involving Minority Serving Institutions (MSI) scholars, and support research activities at MSIs. Future updates to the solicitation will further target greater MSI participation in research proposals submitted to B2.

OPP: In FY 2020, COVs reviewed the Antarctic and the Arctic programs. The COVs presented their reports to the Office of Polar Programs Advisory Committee (OPP AC), which convened in fall of 2020. The COVs made several recommendations including that OPP, in both polar regions, expand efforts

[14] www.nsf.gov/od/oia/activities/cov/covs.jsp, NSF Committee of Visitors (COV) Reports.

to broaden participation of under-represented individuals (PIs, students, and reviewers) and institutions. OPP provided responses to both 2020 COV reports during the spring 2021 OPP AC. In FY 2022 the OPP AC sub-committee on diversity and inclusion will deliver its report on broadening participation in polar research.

Workshops and Reports

BIO

BIO supported various workshops in FY 2021 that inform planning of the directorate's research programs.

- A workshop entitled "Trans-U.S. Government expert meeting to examine synthetic biology roadmap" was held in October 2019. The workshop, which included attendees across academia, industry, and U.S. 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. An ongoing Dear Colleague Letter in plant synthetic biology, released in FY 2020 and supported by BIO and ENG at NSF, is one early outcome of this activity. In FY 2021, a follow up retreat was held, involving government employees only, to refresh and reprioritize the science needs that will enable the rapid advance of synthetic biology to address societal problems. Priorities included artificial intelligence, infrastructure and sequencing as well as microbial consortia as tools to advance synthetic biology or the products of synthetic biology. In FY 2022, a new partnership between NSF and DOE was launched (Accelerating Innovations in Biomanufacturing Approaches through Collaboration Between NSF and the DOE BETO funded Agile BioFoundry (NSF-DOE/ABF Collaboration), NSF 22-549) to enable access to infrastructure for synthetic biology more broadly in the science community.
- A series of virtual workshops are being held in the spring of 2022 to bring together diverse members of the research community to discuss creative strategies and build new research collaborations aimed at exploring how rules governing genotype-environment-phenotype relationships might be used to address grand challenges facing our society. Expected outcomes are to identify concrete ideas to inform the FY 2023 URoL solicitation based on Using the Rules of Life to Address Societal Challenges; the formation of interdisciplinary teams poised to advance these scientific questions; and insight into the readiness of the broader research community to engage in use-inspired research.

DBI supported multiple workshops in FY 2021 to inform the planning of the division's promotion of open data platforms for the BIO community and to inform future program management.

- As part of award #2027654 ("iDigBio: Sustaining the digitization, mobilization, accessibility, and use of biodiversity specimen data in U.S. museum and academic collections"; PI: Nelson), a workshop was conducted to address issues related to diversity, equity, and inclusion amongst the collections-based research community. The meeting was held on November 30, 2021 and was arranged as a listening session primarily to identify bottlenecks and barriers to participation by MSIs. The workshop was attended by several DBI POs to better engage with attendees and increase understanding of the impediments to their full participation in BIO programs.
- DBI supported a workshop in 2021 entitled "2020 Hackseq RNA Workshop" (award # 2024136). The goal of this workshop was to organize a coding intensive workshop where graduate students, post-docs, and researchers work together to uncover the role of uncharacterized ("dark") regions

- A virtual workshop entitled "The Moving Mountains Summit: Collaboratively Redefining the Future of Mountain Environments and Society" was funded and will allow for themes of agriculture, energy, and tourism to be addressed to explore cross-sector issues for rebuilding in a post-COVID mountain world. This workshop will include a broad set of stakeholders, including Indigenous communities from mountainous regions. This workshop will also help inform broadening participation efforts.
- A virtual workshop series titled "International Scientific Community Workshop Series on the Access and Benefit Sharing of Digital Sequence Information" was funded, to increase activity and engagement of U.S. stakeholders across science and industry in public comment on Nagoya Protocol issues. The aim is the co-development among scientific societies of practical, ethical, and collective solutions to catalyze fair and equitable benefits from biodiversity sequencing without slowing the pace of sequencing, publication efforts, and benefits. This effort held 3 (of 6) planned workshops, discussing Nagoya Protocol issues around bioethics of studying humans, using museum collections, and agricultural pathogens. Several white papers are in preparation and will inform efforts to prepare the DEB scientific community for navigating Nagoya Protocol issues in the context of their research data collection.

The Division of Integrative Organismal Systems (IOS) supported multiple workshops and meetings in FY 2021 that informed planning for research programs.

- The report from the IOS-commissioned National Academies workshop held February 10-12, 2020, entitled "Next Steps for Functional Genomics," continues to guide investments in plant and animal genomics across IOS and BIO.
- Both the report "Interagency Strategic Plan for Microbiome Research FY 2018-2022," released in April 2018, and the outcomes from community visioning workshop entitled "Deciphering the Microbiome," held in December 2019, continue to guide IOS investment into microbiomes, including energy production, microbial interactions with plants and animals in the warming world, and soil stability, fertility, and sustainability.
- The report from the NSF-sponsored National Academies 2018 workshop entitled "Science Breakthroughs to Advance Food and Agricultural Research by 2030" and the 2021 report from the NSF workshop series Innovation in the Bioeconomy on "Feeding the Planet Sustainably" continue to inform our investments in basic research to enable agriculture, including biotechnology, plant physiology, transformation and genomics, clean energy, and synthetic biology.
- During 2020 and 2021, IOS held a series of community visioning workshops with CAREER awardees, investigators receiving COVID RAPIDs, researchers developing novel neurotechnologies, and investigators working in plant and animal genomics to discuss gaps and future directions. These discussions informed subsequent development of Dear Colleague Letters, Solicitations, and investments in basic research, biotechnologies, climate impacts and their mitigation, and diversity in STEM.

The Division of Molecular and Cellular Biosciences (MCB) supported multiple workshops in FY 2021 that inform the planning of research programs.

- An Organization for Economic Cooperation and Development (OECD) Workshop, titled "Collaborative Platforms for Engineering Biology: Biofoundries and Distributed Biofoundries" was supported in FY 2020 as one in a series of activities to catalyze the development of a global network of biofoundries capable of addressing societal needs, including rapid response to pandemics. The workshop was part of the U.S. voluntary contribution to OECD work in the circular bioeconomy space and helped inform the development of a new MCB solicitation in collaboration with DOE titled "Accelerating Innovations in Biomanufacturing Approaches through Collaboration Between NSF and the DOE BETO funded Agile BioFoundry" (NSF 22-549). The first round of submissions to this solicitation will occur in FY 2022.

- A workshop on "The Plant Cell Atlas Initiative" was held in January 2020. The workshop aimed to bring together a plant cell biology community to develop an atlas of imaging resources for plant biology. This workshop led to the development and funding in FY 2021 of a Research Coordination Network, RCN: Creating and Fostering a Plant Cell Atlas Community, a five-year effort to develop a community of practitioners as well as develop data standards and best practices for this field (MCB-2052590).
- MCB funded a series of workshops from 2017 – 2019 titled "Finding Your Inner Modeler" that led to the development of a Research Coordination Network, funded in 2021, that aims to catalyze collaborations between mathematical modelers and cell biologists and grow a community of practice of cell biologists working across disciplines to solve complex biological problems using computational approaches (MCB-2003415).
- A workshop entitled "Workshop: Biology, Information, Communication and Coding Theory" was funded in FY 2019 and was held in January 2020. The workshop and report helped frame the newest Semiconductor synthetic biology solicitation, released in FY 2022, Semiconductor Synthetic Biology Circuits and Communication for Information Storage (SemiSynBio III), (NSF 22-557).
- Two workshops were funded in FY 2021 to convene parts of the MCB community together to explore how best enable data reuse, data synthesis, and integration, and to consider inclusive models of shared computational resources and training to foster collaboration on large scale problems in the molecular and cellular biosciences. The workshop proposals were received in response to a Dear Colleague Letter for Conferences to prepare for the transformation of Molecular and Cellular Biosciences Research through Information Synthesis and Integration (MoCeIS-DCL) in 2021 (NSF 21-017). The two workshops (MCB-2129768 and MCB-2133405) were held in late FY 2021 or early FY 2022 and represent distinct perspectives from different subdisciplines supported by MCB on opportunities for synthesis.
- MCB supported a series of five workshops facilitated by University Industry Demonstration Partnerships (UIDP) that brought together stakeholders and experts from different industries, including small businesses, government (e.g., NIH, NSF, DoD), and academia, to better understand how to catalyze the community to prepare for a society that will increasingly leverage the capabilities of biotechnology. Topics covered by these workshops have centered around areas of research that are of high priority, including the circular bioeconomy, feeding the planet sustainably, and biotechnological solutions to mitigating climate change. The workshops have also brought together social scientists and economists to address public engagement, consumer behavior, the intersection of regulation, policy, and economic models, and equitable distribution of the benefits of biotechnology. The results of these workshops will inform planning for new investments in biotechnology either through the new Technology, Innovation and Partnerships Directorate or in MCB and BIO (MCB-2137471).
- MCB supported two workshops to address the state of the art of the synthetic cell community. A grantee meeting was held in FY 2021 (MCB-2024029) to convene the awardees of the 8 projects funded through the NSF Understanding the Rules of Life: Building a Synthetic Cell, An Ideas Lab Activity (NSF 18-599). In addition, a workshop entitled "Reconstituting Biology – a chart to minimal cells" was funded in FY 2021 that will take place in 2022 (postponed because of COVID) that will examine the state of the field of synthetic and artificial cells after the investments in the area by the NSF Understanding the Rules of Life: Building a Synthetic Cell, An Ideas Lab Activity and the

Designing Synthetic Cells Beyond the Bounds of Evolution solicitation (NSF 21-531), released in FY 2021 that resulted in the funding of 9 projects in FY 2021.

- A two-day workshop titled "Broadening access to research opportunities at PUIs and HBCs in the Memphis region" was funded in FY 2020. The workshop was designed to increase awareness of funding opportunities and increase funding success in obtaining NSF funding for predominately undergraduate institutions including the host institution, Rhodes College, and three historically Black Colleges (HBCs) in the Memphis, TN, region, and led to the development of a grant writing bootcamp for faculty and staff from partnering institutions. The outcomes of this workshop and the subsequent bootcamp are informing discussions on how to build solicitations that will attract and benefit a broader PI base (MCB-2016838).

<u>CISE</u>

CISE has funded several studies led by the Computer Science and Telecommunications Board (CSTB) within the National Academies that resonate with the directorate's FY 2023 investments.

- In FY 2021, the CSTB published a report, *Information Technology Innovation: Resurgence, Confluence, and Continuing Impact*,[17] that analyzes the IT innovation ecosystem and assesses the long-term economic impact of CISE investments. Earlier reports in 2009 and 2012 had provided an in-depth articulation of the nature and successes of U.S. research partnerships among government, industry, and universities, and how these partnerships led to the creation of a significant number of IT industries since 1965 that are valued at a minimum of $1 billion each. The most recent report identifies new products and industries, illustrates the interconnections across research areas and industry sectors, and underscores the rich economic payoffs of these research investments. For example, the report provides a comprehensive overview of the evolution of the field of AI, including the role that NSF and other federal agencies have had in driving seminal advances.
- Another CSTB study examined strategies to improve representation of women of color in technology and issued a report in 2021: *Transforming Trajectories for Women of Color in Tech*.[18] This report uses current research as well as information obtained through four public information-gathering workshops to provide recommendations to a broad set of stakeholders within the tech ecosystem for increasing recruitment, retention, and advancement of women of color. It identifies gaps in existing research that obscure the nature of challenges faced by women of color in tech, addresses systemic issues that negatively affect outcomes for women of color in tech, and provides guidance for transforming existing systems and implementing evidence-based policies and practices to increase the success of women of color in tech.
- An ongoing study on *Responsible Computing Research: Ethics and Governance of Computing Research and its Applications*[19] will identify ethical principles and practices that research funders, research-performing institutions, and individual researchers can use to formulate, conduct, and evaluate research and associated activities in the CISE topic spaces responsibly. It will also address how these principles and practices can be promulgated and adopted by the broader computing research community. The report is expected to be completed by Summer 2022.

The Computing Community Consortium (CCC) has led several community visioning efforts that resonate with the directorate's FY 2023 investments:

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[17] www.nap.edu/catalog/25961/information-technology-innovation-resurgence-confluence-and-continuing-impact

[18] www.nationalacademies.org/our-work/addressing-the-underrepresentation-of-women-of-color-in-tech

[19] www.nationalacademies.org/our-work/responsible-computing-research-ethics-and-governance-of-computing-research-and-its-applications

- "Computing Research for the Climate Crisis 2021" brought together researchers from multiple disciplines to explore the role of computing in mitigating, adapting, and enhancing resiliency to climate change-induced challenges; the white paper identifies key areas in which these challenges will arise—energy, environmental justice, transportation, infrastructure, agriculture, and environmental monitoring and forecasting—and describes the- specific ways in which computing research can help address the associated problems.[20]
- "5G Security and Privacy: A Research Roadmap" identifies several research directions to identify and mitigate vulnerabilities that not only jeopardize the security of the 5G wireless networking ecosystem but also impact user privacy.[21]
- "A National Discovery Cloud: Preparing the U.S. for Global Competitiveness in the New Era of 21st Century Digital Transformation" outlines how to effectively harness cloud computing to advance data-driven discovery and computational modeling and simulation throughout the U.S. research and education enterprise.[22]
- "Assured Autonomy: Path Toward Living with Autonomous Systems We Can Trust" led a series of three workshops exploring assured autonomy, with the aim to create a unified understanding of the challenges of assuring the safety and security of autonomous systems, and the research needed to support these goals both economically and at scale.[23]
- "The Role of Robotics in Infectious Disease Crises" jointly with the National Academies, convened a virtual workshop with representation from the robotics community, clinicians, critical care workers, public health and safety experts, and emergency responders, to study the role of robotic systems in increasing national preparedness in infectious disease emergencies.[24]
- "A National Research Agenda for Intelligent Infrastructure: 2021" updated the 2017 research agenda for intelligent infrastructure, with a new focus on pandemics and worldwide natural disasters, sustainability and energy efficiency, job recovery and employment opportunities, and the advancement of social justice.[25]
- "A 20-Year Community Roadmap for Artificial Intelligence Research in the U.S." developed a roadmap for AI research over the next 20 years, including research priorities, challenges, and recommendations.[26]

CISE-funded community workshops and focus group studies also inform the directorate's FY 2023 investments.

- In FY 2021, CISE joined with other NSF directorates to support a series of interdisciplinary workshops on Pandemic Prediction and Prevention[27] which informed the development of the "Predictive Intelligence for Pandemic Prevention (PIPP)" program. These workshops spanned the underlying molecular, cellular, and physiological interactions giving rise to global behaviors of organisms; advanced biosensing, surveillance, and population risk modeling; identification of pre-

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[20] cra.org/ccc/wp-content/uploads/sites/2/2021/08/Computing-Research-and-Climate-Change-—-August-2021.pdf
[21] cra.org/ccc/wp-content/uploads/sites/2/2020/03/5G-Security-and-Privacy-A-Research-Roadmap.pdf
[22] cra.org/ccc/wp-content/uploads/sites/2/2021/04/CCC-Whitepaper-National-Discovery-Cloud-2021.pdf
[23] cra.org/ccc/wp-content/uploads/sites/2/2020/10/Assured-Autonomy-Workshop-Report-Final.pdf
[24] cra.org/ccc/wp-content/uploads/sites/2/2020/10/Workshop-Final-Report-The-Role-of-Robotics-in-Infectious-Disease-Crises.pdf
[25] cra.org/ccc/wp-content/uploads/sites/2/2021/01/A-National-Research-Agenda-for-Intelligent-Infrastructure_-2021-Update-FINAL.pdf
[26] cra.org/ccc/wp-content/uploads/sites/2/2019/08/Community-Roadmap-for-AI-Research.pdf
[27] www.nsf.gov/events/event_summ.jsp?cntn_id=302023&org=NSF

emergence and prediction of rare events in multiscale, complex, dynamical systems; and human attitudes, social behaviors, and the drivers underlying infectious-disease transmission, control, and eradication.

- In FY 2020, CISE supported a series of workshops to initiate a national dialogue on envisioning the future of the role of computing in undergraduate education.[28] Computing educators and computer science departments, as well as colleagues and academic units representing other stakeholder disciplines, worked together to understand the challenges associated with the growing demand and increasingly diverse student body seeking to learn more about computing, computer science, and the role of computation in their own disciplines, and to develop a research and teaching agenda for both computer science and other stakeholder disciplines.
- In FY 2020, CISE funded several studies to measure the utilization of the Internet given the significant increase in the population working from home in response to the COVID-19 pandemic. These studies helped to identify gaps in Internet measurement, such as measurement research being conducted in a piecemeal and uncoordinated manner, and limited by network access, as well as measurement techniques failing to provide a comprehensive portrait of Internet performance, connectivity, and cybersecurity threats. In January and April 2021, CISE sponsored two workshops on *"Overcoming Measurement Barriers to Internet Research"*[29,30] with the goal of understanding the challenges in network and security data collection and sharing. The final report from these workshops[31] was published in July 2021 and helped inform the development of a program on Internet Measurement Research that CISE recently launched.
- In FY 2020, CISE supported a workshop on "Next Generation (NextG) Security"[32] that brought together researchers with expertise in wireless communications, networked systems, and security to generate a research agenda that would lead to new knowledge on securing NextG mobile networking. The workshop focused on physical-layer security, infrastructure security, validation and verification for securing the NextG mobile platforms, and data privacy. In August 2020, NSF also supported a workshop on "Wireless, Spectrum & Innovation"[33] to collect community input and create a roadmap of transformative technologies related to wireless communications, networking, and spectrum use that that could serve as a strategic guide for future research investments. The outputs from these workshops informed the eventual Resilient & Intelligent NextG Systems (RINGS) program that CISE launched in collaboration with two other federal agencies and nine industry partners.
- In FY 2021, in collaboration with the National Institute of Information and Communications Technology (NICT) of Japan, CISE supported a workshop on "Programmable Networking"[34]. This workshop brought together researchers from the U.S. and Japan networking communities to assess current collaborative research projects, share future research goals, and identify new joint research opportunities. The resultant workshop report[35] informed the development of a joint program between CISE and NICT, Japan-U.S. Network Opportunity 3 (JUNO3): R&D for Programmable Networking for Next-Generation Core and Beyond 5G/6G Networks, launched later in the year.

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[28] cra.org/crn/2020/08/cue-next-envisioning-the-future-of-computing-in-undergraduate-education/
[29] www.caida.org/workshops/wombir/2101/
[30] www.caida.org/workshops/wombir/2104/
[31] www.caida.org/catalog/papers/2021_wombir2021_report/wombir2021_report.pdf
[32] nsf-nextg-security.cs.ucsb.edu/
[33] sites.google.com/view/nsf-workshop
[34] sites.google.com/view/us-japan-workshop/home
[35] https://drive.google.com/file/d/1wQBKYnh5KILfHxx3IkhY3mJTe8YFvOfL/view

- In FY 2021, CISE supported a focus group study on democratizing the use of advanced computational resources. The study involved a total of 15 focus groups, and six additional individual interviews were conducted with 88 key stakeholders of research cyberinfrastructure (CI) investments to more fully identify opportunities to democratize computation and bridge digital divides in ways that would better reach underrepresented groups in the field. The report from this study, *The Missing Millions: Democratizing Computation and Data to Bridge Digital Divides and Increase Access to Science for Underrepresented Communities*,[36] is helping to inform CISE efforts to enhance accessibility, equity, and diversity among users of NSF-funded CI resources.
- In FY 2020, CISE supported a workshop on the development of the CI workforce.[37] The report from this workshop, *Building the Research Innovation Workforce*,[38] identified the need for a coherent, collective, and coordinated national strategy and action plan to address the factors that inhibit the expansion and sustainment of a healthy CI and research computing workforce ecosystem. The findings in turn informed the recent Training-based Workforce Development for Advanced Cyberinfrastructure and Research Coordination Networks: Fostering and Nurturing a Diverse Community of CI Professionals programs.

<u>EDU</u>

- In FY 2021 the Science and Technology Policy Institute (STPI) completed a report titled *Broadening Participation Research Thematic Portfolio Review* focused on the activities of the Division of Human Resource Development, (to be renamed the Division of Equity for Excellence in STEM, EES, in FY 2023).
- EDU funded the "Roundtable on Systemic Change and the Future of Undergraduate STEM Education," an initiative to coordinate and catalyze national efforts to improve undergraduate STEM education so that learners are better prepared to be scientifically informed members of society and participate in the future STEM workforce. The National Academies' Board on Science Education and Board on Higher Education and Workforce will utilize the Roundtable to harness and accelerate on-going, evidence-based efforts to improve undergraduate STEM education while at the same time developing strategies for responding to the major transformations that face higher education in the coming decades. Through a series of interconnected projects and convenings engaging experts with diverse roles in higher education (e.g., classroom teaching laboratory instruction, research on education, professional development for faculty and instructors, department chairs, deans, provosts, and presidents) as well as experts from different sectors within and around higher education, the Roundtable will help the field anticipate STEM teaching and learning needs in light of the rapidly changing social and economic environments.
- In FY 2021, EDU Core Research provided funding to support a three-year initiative, Equity in PreK-12 STEM Education. Using the consensus study process of the National Academies, the National Academies' Board on Science Education (BOSE) convened an expert committee to investigate the specific ways that educational inequity manifests in STEM education and make actionable recommendations for how education stakeholders at all levels can take steps to address these inequities. The committee will write a consensus report that discussed how systemic inequity in STEM education can be addressed at all levels of the PREK-12 system to promote success in STEM for all students, regardless of background, demographic status, and community.[39]

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[36] www.rti.org/publication/missing-millions
[37] www.rcac.purdue.edu/ciworkforce2020
[38] www.rcac.purdue.edu/ciworkforce2020/report
[39] www.nationalacademies.org/our-work/equity-in-prek-12-stem-education

ENG

- Science and Technology Policy Institute (STPI) Reports: In FY 2022, ENG/EFMA expects to receive STPI's final report on its evaluation of NSF ENG's Research Experience and Mentoring (REM) program. REM supports hands-on research and ongoing mentorship in STEM fields for high school students, STEM teachers, undergraduate STEM students, faculty, and veterans through supplements to EFMA, ERC, and IUCRC awards.
- CBET, MPS's Division of Chemistry, and the Department of Energy's Basic Energy Sciences program co-funded a 2020 workshop in Washington, DC led by Iowa State University "The Changing Landscape of Feedstocks for Chemical Production--Implications for Catalysis." The workshop explored opportunities to manufacture organic chemicals by renewable electricity and biomass feedstocks, as alternatives to conventional thermal catalysis and fossil feedstocks. A final report documenting opportunities for greenhouse gas reduction related to climate change is expected in FY 2022.
- In December 2020 and June-July 2021, two CMMI-funded workshops, co-sponsored with NIST, were held on "Strategy for Resilient Manufacturing Ecosystems Through Artificial Intelligence" by the University of California, Los Angeles. The first workshop identified key areas of artificial intelligence (AI) adoption that are synergistic with and build on a growing foundation of manufacturing digitalization.[40] The second workshop identified the most important research, development, and workforce education and training priorities for industry-wide adoption of AI, with the goal of dramatically improving the competitiveness, efficiency, and resilience of U.S. manufacturing.[41] The workshops informed NSF programs for advanced manufacturing and AI, as well as the Subcommittee on Advanced Manufacturing and the Subcommittee on Machine Learning and Artificial Intelligence of the National Science and Technology Council.
- In January 2021, the Division of Electrical, Communications, and Cyber Systems (ECCS) funded a workshop on "Addressing Wireless Communication Needs in Underwater Technologies" held by Lehigh University. The workshop explored the most important applications, performance requirements, and environmental impacts of underwater wireless communications for the research community to focus on in the next five to ten years and the research needed to achieve the desired technology advances. The workshop report[42] is informing ECCS investment in wireless communication technologies.
- In February 2021, an ECCS-supported workshop on "Pandemic Readiness for Emerging Pathogens" was held by the University of California, Los Angeles; this workshop was part of the four-part series supported by ENG, BIO, CISE, and SBE for Predictive Intelligence for Pandemic Prevention. The workshop outcomes[43] informed the development of NSF's Predictive Intelligence for Pandemic Prevention program.
- In February 2021, an EEC-supported workshop on quantum engineering undergraduate education[44] was held by the Colorado School of Mines. The workshop focused on determining the

[40] https://oarc.ucla.edu/sites/default/files/Workshop%201_%20Report_v9_03172021.pdf, Strategy for Resilient Manufacturing Ecosystems Through Artificial Intelligence, first workshop report.
[41] https://oarc.ucla.edu/sites/default/files/Workshop2ReportFinal11102021.pdf, Strategy for Resilient Manufacturing Ecosystems Through Artificial Intelligence, second workshop report.
[42] www.blue-uci2021.org/report.pdf, Workshop report on Advancing Underwater Cyber Infrastructure for Blue Science
[43] https://thepipp.org/workshop-summary, Workshop Summary on Pandemic Readiness for Emerging Pathogens
[44] https://quantum.mines.edu/nsf-qe-ed/, Workshop on Quantum Engineering Education, February 26-27, 2021

best way to introduce undergraduate quantum engineering education into universities and colleges nationwide. The workshop report[45] was delivered in August 2021.

- In April 2021, the Office of Emerging Frontiers and Multidisciplinary Activities (EFMA) established the Engineering Research Visioning Alliance (ERVA)[46] to convene the engineering community to identify important engineering research challenges and opportunities. ERVA held its first visioning event in December 2021, "The Role of Engineering in Addressing Climate Change." The second visioning event is scheduled for March 2022, "Leveraging Biology to Power Engineering Impact." These events will lead to reports in 2022 on future research visions that may have programmatic impacts.
- In June 2021, a workshop co-funded by CBET, CMMI, and MPS/DMR on "Emerging Opportunities at the Intersection of Quantum and Thermal Sciences"[47] identified potential roles for thermal engineering in advancing quantum information science and technology. The workshop informed the CBET Thermal Transport Processes program and the November 2021 CBET-CMMI-DMR DCL on "Cryogenics below 1K - Systems, Cycles, and Materials" (NSF 22-018)[48], which seeks new approaches to refrigeration at ultra-low temperatures without using the rare ^{3}He isotope.
- In August 2021, a CBET-supported workshop on resilient supply of critical minerals, including critical minerals research and workforce development, was hosted by the Missouri University of Science and Technology; the workshop was co-funded by GEO/EAR and other Federal agencies. The workshop and report[49] informed CBET programs and the work of the NSTC Critical Minerals Subcommittee, on which CBET participates. A second workshop is planned for August 2022.
- In 2022, an EEC-funded two-part workshop series on "Defining and Building the Engineering Workforce of the Future"[50] will be held by the American Society for Engineering Education. The workshops will identify the key competencies required for a future-ready engineering workforce and the elements of an education action plan to equip this workforce, which will inform directorate investment in engineering education.
- In 2021, NSF submitted its second biennial report[51] to Congress about the I-Corps program, in response to the American Innovation and Competitiveness Act (AICA) (P.L. 114-329), which requires NSF to develop program metrics and summarize progress.
- NSF held a workshop May 12-13, 2021, to enable a wide range of stakeholders, including academia, industry, government, philanthropy, investors, civil society, and communities of practice, to come together and explore the concept of a national network of research institutes. The recommendations of this workshop[52] informed the development of the Regional Innovation Engines program.
- NSF continued to fund workshops and other community engagements to better understand the role of federal investment in advancing the Nation's innovation and entrepreneurship ecosystem.

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[45] https://doi.org/10.48550/arXiv.2108.01311, Building a Quantum Engineering Undergraduate Program report
[46] www.nsf.gov/news/news_summ.jsp?cntn_id=302437&org=ENG, "NSF funds the Engineering Research Visioning Alliance," April 7, 2021
[47] https://cvent.utexas.edu/2021NSF-QTSW, NSF Workshop on Emerging Opportunities at the Intersection of Quantum and Thermal Sciences
[48] https://www.nsf.gov/pubs/2022/nsf22018/nsf22018.jsp, DCL: Cryogenics below 1K - Systems, Cycles, and Materials (NSF 22-018)
[49] https://criticalminerals.mst.edu/wp-content/uploads/sites/7/2021/10/Findings-Report_Workshop-on-Resilient-Supply-of-Critical-Minerals_Locmelis-et-al.-2021.pdf, Workshop on Resilient Supply of Critical Minerals report
[50] https://nsf.gov/awardsearch/showAward?AWD_ID=2042343, EEC award for engineering education workshops
[51] www.nsf.gov/news/special_reports/i-corps/pdf/NSFI-Corps2021BiennialReport.pdf
[52] https://gaia.cs.umass.edu/NNRI/NSF_NNRI_Workshop%20_Report_Final.pdf

For example, on February 26, 2020, the first NSF-funded "Engineering Innovation Leadership Council (EILC)" workshop was held in Alexandria, Virginia, with more than 40 attendees from academia and government agencies. The workshop explored the role that university leadership plays in academic innovation and entrepreneurship ecosystems, and the broader impacts across communities, regions, and the Nation.

- From September 2020 through April 2021, NSF funded a series of monthly virtual seminars, "The Deep Dive Into Deep Tech Incubation," to better understand relationships among incubators, accelerators, universities, governments, investors, and industrial partners; explore how to most effectively engage with incubators and other venture development organizations that provide deep tech incubation; study how to advance the deep tech incubation ecosystem and grow more and stronger early-stage deep-tech companies in the United States; and share best practices among stakeholders.

GEO

- In FY 2020, GEO divisions made an award to the National Academies to conduct a workshop to identify new priorities and themes for paleoclimate research at NSF, "Identifying New Community-Driven Science Themes for National Science Foundation (NSF)'s Support of Paleo Perspectives on Climate Change (P2C2): A Workshop". The workshop was held in June 2021 and a report was delivered in November 2021. The report recommendations are being used to develop a new paleoclimate solicitation that will involve all GEO divisions.[53]
- In early FY 2022, the Division of Atmospheric and Geospace Sciences made an award to the National Academies to support a Decadal Survey for Solar and Space Physics (2024-2033). The survey is also supported by NASA and NOAA. Over the next two years, the process will solicit community input and create detailed recommendations for science and research infrastructure priorities for the next decade, as well as evaluated needs for training a scientifically- and technically skilled workforce in solar and space physics.
- In FY 2020, the National Academies released *Earth in Time, a vision for NSF Earth Sciences, 2020-2030*. The study identified high-priority challenges for the Division of Earth Sciences (EAR). The Report identified 12 compelling, high-priority research questions that underscore the intertwined nature of Earth's processes as an active, dynamic, open system in which all components interact to shape the state of the planet. The Report concludes that to predict how present-day natural and anthropogenic changes are likely to influence human society, over the coming decade it is critical to generate a clear understanding of how the Earth works today as an integrated system and how it has worked in the past. The Report includes 14 recommendations to achieve these goals. EAR has established Working Groups that are prioritizing them and planning their implementation.[54]
- In FY 2020 the Instrumental Portfolio Review Committee (IPRC), a sub-committee of the Advisory Committee for Geosciences (AC/GEO), released its review of EAR's geophysical instrumentation. Its primary goal was to review the portfolio of capabilities provided by Seismological Facility for the Advancement of Geoscience (SAGE) and Geodetic Facility for the Advancement of Geoscience (GAGE) with special reference to the recommendations in the National Academies Earth in Time Report. In addition, it evaluated recent advances in seismic and geodetic instrumentation that are not currently provided by SAGE and GAGE. It recommended a prioritized set of capabilities that

[53] www.nap.edu/catalog/26377/identifying-new-community-driven-science-themes-for-nsfs-support-of-paleoclimate-research
[54] www.nap.edu/catalog/25761/a-vision-for-nsf-earth-sciences-2020-2030-earth-in

should be provided by the geophysical facility that will be formed by the coming merger of SAGE and GAGE to maximize progress on compelling science over the next decade.[55]

- In September 2021 AC/GEO released a report *Imperative Science for the 21st Century: Why a Vibrant Geoscience Research and Educational Enterprise Is Essential to American Society and How the National Science Foundation Can Ensure Its Vitality*. This report highlights the importance of geoscience to the nation, the necessity of utilizing a systems approach in understanding the interconnected and dynamic Earth system, and the importance of broadening diversity and inclusivity in the geosciences.[56]
- In 2021 the National Academies released a report *Next Generation Earth Systems Science at the National Science Foundation*. This report presents a vision for a robust, integrated approach for studying the Earth's systems and identifies NSF facilities, infrastructure, coordinating mechanisms, computing, and workforce development to support this vision.[57]

<u>MPS</u>
In July 2021, MPS/AST received the *Final Report*[58] *of the Extreme Precision Radial Velocity Working Group*. This community working group was formed to follow up on the 2018 *Exoplanet Science Strategy* consensus study report[59] by the National Academies. Their intensive 2-year study presents a range of program architectures and identifies opportunities for NSF and NASA cooperation in the quest to discover other Earth-like planets

The Division of Chemistry (CHE) supported multiple workshops in FY 2021 that inform the planning of research programs.

- MPS/CHE, DOE/Basic Energy Sciences (BES)/Chemical Sciences, Geosciences and Biosciences (CSGB), the National Institutes of Standards and Technology (NIST) and the American Chemical Society (ACS) continued a consensus study through the National Academies Board on Chemical Sciences and Technologies (BCST) on *Enhancing the U.S. Chemical Economy through Investments in Fundamental Research in the Chemical Sciences*. This study is expected to examine and define the roles of the chemical industry in the U.S. economy, assess how investments in long-term fundamental research in the chemical sciences contribute to the division, agency, and administration's goals of national security, environmental sustainability, manufacturing industries, and energy-technology development while exploring strategies for targeted research and chemical workforce investments. Results, expected in calendar year (CY) 2022, will help inform the scope of core funding activities in the chemical sciences.
- MPS/CHE and DOE/Basic Energy Sciences (BES)/Chemical Sciences, Geosciences and Biosciences (CSGB) co-sponsored a consensus study through the National Academies Board on Chemical Sciences and Technologies (BCST) on *Identifying Opportunities at the Interface of Chemistry and Quantum Information Science (QIS)*. This study is expected to identify the opportunities and research priorities that exist at the boundaries of chemistry and quantum information science (QIS). The expected outcome is a report with recommendations on how chemistry can move forward and expand the field of QIS while also identifying ways that QIS can impact the field of chemistry. Final results from this study are expected in CY 2023.

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[55] www.nsf.gov/geo/adgeo/ear-instrumentation-review/AC-GEO-EAR-Instrumentation-Portfolio-Review-April-2021%20Report.pdf
[56] www.nsf.gov/geo/acgeo/geovision/acgeo-imperative-science-report-sept2021.pdf
[57] http://nap.edu/26042
[58] https://exoplanets.nasa.gov/exep/NNExplore/EPRV/
[59] www.nationalacademies.org/our-work/exoplanet-science-strategy

- MPS/CHE sponsored a "NSF ChemData/AI Researcher Meeting: Evaluate Progress and Think About What the Future Brings" in August 2021. The workshop aimed to assess the current landscape of data-driven chemical research and its impact; identify challenges that have hindered stronger engagement of the research community, and research opportunities that may lead to more impactful utilization of data-driven chemical research; identify needs for infrastructure and resources, ranging from laboratory scale to mid-scale, from tool development to community building, to maximize the impacts of data science on chemistry and advance chemistry through data science and vice versa; and identify needs and opportunities for workforce development that integrate data science, automation, and modern chemical education to explore solution landscapes. The workshop report is expected to become available in CY 2022.
- MPS/CHE (co)sponsored several educational and outreach activities, including the 2021 Chemistry Early Career Workshop attended by around 50 new faculty members from across the United States. The National Institutes of Health (NIH), DOE, and other federal agencies participated. CHE also organized community meetings at the American Chemical Society National Meeting (ACS Spring 2021, with representatives from DOE BES, NIH-NIGMS, and AFOSR; April 2021), the National Organization for the Professional Advancement of Black Chemists and Chemical Engineers (NOBCChE, September 2021), and the Society for Advancement of Chicanos/Hispanics and Native Americans in Science (SACNAS, October. 2021). Together, these outreach activities serve an important role in promoting high priority research initiatives and broadening participation of underrepresented and underserved populations in chemically-related sciences and engineering.

DMR supported multiple workshops in FY 2021 that inform the planning of research programs.

- MPS/DMR supported the Sustainable Polymers Square Table, which resulted in a workshop report[60] and an editorial[61] in the Macromolecules scientific journal.
- MPS/DMR held a joint workshop, intended to provide guidance on community needs and opportunities in experiment, theory, computation, and data-intensive research spanning the responsibilities of two programs in the areas of metals and metallic nanostructures. A report is forthcoming.
- MPS/DMR MRSEC program held a panel on "Emerging Frontiers in Materials Research – Beyond NSF's 10 Big Ideas." A report from the panel discussion was used to inform the current MRSEC Program Solicitation (NSF 21-625).
- MPS/DMR co-funded the Workshop on "Soft Matter Far from Equilibrium"[62] held at the Cornell High Energy Synchrotron Source. This highly interdisciplinary workshop aimed at identifying important fundamental questions related to soft matter far from equilibrium, highlighting the critical role x-ray-based tools play in answering these questions, and increasing the user community of synchrotrons.
- MPS/DMR co-sponsored the "US MUON Workshop 2021"[63] in a joint effort with DOE. The workshop aimed at assessing the science case for a future muon spectrometer. A report is forthcoming.
- MPS/DMR MRSEC program held a PI meeting on MRSEC umbrella activities (education, broadening participation, communication, facilities, industry). Discussion outcomes and planned next steps will be used to realign these activities with the mission of the MRSEC Program, so that it can grow its impacts and visibility.

[60] https://chemrxiv.org/engage/chemrxiv/article-details/60fed3e78804437c0ee3a401
[61] https://pubs.acs.org/doi/10.1021/acs.macromol.1c01751
[62] www.chess.cornell.edu/soft-matter-far-equilibrium-chess-2030-workshop-june-10-11-2021
[63] https://mrs.org/muon-2021

- MPS/DMR organized the "2D Interfacial and Layered Materials Forum," led by two Materials Innovation Platforms (MIP), which addressed teaching, training, and trusting data science for materials; democratization of data and data-tools access and archiving; interconnection between data and knowledge; AI-enabled digital twins; inorganic synthesis science; translation of materials and data from discovery to technology and to industry. A forthcoming report will be used to inform MIP activities, as well as to create opportunities to strengthen the connections between the MIPs and the scientific ecosystem that they interact with.
- In FY 2022, MPS/DMR will organize a workshop for faculty from PUIs, HBCUs, and MSIs motivating and leading faculty in ceramic and glass materials science and engineering to develop and expand vigorous undergraduate research programs. Its aim is to enhance the educational experiences of college students across a variety of institution types by increasing their exposure and experience with rigorous and up-to-date scientific activity.
- MPS/DMR-led DMREF program will sponsor a joint Materials Genome Initiative (MGI) PI meeting with DOE to discuss the new NSTC MGI Strategic Plan[64] and support a MGI Workforce workshop to respond to the *2019 TMS Creating the Next-Generation Materials Genome Initiative Workforce* study[65] and the new NSTC MGI Strategic Plan.[66]
- In FY 2023, MPS/DMR plans to hold a workshop on out-of-equilibrium soft matter, which besides materials research and physics connects to both the biological and the geological sciences. The purpose of the workshop is to bridge communities, and to identify opportunities as well as grand challenges.
- In FY 2023, MPS/DMR plans to hold a workshop on opportunities intended to provide guidance on community needs and opportunities in theory, simulation, and data-intensive research in soft-matter and polymeric materials. This is part of a foundational workshop series for the CMMT community to strengthen and bring together the diverse CMMT community.

The Division of Mathematical Sciences (DMS) supported multiple workshops in FY 2021 that inform the planning of research programs.

- In FY 2021, MPS/DMS and SBE supported a strategic study through a workshop on "Research on Enhancing Socially and Behaviorally Modulated Mathematical Models for Human Epidemiology," with a focus on the COVID-19 virus spreading. The report[67] informed the Foundation that current epidemiological models have proved inadequate in large part due to human behavioral and social processes that are missing from the existing models but that have appeared to be key to understanding the course of the pandemic. This report has guided the development of a partnership program/DCL (IHBEM) among MPS/DMS, SBE/SES, SBE/Division of Behavioral and Cognitive Sciences (BCS), and BIO/DEB to support convergent research that shall provide more reliable modeling tools to inform decision making and to evaluate public health policies during pandemics and other public health crises, with the premise that important advances will be made by incorporating human behavioral and social processes into mathematical epidemiological models.

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[64] www.mgi.gov/sites/default/files/documents/MGI-2021-Strategic-Plan.pdf
[65] www.tms.org/portal/Publications/Studies/MGIworkforce/MGIworkforce.aspx
[66] www.mgi.gov/sites/default/files/documents/MGI-2021-Strategic-Plan.pdf
[67] Research on Enhancing Socially and Behaviorally Modulated Mathematical Models for Human Epidemiology (2021). https://giesbusiness.illinois.edu/bridging-disciplinary-divides-conference

- The SIAM Report[68] on *Research and Education Priorities to Address Climate Change, Boost Environmental Resilience, and Advance Clean Energy* recommended that NSF math-specific programs such as the Research Training Groups in the Mathematical Sciences (RTG) should prioritize training efforts that give student convergent research experiences and skills. The report recommends that NSF incentivize mathematicians and computational scientists to learn a completely new discipline or to explore new synergies and advance climate innovation, and that NSF should use their post-doctoral support to encourage interdisciplinary training, acquisition of computational and data science skills, and time spent with mentors in other disciplines or in practicums with other agencies.
- In FY 2021, the National Academies Report[69] on *The Future of Electric Power in the United States* supported the continuation of the joint MPS/DMS and DOE/OE program on "The Algorithms for Modern Power Systems (AMPS).[70]"

<u>SBE</u>

- In FY 2022, NCSES is sponsoring a workshop[71] with the National Academies to address measurement needs and related gaps in the theory on globalization of R&D and publish a proceedings volume summarizing the workshop discussions. NCSES hopes to use the outcome of this study to help shape the Federal Statistical System's approach to these topics in the future.
- In FY 2022, NCSES released *Doctorate Recipients from U.S. Universities*.[72] This annual report provides the major trends in doctoral education, organized into themes highlighting important questions about doctorate recipients. The report shows that doctorate recipients begin careers in large and small organizations, teach in universities, and start new businesses; that doctoral education develops human resources that are critical to a nation's progress—scientists, engineers, researchers, and scholars who create and share new knowledge and new ways of thinking that lead, directly and indirectly, to innovative products and services; and that in doing so, doctorate recipients contribute to the nation's economic growth, cultural development, and rising standard of living.
- In FY 2022, NCSES released *The State of U.S. Science and Engineering 2022*.[73] This biennial, congressionally mandated report provides information on the state of the U.S. science and engineering (S&E) enterprise over time and within a global context. NCSES also released nine other "thematic" reports that are part of the *Science and Engineering Indicators* suite of products providing in-depth data and information on science, technology, engineering, and mathematics (STEM) education at all levels; the STEM workforce; U.S. and international research and development performance; U.S. competitiveness in high-technology industries; invention, knowledge transfer, and innovation; and public perceptions and awareness of science and technology.
- In FY 2022, NCSES released *National Patterns of R&D Resources*.[74] This annual report provides current data on the levels and key trends of the performance and funding of research and experimental development in the United States

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[68]www.siam.org/Portals/0/Publications/Reports/SIAM_Climate_Task_Force_Report_with_Appendix.pdf?ver=2021-08-12-091101-927
[69] www.nap.edu/catalog/25968/the-future-of-electric-power-in-the-united-states
[70] www.nsf.gov/pubs/2022/nsf22569/nsf22569.htm
[71] www.nationalacademies.org/our-work/understanding-the-impact-of-global-value-chains-a-workshop
[72] https://ncses.nsf.gov/pubs/nsf22300
[73] https://ncses.nsf.gov/pubs/nsb20221
[74] https://ncses.nsf.gov/pubs/nsf22320

- In FY 2020, SBE supported, in partnership with NIH, a National Academies ad hoc committee that will gather, review, and discuss the literature on the development of ontologies in scientific disciplines with a focus on developing the same in the behavioral sciences. The committee will provide recommendations for improving behavioral ontology advancement including: best practices and parameters for ontology development; resource, infrastructure and training needs; governance principles; identification of high priority research areas; recommendations for enhancing uptake and use in behavioral research; and recommendations for sustainability of the ontologies. The National Academies committee meetings and recommendation development continue to occur in FY 2022.
- In FY 2021, SBE funded a workshop to provide input for "Developing a Vision for a 21st Century National Data Infrastructure for Federal Statistics and Social and Economic Research." This project will convene a series of workshops, to develop a vision for a new national data infrastructure for the social and behavioral sciences.

<u>OIA</u>

- In FY 2020, the National Academies released a report titled *Promising Practices for Addressing the Underrepresentation of Women in Science, Engineering, and Medicine.*[75] The study and report production and dissemination was, in part, sponsored by federal funding from NSF and the National Institutes of Health (NIH). The report includes recommendations of evidence-based practices for increasing the participation, retention, and advancement of women in science, engineering, and medicine. NSF contributed to a wider dissemination of this report through funding provided in FY 2021.
- In FY 2020, NSF was one of several sponsors of a National Academies consensus study on *Advancing Anti-Racism, Diversity, Equity, and Inclusion in STEM Organizations*. The study report is anticipated in FY 2023.
- In FY 2021, building on the National Academies study and report on *Promising Practices for Addressing Underrepresentation of Women in Science, Engineering, and Medicine*, NSF and other federal and private partners sponsored a National Academies report to investigate the impact of the COVID-19 pandemic on academic careers of women in S&E fields. The report was published in FY 2021.[76]
- In FY 2021, the Committee on Equal Opportunity in Science and Engineering (CEOSE) transmitted to Congress its biennial report for 2019-2020, which is the first of a series of three reports focused on increasing the presence of underrepresented groups within the Nation's STEM enterprise.[77] The 2019-2020 report emphasized bold leadership actions. The next biennial report is anticipated in FY 2023.
- In FY 2021, NSF sponsored a workshop on leadership focused on increasing STEM leaders from historically underrepresented groups.[78] The three-day workshop concluded in January 2022, and provided an opportunity for participants to learn and document the characteristics of leaders from underrepresented groups, efforts to increase representation in STEM leadership, perspectives on STEM diversity and inclusion, strategies to develop the next generation of leaders, and approaches to integrate STEM and social science processes.

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[75] www.nap.edu/catalog/25585/promising-practices-for-addressing-the-underrepresentation-of-women-in-science-engineering-and-medicine#toc

[76] www.nap.edu/catalog/26061/the-impact-of-covid-19-on-the-careers-of-women-in-academic-sciences-engineering-and-medicine

[77] www.nsf.gov/od/oia/activities/ceose/reports/2019-2020-ceose-biennial-report-508.pdf

[78] https://leadershipinstem.psu.edu/schedule/

- In FY 2021, the NSF Advisory Committee for Environmental Research and Education provided NSF with two reports, *Environmental and Human Health: Research Priorities*[79] and *Environmental Change and Human Security: Research Directions*.[80] The first report articulates key priorities for future research into the ways in which human and environmental health intersect, as well as how to respond to these impacts as a scientific community. The report identifies new collaborations and scientific advances that are needed to anticipate and respond to future events that are meant to inform researchers and funders focused on the health-environment nexus. The second report describes opportunities to promote research at the intersection of environmental science and security and identifies near-term opportunities to promote important research through existing disciplinary approaches; more diverse and robust interdisciplinary/convergent research; and novel mechanisms to overcome barriers between academic groups and the national security community.

<u>OPP</u>

- In FY 2021, OPP and CISE's Office of Advanced Cyberinfrastructure jointly funded a workshop assembling a diverse mix of Antarctic domain science investigators to assess the science merits and benefits of a subsea telecommunications cable between New Zealand's South Island and McMurdo Station. It addressed how high speed/low latency telecommunications could transform scientific discovery in Antarctica as well as the potential to use the cable itself as a scientific instrument for such purposes as climate change research, ocean monitoring, seismic monitoring, and tsunami early warning. The general conclusion of the workshop report was that the cable concept was meritorious for further investigation.[81]
- In FY 2022 OPP is sponsoring the National Academies to conduct a workshop on technology developments to advance Antarctic research. A workshop report will be released in FY 2022. The workshop goal is to solicit community ideas and input on how technological innovation can:
  - Advance, facilitate, and transform Antarctic research and facilitate improvements to science support logistics;
  - Increase the reach of scientific investigations in Antarctica while reducing the logistics and environmental footprint of these operations; and
  - Facilitate broader, more diverse participation in Antarctic research.

[79] www.nsf.gov/ere/ereweb/reports/AC-ERE-Environmental-and-Human-Health-Report_June7-508.pdf
[80] www.nsf.gov/ere/ereweb/reports/AC-ERE-Environmental-Security-Report-508.pdf
[81] www.pgc.umn.edu/workshops/antarctic-cable/

OTHER INFORMATION

Management Reviews

Each quarter, NSF senior leadership reviews progress towards all performance goals of the agency, including the Agency Priority Goals, in a data-driven review meeting led by the Chief Operating Officer and Performance Improvement Officer.

Alignment of Human Capital Efforts with Organizational Performance

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. The Annual Performance Plan for FY 2023 establishes a framework for incorporating the agency's Human Capital Operating Plan into the Annual Performance Plan on an ongoing basis. As the Human Capital Operating Plan is updated in FY 2022 to reflect the agency's new Strategic Plan, NSF expects that its integration with the Annual Performance Plan will be further refined and expanded in future years. This will parallel the agency's continued use of HRStat[1] to report on and articulate the nexus between NSF's strategic goals and objectives, including annual goals, and human capital initiatives at the agency. Senior leaders are briefed quarterly regarding the status of annual 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.

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 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]

[1] HRStat is a strategic human capital performance evaluation process that identifies, measures, and analyzes human capital data to inform the impact of an agency's human capital management on organizational results with the intent to improve human capital outcomes. For more information, see: https://www.opm.gov/policy-data-oversight/human-capital-management/hr-stat/#url=Overview

performance information will be credible."[2] In FY 2021, 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 2021 report concluded that, "NSF relies on sound data collection practices, internal controls, and manual checks of system queries to ensure accurate performance reporting. Based on the verification and validation assessment, the Nexight Team has confidence in the systems, policies, and procedures used by NSF to calculate results for its performance measures."[3]

The data and information required to measure progress towards NSF's performance goals fall into three broad categories.

1. NSF automated administrative systems. 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. Data requests of external parties. Qualitative or quantitative information is solicited directly from awardees.
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

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[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 2021 Report*. December 2021.

TECHNICAL INFORMATION

For definitions of common acronyms used throughout NSF's FY 2023 Budget Request, see the NOTES found at the beginning of the entire document on pages iii-iv.

FY 2023 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; $8,425,987,000, to remain available until September 30, 2024, of which not to exceed $640,000,000 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.

STEM EDUCATION

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, $1,377,180,000, to remain available until September 30, 2024.

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; $473,200,000: 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 2023 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, $23,393,000, of which $400,000 shall remain available until September 30, 2024.

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.), $5,090,000: Provided, that not to exceed $2,500 shall be available for official reception and representation expenses.

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, $187,230,000, to remain available until expended.

ADMINISTRATIVE PROVISIONS
(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 504 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.

NSF NONRECURRING EXPENSES FUND

There is hereby established in the Treasury of the United States a fund to be known as the nonrecurring expenses fund (the Fund): Provided, That unobligated balances of expired discretionary funds appropriated for this or any succeeding fiscal year from the General Fund of the Treasury to the National Science Foundation by this or any other Act may be transferred (not later than the end of the fifth fiscal year after the last fiscal year for which such funds are available for the purposes for which appropriated) into the Fund: Provided further, That amounts deposited in the Fund shall be available until expended, and in addition to such other funds as may be available for such purposes, for information and business technology system modernization and facilities infrastructure improvements, including nonrecurring maintenance, necessary for the operation of the Foundation or its funded research facilities subject to approval by the Office of Management and Budget: Provided further, That amounts in the Fund may be obligated only after the Committees on Appropriations of the House of Representatives and the Senate are notified at least 15 days in advance of the planned use of funds.

SUMMARY JUSTIFICATION FOR A NON-RECURRING EXPENSES FUND

NSF requests Congressional concurrence on the establishment of a Non-recurring Expenses Fund (NEF) for agency use on cancelled funding resulting from appropriations in FY 2023, and all subsequent fiscal years. NSF's NEF would closely resemble similar Funds established across the government in agencies such as the Department of Veterans Affairs, the Department of Health and Human Services, the Department of Education, and the Department of Agriculture.

Since FY 2016, NSF has returned to the Treasury between $60 million and $92 million each year. Most of these cancelling funds are in the Research and Related Activities (R&RA) and STEM Education (EDU) accounts.

NSF Cancelled Appropriated Funding by Account

(Dollars in Millions)

	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021
Research and Related Activities	$51.06	$52.08	$56.49	$42.86	$56.29	$62.51
STEM Education[1]	15.12	15.56	14.02	12.08	19.01	24.93
Agency Operations and Award Management	3.46	2.76	3.35	4.98	3.44	3.53
Office of Inspector General	0.19	0.07	0.06	0.17	0.34	0.97
Office of the National Science Board	0.16	0.22	0.11	0.07	0.24	0.11
Total Cancelled Appropriated Funds	**$69.99**	**$70.69**	**$74.04**	**$60.16**	**$79.32**	**$92.05**

[1] Education and Human Resources account is renamed to STEM Education.

With authority to establish an NEF, instead of these funds canceling and returning to the Treasury, NSF would be able to use the funds for the limited purposes included in the legislation: information and business technology system modernization and facilities infrastructure improvements, including nonrecurring maintenance necessary for the operation of the Agency and its funded research facilities.

If passed in FY 2023, this legislation proposed would only apply to funds appropriated in FY 2023 and after. This would not apply to any funds appropriated prior to FY 2023.

SUMMARY OF FY 2023 BUDGETARY RESOURCES BY ACCOUNT

(Dollars in Millions)

Discretionary Accounts	FY 2021 Actual	FY 2022 Annualized CR	FY 2023 Request	Change Over FY 2022 Annualized CR Amount	Change Over FY 2022 Annualized CR Percent
RESEARCH AND RELATED ACTIVITIES					
Appropriation	$7,376.68	$6,909.77	$8,425.99	$1,516.22	21.9%
Unobligated Balance Available Start of Year	10.27	280.82		-280.82	
Unobligated Balance Available End of Year	-280.82				
Adjustments to Prior Year Accounts[1]	22.24				
Subtotal, R&RA	7,128.37	7,190.59	8,425.99		
Transfer to/from other funds	-29.29	-			
Total Budgetary Resources	$7,099.08	$7,190.59	$8,425.99	$1,235.40	17.2%
STEM EDUCATION (formerly EDUCATION AND HUMAN RESOURCES)					
Appropriation	$1,029.00	$968.00	$1,377.18	$409.18	42.3%
Unobligated Balance Available Start of Year	4.25	42.67		-42.67	
Unobligated Balance Available End of Year	-42.67				
Adjustments to Prior Year Accounts[1]	2.08				
Subtotal, EDU	992.66	1,010.67	1,377.18		
Transfer to/from other funds					
Total Budgetary Resources	$992.66	$1,010.67	$1,377.18	$366.51	36.3%
MAJOR RESEARCH EQUIPMENT & FACILITIES CONSTRUCTION					
Appropriation	$301.00	$266.00	$187.23	-$78.77	-29.6%
Unobligated Balance Available Start of Year	129.35	260.21		-260.21	
Unobligated Balance Available End of Year	-260.21				
Adjustments to Prior Year Accounts[1]	0.08				
Subtotal, MREFC	170.22	526.21	187.23		
Transfer to/from other funds	-				
Total Budgetary Resources	$170.22	$526.21	$187.23	-$338.98	-64.4%

Totals exclude reimbursable amounts.

[1]Adjustments include upward and downward adjustments to prior year obligations in unexpired accounts.

SUMMARY OF FY 2023 BUDGETARY RESOURCES BY ACCOUNT

(Dollars in Millions)

Discretionary Accounts	FY 2021 Actual	FY 2022 Annualized CR	FY 2023 Request	Change Over FY 2022 Annualized CR Amount	Change Over FY 2022 Annualized CR Percent
AGENCY OPERATIONS AND AWARD MANAGEMENT					
Appropriation	$357.64	$345.64	$473.20	$127.56	36.9%
Unobligated Balance Available Start of Year	9.20	-		-	
Unobligated Balance Available End of Year	-				
Adjustments to Prior Year Accounts[1]	0.39				
Subtotal, AOAM	367.23	345.64	473.20		
Transfer to/from other funds	29.29	-			
Total Budgetary Resources	$396.52	$345.64	$473.20	$127.56	36.9%
NATIONAL SCIENCE BOARD					
Appropriation	$4.50	$4.50	$5.09	$0.59	13.1%
Unobligated Balance - Expired	-0.07				
Total Budgetary Resources	$4.43	$4.50	$5.09	$0.59	13.1%
OFFICE OF INSPECTOR GENERAL					
Appropriation	$17.85	$17.85	$23.39	$5.54	31.1%
Unobligated Balance Available Start of Year	0.40	0.40		-0.40	
Unobligated Balance Available End of Year	-0.40				
Unobligated Balance - Expired	-0.24				
Total Budgetary Resources	$17.61	$18.25	$23.39	$5.14	28.2%
TOTAL DISCRETIONARY, NATIONAL SCIENCE FOUNDATION	$8,680.52	$9,095.86	$10,492.07	$1,396.21	15.3%

Totals exclude reimbursable amounts.

[1] Adjustments include upward and downward adjustments to prior year obligations in unexpired accounts.

SUMMARY OF FY 2023 BUDGETARY RESOURCES BY ACCOUNT

(Dollars in Millions)

Mandatory Accounts	FY 2021 Actual	FY 2022 Annualized CR	FY 2023 Request	Change Over FY 2022 Annualized CR Amount	Percent
STEM EDUCATION, H-1B					
Appropriation, Mandatory (H1-B Non-Immigrant	$213.46	$162.47	$158.86	-$3.61	-2.2%
Unobligated Balance Available Start of Year	124.67	137.24		-137.24	
Sequestration Previously Unavailable	9.03	8.75	9.03	0.28	
Sequestration Pursuant OMB M-13-06	-8.75	-9.03	-9.05		
Unobligated Balance Available End of Year	-137.24				
Adjustments to Prior Year Accounts[1]	-54.66				
Total Budgetary Resources	$146.51	$299.43	$158.84	-$140.59	-47.0%
DONATIONS					
Mandatory Programs (Special or Trust Fund)	$32.24	$10.00	$10.00	-	-
Unobligated Balance Available Start of Year	31.50	37.88		-37.88	
Sequestration Previously Unavailable	-	-	-	-	
Sequestration Pursuant OMB M-13-06	-	-			
Unobligated Balance Available End of Year	-37.88				
Adjustments to Prior Year Accounts[1]	0.08				
Total Budgetary Resources	$25.94	$47.88	$10.00	-$37.88	-79.1%
TOTAL MANDATORY, NATIONAL SCIENCE FOUNDATION	$172.45	$347.31	$168.84	-$178.47	-51.4%

Totals exclude reimbursable amounts.

[1]Adjustments include upward and downward adjustments to prior year obligations in unexpired accounts.

NSF FY 2023 REQUEST FUNDING BY PROGRAM
(Dollars in Millions)

	FY 2021 Actual	FY 2021 ARP Actual	FY 2021 Total	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request change over FY 2021 Actual	
						Amount	Percent
BIOLOGICAL SCIENCES (BIO)							
BIOLOGICAL INFRASTRUCTURE	$167.01	-	$167.01	-	$221.28	$54.27	32.5%
EMERGING FRONTIERS	109.51	9.18	118.69	-	185.52	76.01	69.4%
ENVIRONMENTAL BIOLOGY	178.78	-	178.78	-	186.15	7.37	4.1%
INTEGRATIVE ORGANISMAL SYSTEMS	206.89	-	206.89	-	214.81	7.92	3.8%
MOLECULAR & CELLULAR BIOSCIENCES	155.55	-	155.55	-	162.47	6.92	4.5%
TOTAL, BIO	**$817.74**	**$9.18**	**$826.92**	**-**	**$970.23**	**$152.49**	**18.6%**
COMPUTER & INFORMATION SCIENCE & ENGINEERING (CISE)							
ADVANCED CYBERINFRASTRUCTURE	$230.44	$6.59	$237.04	-	$252.25	$21.81	9.5%
COMPUTING & COMMUNICATION FOUNDATIONS	200.95	1.75	202.70	-	218.57	17.62	8.8%
COMPUTER & NETWORK SYSTEMS	238.02	4.87	242.90	-	266.06	28.04	11.8%
INFORMATION & INTELLIGENT SYSTEMS	217.78	1.75	219.53	-	248.16	30.38	14.0%
INFORMATION TECHNOLOGY RESEARCH	119.94	20.75	140.69	-	165.74	45.80	38.2%
TOTAL, CISE	**$1,007.13**	**$35.72**	**$1,042.85**	**-**	**$1,150.78**	**$143.65**	**14.3%**
ENGINEERING (ENG)[1,2]							
CHEMICAL, BIOENGINEERING, ENVIRONMENTAL, & TRANSPORT SYSTEMS	$199.87	-	$199.87	-	$226.17	$26.30	13.2%
CIVIL, MECHANICAL, & MANUFACTURING INNOVATION	241.58	3.00	244.58	-	265.86	24.28	10.1%
ELECTRICAL, COMMUNICATIONS, & CYBER SYSTEMS	124.00	-	124.00	-	137.20	13.20	10.6%
EMERGING FRONTIERS AND MULTIDISCIPLINARY	71.76	-	71.76	-	166.59	94.83	132.1%
ENGINEERING EDUCATION & CENTERS	127.23	-	127.23	-	144.46	17.23	13.5%
TOTAL, ENG	**$764.43**	**$3.00**	**$767.43**	**-**	**$940.28**	**$175.85**	**23.0%**

NSF FY 2023 REQUEST FUNDING BY PROGRAM
(Dollars in Millions)

	FY 2021 Actual	FY 2021 ARP Actual	FY 2021 Total	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request change over FY 2021 Actual: Amount	FY 2023 Request change over FY 2021 Actual: Percent
GEOSCIENCES (GEO)							
ATMOSPHERIC & GEOSPACE SCIENCES	$283.35	$17.29	$300.64	-	$301.37	$18.02	6.4%
EARTH SCIENCES	201.65	16.74	218.39	-	206.36	4.71	2.3%
RESEARCH, INNOVATION, SYNERGIES and EDUCATION	116.27	15.00	131.27	-	299.54	183.27	157.6%
OCEAN SCIENCES	402.99	22.01	425.00	-	431.78	28.79	7.1%
TOTAL, GEO	**$1,004.27**	**$71.04**	**$1,075.30**	**-**	**$1,239.05**	**$234.78**	**23.4%**
MATHEMATICAL & PHYSICAL SCIENCES (MPS)							
ASTRONOMICAL SCIENCES	$289.27	-	$289.27	-	$294.05	$4.78	1.7%
CHEMISTRY	259.60	-	259.60	-	284.14	24.54	9.5%
MATERIALS RESEARCH	330.07	-	330.07	-	349.92	19.85	6.0%
MATHEMATICAL SCIENCES	243.66	-	243.66	-	259.47	15.81	6.5%
PHYSICS	304.42	-	304.42	-	316.59	12.17	4.0%
MULTIDISCIPLINARY ACTIVITIES	166.29	20.33	186.62	-	242.68	76.38	45.9%
TOTAL, MPS	**$1,593.31**	**$20.33**	**$1,613.64**	**-**	**$1,746.85**	**$153.54**	**9.6%**
SOCIAL, BEHAVIORAL & ECONOMIC SCIENCES (SBE)							
BEHAVIORAL AND COGNITIVE SCIENCES	$99.42	$7.63	$107.05	-	$113.14	$13.72	13.8%
SOCIAL AND ECONOMIC SCIENCES	102.91	7.63	110.54	-	114.56	11.65	11.3%
MULTIDISCIPLINARY ACTIVITIES	24.32	2.90	27.22	-	27.62	3.30	13.6%
NATIONAL CENTER FOR SCIENCE & ENGINEERING	55.46	-	55.46	-	74.89	19.43	35.0%
TOTAL, SBE	**$282.11**	**$18.16**	**$300.27**	**-**	**$330.21**	**$48.10**	**17.0%**

NSF FY 2023 REQUEST FUNDING BY PROGRAM
(Dollars in Millions)

	FY 2021 Actual	FY 2021 ARP Actual	FY 2021 Total	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request change over FY 2021 Actual: Amount	FY 2023 Request change over FY 2021 Actual: Percent
TECHNOLOGY, INNOVATION & PARTNERSHIPS (TIP)[2]							
TRANSLATIONAL IMPACTS	$294.11	$17.87	$311.98	-	$419.00	$124.89	42.5%
[SBIR/STTR, including operations]	*[232.28]*	*[17.87]*	*[232.28]*	-	*[283.06]*	*[34.83]*	*[17.0%]*
INNOVATION AND TECHNOLOGY ECOSYSTEMS	74.89	2.00	76.89	-	265.00	190.11	253.8%
TECHNOLOGY FRONTIERS	-	-	-	-	145.00	145.00	N/A
STRATEGIC PARTNERSHIPS OFFICE	-	-	-	-	50.87	50.87	N/A
TOTAL, TIP	**$369.01**	**$19.87**	**$388.88**	**-**	**$879.87**	**$510.86**	**138.4%**
OFFICE OF INTERNATIONAL SCIENCE AND ENGINEERING (OISE)	**$51.29**	**$1.45**	**$51.04**	**-**	**$74.04**	**$22.75**	**44.4%**
OFFICE OF POLAR PROGRAMS (OPP)							
OFFICE OF POLAR PROGRAMS	$484.04	$14.52	$498.56	-	$547.10	$63.06	13.0%
[US Antarctic Logistical Support Activities]	*[77.00]*	*[-]*	*[77.00]*	-	*[90.00]*	*[13.00]*	*[0.17%]*
Total, OPP	**$484.04**	**$14.52**	**$498.56**	**-**	**$547.10**	**$63.06**	**13.0%**
INTEGRATIVE ACTIVITIES (IA)							
ESTABLISHED PROGRAM TO STIMULATE COMPETITIVE RESEARCH (EPSCoR)	$200.16	-	$200.16	-	$247.25	$47.09	23.5%
INTEGRATIVE ACTIVITIES	186.25	2.28	188.53	-	298.61	112.36	60.3%
TOTAL, IA	**$386.42**	**$2.28**	**$388.70**	**-**	**$545.86**	**$159.44**	**41.3%**
UNITED STATES ARCTIC RESEARCH COMMISSION	**$1.60**	**-**	**$1.60**	**-**	**$1.72**	**$0.12**	**7.5%**
TOTAL, RESEARCH AND RELATED ACTIVITIES	**$6,761.35**	**$195.54**	**$6,955.19**	**$6,909.77**	**$8,425.99**	**$1,664.64**	**24.6%**

NSF FY 2023 REQUEST FUNDING BY PROGRAM

(Dollars in Millions)

	FY 2021 Actual	FY 2021 ARP Actual	FY 2021 Total	FY 2022 Annualized CR	FY 2023 Request	FY 2023 Request change over FY 2021 Actual: Amount	FY 2023 Request change over FY 2021 Actual: Percent
STEM EDUCATION (EDU)							
EQUITY FOR EXCELLENCE IN STEM (EES)[3]	$214.00	$5.00	$219.00	-	$323.88	$109.88	51.3%
GRADUATE EDUCATION[4]	420.57	9.00	429.57	-	519.12	98.55	23.4%
RESEARCH ON LEARNING IN FORMAL AND INFORMAL SETTINGS	204.16	9.99	214.15	-	242.58	38.42	18.8%
UNDERGRADUATE EDUCATION	272.12	-	272.12	-	291.60	19.48	7.2%
TOTAL, STEM EDUCATION	**$1,110.85**	**$23.99**	**$1,134.85**	**$968.00**	**$1,377.18**	**$266.33**	**24.0%**
MAJOR RESEARCH EQUIPMENT & FACILITIES CONSTRUCTION	**$161.27**	**$8.95**	**$170.22**	**$266.00**	**$187.23**	**$25.96**	**16.1%**
AGENCY OPERATIONS AND AWARD MANAGEMENT	**$384.52**	**$12.00**	**$396.52**	**$345.64**	**$473.20**	**$88.68**	**23.1%**
OFFICE OF INSPECTOR GENERAL	**$17.61**	-	**$17.61**	**$17.85**	**$23.39**	**$5.78**	**32.8%**
OFFICE OF THE NATIONAL SCIENCE BOARD	**$4.43**	-	**$4.43**	**$4.50**	**$5.09**	**$0.66**	**14.8%**
TOTAL, NATIONAL SCIENCE FOUNDATION	**$8,440.03**	**$240.48**	**$8,678.81**	**$8,511.76**	**$10,492.08**	**$2,052.05**	**24.3%**

[1] The Division of Industrial Innovation and Partnerships (IIP) is being dissolved in FY 2022, with the bulk of its programs moving to the new Directorate for Technology, Innovation, and Partnerships (TIP) and the remainder to EEC. Funding above is presented in the new structure across all fiscal years for comparability.

[2] FY 2021 funding is adjusted for comparability to reflect the movement of activites to TIP in FY 2022.

[3] Formerly this division was named the Division of Human Resource Development (HRD). NSF proposes to rename this division as shown.

[4] The Graduate Research Fellowship Program is consolidated within the EDU, Division of Graduate Education in FY 2022, and is restated in prior years for comparability.

OBJECT CLASSIFICATION
NSF Consolidated Obligations
(Dollars in Millions)

Object Class	Standard Title	FY 2021 Actual	FY 2022 TBD	FY 2023 Request
11.1	Full-time permanent	$192	-	$241
11.3	Other than full-time permanent	14	-	15
11.5	Other personnel compensation	7	-	7
11.8	Special personal service payment	48	-	49
	Total personnel compensation	261	-	312
12.1	Civilian personnel benefits	71	-	92
21.0	Travel and transportation of persons	2	-	10
22.0	Transportation of things	1	-	1
23.1	Rental payments	40	-	26
23.2	Rental payments to others	1	-	1
23.3	Communications, utilities, and	-	-	1
25.1	Advisory and assistance services	217	-	222
25.2	Other services	40	-	50
25.3	Purchases of goods and services from Government	161	-	163
25.4	Operation and maintenance of facilities	233	-	283
25.5	Research and development contracts	11	-	11
25.7	Operation and maintenance of equipment	4	-	4
26.0	Supplies and materials	1	-	1
31.0	Equipment	6	-	6
41.0	Grants, subsidies, and contributions	7,632	-	9,309
	Total, Direct obligations [1,2]	**$8,681**	**-**	**$10,492**

[1] Excludes obligations for mandatory and reimbursable accounts.

[2]This table does not match MAX due to an error.

REIMBURSABLE ACTIVITY

Reimbursements for the Research and Related Activities Appropriation and the STEM Education (formerly 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.

NSF Reimbursements by Agency
(Dollars in Millions)

DEPARTMENT/AGENCY	FY 2021 Actual
DEFENSE	
Air Force	*$12.08*
Defense	*8.63*
Navy	*4.85*
Army	*4.90*
Subtotal, DoD	$30.46
Commerce (Including Census, NOAA, & NIST)	4.71
Interior	2.08
Energy	5.64
Health & Human Services	30.42
Homeland Security	10.70
NASA	3.21
Corps of Engineers, Civil	1.74
Transportation	2.02
OTHER (less than $500,000)	2.07
TOTAL REIMBURSEMENTS	**$93.05**

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 2021 CARRYOVER INTO FY 2022 BY ACCOUNT

The National Science Foundation's total unobligated balance of $759.22 million ($584.10 million from Discretionary accounts, and $175.12 million from Mandatory accounts) is described below.

Discretionary and Mandatory Accounts:
Distribution of NSF FY 2021 Carryover into FY 2022
(Dollars in Millions)

Discretionary Accounts	Amount
Research and Related Activities	$9.36
Research and Related Activities (ARP)	271.46
STEM Education	5.67
STEM Education (ARP)	37.00
Major Research Equipment and Facilities Construction	209.16
Major Research Equipment and Facilities Construction (ARP)	51.05
Office of Inspector General	0.40
Total, Discretionary	**$584.10**

Mandatory Accounts	
H-1B Non-Immigrant Petitioner	$137.24
PL 116-260 - Temporary Rescission	[-60.00]
Donations	37.88
Total, Mandatory	**$175.12**
TOTAL, NSF	**$759.22**

Discretionary

R&RA
Within the R&RA account, $280.82 million (including $271.46 million in American Rescue Plan Funding) was carried over into FY 2022.

Integrative Activities Research Investment Communications
- Amount: $299,000
- Purpose: Funds will be used for NSF multimedia contract awards that were not ready for obligation in FY 2021. Funding will be used on four procurement actions in process that will be completed in time for award this fiscal year.
- Obligation: FY 2022 Quarter 2.

Integrative Activities for Program Planning and Policy Development
- Amount: $840,000
- Purpose: These funds will support activities associated with NSF's merit review process including survey, studies, and committee of visitors data maintenance. Additionally, NSF funded an award supporting the core activities of the National Academies' Committee on Science, Engineering, Medicine, and Public Policy.
- Obligation: Anticipated FY 2022 Quarter 4.

Integrative Activities for Evaluation and Assessment Capabilities program

- Amount: $251,000
- Purpose: These carryover funds will be used for Evaluation and Assessment Program Services contract to support NSF's implementation of Evidence Act requirements, notably those identified in NSF's draft Learning Agenda and Capacity Assessment.
- Obligation: Anticipated FY 2022 Quarter 3.

Integrative Activities for Historically Black Colleges and Universities – Excellence in Research

- Amount: $993,000
- Purpose: Funds will provide supplemental support to postdoctoral researchers, graduate students, and undergraduate students disproportionately impacted by the COVID-19 pandemic.
- Obligation: Anticipated FY 2022 Quarter 3.

National Coordination Office for Networking and Information Technology Research and Development

- Amount: $60,276
- Purpose: Funding to continue government procurements and operational expenses (i.e., credit card purchases, government travel, mailroom operations, etc.).
- Obligation: Anticipated FY 2022 Quarter 4.

National Nanotechnology Coordination Office

- Amount: $214,130
- Purpose: Funding for the National Nanotechnology Coordination Office (NNCO) for NNCO operational expenses.
- Obligation: Anticipated FY 2022 Quarter 4.

American Rescue Plan (R&RA)

- Amount: $271.46 million
- Purpose: Funds will be used for awards that were not ready for obligation in FY 2021.
- Obligation: FY 2022 Quarter 1–2 and remaining amounts to be obligated in Quarter 3

The remaining $6.70 million within discretionary R&RA consists of funds from throughout the Foundation for projects not funded in FY 2021.

<u>STEM Education (EDU; formerly Education and Human Resources)</u>

Within the EDU account, $42.67 million was carried over into FY 2022, (including $37.0 million in American Rescue Plan Funding) was carried over into FY 2022.

Presidential Award for Excellence and Teaching

- Amount: $1.35 million
- Purpose: These carryover funds will be used to recognize recipients of the Presidential Awards for Excellence in Mathematics, Science Teaching and recipients of the Presidential Awards for Excellence in Science, Mathematics, and Engineering Mentoring.
- Obligation: FY 2022 Quarter 2 and Anticipated FY 2022 Quarter 3.

Robert Noyce Teacher Scholarship Program (Noyce)
- Amount: $4.31 million
- Purpose: These funds will be used to invest in teacher preparation and/or support Noyce fellows during completion of a teaching obligation.
- Obligation: FY 2022 Quarter 3.

American Rescue Plan (EDU)
- Amount: $37.0 million
- Purpose: Funds will be used for awards that were not read for obligation in FY 2021.
- Obligation: FY 2022 Quarter 1–2 and remaining amounts to be obligated in Quarter 3.

The remaining $10,000 consists of funds from EDU for projects not funded in FY 2021.

<u>MREFC</u>
Within the MREFC account, $260.21 million (including $51.05 million in American Rescue Plan Funding) was carried over into FY 2022.

Mid-scale Research Infrastructure Track 2
- Amount: $73.68 million (including $6.45 million in American Rescue Plan funding)
- Purpose: Funding for continuing Mid-scale Track 2 awards, awards pending independent cost estimates required by Congress in the American Innovation and Competitiveness Act (AICA), and to complete the NSF cost analysis on the new projects prior to award.
- Obligation: FY 2022 Quarter 1–2 and remaining amounts to be obligated in Quarter 3.

Antarctic Infrastructure Recapitalization
- Amount: $115.84 million
- Purpose: Baseline and budget contingency funding not obligated in FY 2021.
- Obligation: FY 2022 Quarter 3.

Regional Class Research Vessel
- Amount: $14.05 million in American Rescue Plan funding
- Purpose: Management reserve funding not obligated in FY 2021.
- Obligation: FY 2022 Quarter 1-2.

Vera C. Rubin Observatory
- Amount: $46.74 million (including $30.0 million in American Rescue Plan funding)
- Purpose: Management reserve funding not obligated in FY 2021.
- Obligation: FY 2022 Quarter 1–2 and remaining amounts to be obligated in Quarter 3.

Daniel K. Inouye Solar Telescope
- Amount: $553,350 in American Rescue Plan funding
- Purpose: Management reserve funding not obligated in FY 2021.
- Obligation: FY 2022 Quarter 3.

High-Luminosity Large Hadron Collider
- Amount: $4.26 million
- Purpose: Management reserve funding not obligated in FY 2021.
- Obligation: FY 2022 Quarter 3.

Dedicated Construction Oversight
- Amount: $830,000
- Purpose: Support for major facility construction oversight required under AICA and NSF policy, National Ecological Observatory Network construction close-out.
- Obligation: FY 2022 Quarter 1–2 and remaining amounts to be obligated in Quarter 3.

The remaining $4.25 million consists of funds from recoveries from closed projects not funded in FY 2021.

<u>OIG</u>
Within the OIG two-year account, $400,000 was carried over into FY 2022

Office of the Inspector General
- Amount: $400,000
- Purpose: Funds are expected to be used to procure financial and performance 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 2022 Quarter 3.

MANDATORY

Within the H-1B account, $137.24 million was carried over into FY 2022. Subject to P.L. 116-260, $60.0 million was rescinded in FY 2021.

Innovation Technology Experiences for Students (iTEST)
- Amount: $6.93 million ($21.93 million carryover less $15.0 million rescinded is the amount of iTEST carryover)
- Purpose: Since NSF typically receives the largest amounts from H-1B visa fees in August and September, there was insufficient time to obligate these funds before the end of the fiscal year.
- Obligation: $4.0 million was committed/obligated in Quarter 1-2, remaining amounts to be obligated in FY 2022 Quarter 3.

Scholarships in Science, Technology, Engineering, and Mathematics (S-STEM)
- Amount: $70.31 million ($115.31 million carryover less $45.0 million rescinded is amount of carryover for S-STEM)
- Purpose: Since NSF typically receives the largest amounts from H-1B visa fees in August and September, there was insufficient time to obligate these funds before the end of the fiscal year.
- Obligation: $62.60 million was committed/obligated in Quarter 1-2, remaining amounts to be obligated FY 2022 Quarter 3.

Within the Donations account, $37.88 million was carried over into FY 2022. Of this amount, $28.34 million is from foreign contributions to carry out specific projects with NSF, and was transferred into a Deposit Fund that was created in early FY 2022. The remaining $9.54 million consists of donations from domestic entities.

QUANTITATIVE DATA TABLE
National Science Foundation
Research and Development Special Analysis
(Dollars in Millions)

	FY 2021 Actual	FY 2021 Actual ARP Act	FY 2021 Total	FY 2022 Annualized CR	FY 2023 Request
Investment Activities					
Conduct of Research and Development					
Basic Research	$5,609.01	$158.36	$5,767.37	-	$6,786.96
Applied Research	830.27	33.62	863.89	-	1,114.83
Subtotal, Conduct of R&D	6,439.28	191.98	6,631.27	-	7,901.79
Physical Assets					
Research and Development Facilities	$166.00	$8.95	$174.95	-	$190.74
Research and Development Major Equipment	257.08	0.83	257.91	-	354.51
Subtotal, R&D Facilities & Major Equipment	423.08	9.78	432.86	-	545.25
Total, Research and Development	6,862.36	201.77	7,064.13	-	8,447.04
Conduct of Education and Training	743.80	26.62	770.42	-	969.11
Non-Investment Activities	833.87	12.10	845.97	-	1,075.93
TOTAL	**$8,440.03**	**$240.49**	**$8,680.52**	**$8,511.76**	**$10,492.08**

QUANTITATIVE DATA TABLE
RESEARCH AND RELATED ACTIVITIES
Research and Development Special Analysis
(Dollars in Millions)

	FY 2021 Actual	FY 2021 Actual ARP Act	FY 2021 Total	FY 2022 Annualized CR	FY 2023 Request
Investment Activities					
Conduct of Research and Development					
Basic Research	$5,428.52	$155.86	$5,584.38	-	$6,521.94
Applied Research	542.91	23.13	566.04	-	$681.67
Subtotal, Conduct of R&D	5,971.43	178.99	6,150.42	-	7,203.61
Physical Assets					
Research and Development Facilities	$4.73	-	$4.73	-	$3.51
Research and Development Major Equipment	257.08	0.83	257.91	-	$354.51
Subtotal, R&D Facilities & Major Equipment	261.81	0.83	262.64	-	358.02
Total, Research and Development	6,233.24	179.82	6,413.06	-	7,561.63
Conduct of Education and Training	286.57	15.72	302.29	-	355.67
Non-Investment Activities	383.73	-	383.73	-	508.69
TOTAL	**$6,903.54**	**$195.54**	**$7,099.08**	**$6,909.77**	**$8,425.99**

QUANTITATIVE DATA TABLE

STEM EDUCATION (formerly EDUCATION AND HUMAN RESOURCES)

Research and Development Special Analysis

(Dollars in Millions)

	FY 2021 Actual	FY 2021 Actual ARP Act	FY 2021 Total	FY 2022 Annualized CR	FY 2023 Request
Investment Activities					
Conduct of Research and Development					
Basic Research	$180.49	$2.50	$182.99	-	$265.02
Applied Research	287.36	10.49	297.85	-	433.16
Subtotal, Conduct of R&D	467.85	12.99	480.85	-	698.18
Physical Assets					
Research and Development Facilities	-	-	-	-	
Research and Development Major Equipment	-	-	-	-	-
Subtotal, R&D Facilities & Major Equipment	-	-	-	-	-
Total, Research and Development	467.85	12.99	480.85	-	698.18
Conduct of Education and Training	457.23	10.90	468.13	-	613.44
Non-Investment Activities	43.58	0.10	43.68		65.56
TOTAL	**$968.66**	**$23.99**	**$992.66**	**$968.00**	**1,377.18**

QUANTITATIVE DATA TABLE
MAJOR RESEARCH EQUIPMENT AND FACILITIES CONSTRUCTION
Research and Development Special Analysis

(Dollars in Millions)

	FY 2021 Actual	FY 2021 Actual ARP Act	FY 2021 Total	FY 2022 Annualized CR	FY 2023 Request
Investment Activities					
Conduct of Research and Development					
Basic Research	-	-	-	-	-
Applied Research	-	-	-	-	-
Subtotal, Conduct of R&D	-	-	-	-	-
Physical Assets					
Research and Development Facilities	$161.27	$8.95	$170.22	-	$187.23
Research and Development Major Equipment	-	-	-	-	-
Subtotal, R&D Facilities & Major Equipment	161.27	8.95	170.22	-	187.23
Total, Research and Development	161.27	8.95	170.22	-	187.23
Conduct of Education and Training	-	-	-	-	-
Non-Investment Activities	-	-	-	-	-
TOTAL	**$161.27**	**$8.95**	**$170.22**	**$266.00**	**$187.23**

QUANTITATIVE DATA TABLE
AGENCY OPERATIONS AND AWARD MANAGEMENT
Research and Development Special Analysis
(Dollars in Millions)

	FY 2021 Actual	FY 2021 Actual ARP Act	FY 2021 Total	FY 2022 Annualized CR	FY 2023 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	$384.52	$12.00	$396.52	$345.64	$473.20
TOTAL	**$384.52**	**$12.00**	**$396.52**	**$345.64**	**$473.20**

QUANTITATIVE DATA TABLE
OFFICE OF INSPECTOR GENERAL
Research and Development Special Analysis
(Dollars in Millions)

	FY 2021 Actual	FY 2021 Actual ARP Act	FY 2021 Total	FY 2022 Annualized CR	FY 2023 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	$17.61	-	$17.61	$17.85	$23.39
TOTAL	**$17.61**	**-**	**$17.61**	**$17.85**	**$23.39**

QUANTITATIVE DATA TABLE
OFFICE OF THE NATIONAL SCIENCE BOARD
Research and Development Special Analysis
(Dollars in Millions)

	FY 2021 Actual	FY 2021 Actual ARP Act	FY 2021 Total	FY 2022 Annualized CR	FY 2023 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	$4.43	-	$4.43	-	$5.09
TOTAL	**$4.43**	**-**	**$4.43**	**$4.50**	**$5.09**