# NATIONAL SCIENCE FOUNDATION

# FY 2022 Budget Request to Congress

May 28, 2021

# NOTES

## Table and Figure Notes

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

## Common Acronyms Used in NSF's Budget Submission

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

<u>Directorates and offices</u>
- BFA - Office of Budget, Finance, and Award Management
- BIO - Directorate for Biological Sciences
- CISE - Directorate for Computer and Information Science and Engineering
- ENG - Directorate for Engineering
- EHR - Directorate for Education and Human Resources
- GEO - Directorate for Geosciences
- MPS - Directorate for Mathematical and Physical Sciences
- SBE - Directorate for Social, Behavioral, and Economic Sciences
- 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]

<u>NSF Big Ideas</u>
*Convergence Accelerator*
- CA - NSF Convergence Accelerator

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

*Enabling Big Ideas*
- GCR - Growing Convergence Research at NSF
- Mid-scale RI - Mid-scale Research Infrastructure
- NSF INCLUDES - Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science

NSF-Wide Investments

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

National Science and Technology Council Crosscuts:

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

Other Frequently Used Acronyms

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

**NSF FY 2022 BUDGET REQUEST TO CONGRESS**
**TABLE OF CONTENTS**

**OVERVIEW** .......... **Overview - 1**

**SUMMARY TABLES** .......... **Summary Tables - 1**

**Total NSF Funding**
NSF Summary Table .......... Summary Tables - 3
NSF Funding Profile .......... Summary Tables - 4
Number of People Involved in NSF Activities .......... Summary Tables - 5
NSF Budget Requests and Appropriations by Account:
FY 2000-FY 2022 .......... Summary Tables - 7

**Major NSF-Wide Investments**
NSF Administration Priorities Summary .......... Summary Tables - 9
NSF NSTC Crosscuts Summary .......... Summary Tables - 11
NSF Big Ideas Funding .......... Summary Tables - 13
NSF Selected Cross-cutting Programs .......... Summary Tables - 14
NSF Programs to Broaden Participation .......... Summary Tables - 15

**STEM Education Investments**
NSF Education and Human Resources Funding by Division and Program .......... Summary Tables - 18
CoSTEM Inventory and Postdoctoral Fellowship Programs
by Level of Education .......... Summary Tables - 19

**Research Infrastructure**
NSF Research Infrastructure Funding by Account and Activity .......... Summary Tables - 20
NSF Research Infrastructure Summary .......... Summary Tables - 21

**NSF AUTHORIZATIONS** .......... **Authorizations - 1**
NSF Current Authorizations .......... Authorizations - 3
Computer Science Education Research Report in Compliance
with Public Law 114-329 .......... Authorizations - 9
EPSCoR Report in Compliance with Public Law 114-329 .......... Authorizations - 12

**NSF-WIDE INVESTMENTS** .......... **NSF-Wide Investments - 1**

**Administration Priorities**
Climate: U.S. Global Change Research Program .......... NSF-Wide Investments - 3
Climate: Clean Energy Technology .......... NSF-Wide Investments - 6
Economy: Advanced Manufacturing .......... NSF-Wide Investments - 9
Economy: Advanced Wireless .......... NSF-Wide Investments - 12
Economy: Artificial Intelligence .......... NSF-Wide Investments - 14
Economy: Biotechnology .......... NSF-Wide Investments - 18
Economy: National Nanotechnology Initiative .......... NSF-Wide Investments - 21
Economy: Networking and Information Technology R&D .......... NSF-Wide Investments - 27
Economy: Quantum Information Sciences .......... NSF-Wide Investments - 32

**NSF Research Big Ideas**
Harnessing the Data Revolution for 21st-Century Science and Engineering ........ NSF-Wide Investments - 35
The Future of Work at the Human-Technology Frontier ........ NSF-Wide Investments - 37
Navigating the New Arctic ........ NSF-Wide Investments - 40
Understanding the Rules of Life ........ NSF-Wide Investments - 43
Windows on the Universe ........ NSF-Wide Investments - 45

**NSF Enabling Big Ideas**
Growing Convergence Research ........ NSF-Wide Investments - 47
Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science ........ NSF-Wide Investments - 49
Mid-scale Research Infrastructure ........ NSF-Wide Investments - 52

**Ongoing Major FY 2022 Investments**
NSF Innovation Corps ........ NSF-Wide Investments - 55
NSF Centers ........ NSF-Wide Investments - 57
Secure and Trustworthy Cyberspace ........ NSF-Wide Investments - 67
Selected Crosscutting Programs ........ NSF-Wide Investments - 70
Spectrum Innovation Initiative ........ NSF-Wide Investments - 73

**STEM Education and Workforce**
Improving Undergraduate STEM Education ........ NSF-Wide Investments - 75
Major Investments in Science, Technology, Engineering, and Mathematics (STEM) Graduate Students and Graduate Education ........ NSF-Wide Investments - 77

**RESEARCH AND RELATED ACTIVITIES ........ R&RA - 1**

**Biological Sciences ........ BIO - 1**
Molecular and Cellular Biosciences ........ BIO - 7
Integrative Organismal Systems ........ BIO - 8
Environmental Biology ........ BIO - 9
Biological Infrastructure ........ BIO - 10
Emerging Frontiers ........ BIO - 11

**Computer and Information Science and Engineering ........ CISE - 1**
Office of Advanced Cyberinfrastructure ........ CISE - 7
Computing and Communication Foundations ........ CISE - 8
Computer and Network Systems ........ CISE - 9
Information and Intelligent Systems ........ CISE - 10
Information Technology Research ........ CISE - 11
Appendix A: Advanced Computing Systems and Services Portfolio ........ CISE - 12

**Engineering ........ ENG - 1**
Chemical, Bioengineering, Environmental, and Transport Systems ........ ENG - 7
Civil, Mechanical, and Manufacturing Innovation ........ ENG - 8
Electrical, Communications, and Cyber Systems ........ ENG - 9
Engineering Education and Centers ........ ENG - 10
Emerging Frontiers and Multidisciplinary Activities ........ ENG - 12

**Geosciences** .......... **GEO - 1**
Atmospheric and Geospace Sciences .......... GEO - 5
Earth Sciences .......... GEO - 7
Integrative and Collaborative Education and Research .......... GEO - 9
Ocean Sciences .......... GEO - 10

**Mathematical and Physical Sciences** .......... **MPS - 1**
Astronomical Sciences .......... MPS - 8
Chemistry .......... MPS - 10
Materials Research .......... MPS - 11
Mathematical Sciences .......... MPS - 12
Physics .......... MPS - 13
Office of Multidisciplinary Activities .......... MPS - 14

**Social, Behavioral and Economic Sciences** .......... **SBE - 1**
Behavioral and Cognitive Sciences .......... SBE - 7
Social and Economic Sciences .......... SBE - 8
National Center for Science and Engineering Statistics .......... SBE - 9
SBE Office of Multidisciplinary Activities .......... SBE - 11

**Technology, Innovation and Partnerships** .......... **TIP - 1**
Innovation Ecosystems .......... TIP - 5
Partnerships Office .......... TIP - 6
Technology Frontiers .......... TIP - 7
Translational Impact .......... TIP - 8

**Office of International Science and Engineering** .......... **OISE - 1**

**Office of Polar Programs** .......... **OPP - 1**

**Integrative Activities** .......... **IA - 1**
Established Program to Stimulate Competitive Research (EPSCoR) .......... IA - 5

**U.S. Arctic Research Commission** .......... **USARC - 1**

**EDUCATION AND HUMAN RESOURCES** .......... **EHR - 1**
Research on Learning in Formal and Informal Settings .......... EHR - 7
Undergraduate Education .......... EHR - 9
Human Resource Development .......... EHR - 11
Graduate Education .......... EHR - 13
H-1B Nonimmigrant Petitioner Fees .......... EHR - 15

**MAJOR RESEARCH EQUIPMENT AND FACILITIES CONSTRUCTION** .......... **MREFC - 1**
MREFC Overview .......... MREFC - 3
Antarctic Infrastructure Recapitalization .......... MREFC - 8
Daniel K. Inouye Solar Telescope .......... MREFC - 14
High Luminosity - Large Hadron Collider Upgrade .......... MREFC - 22
Mid-scale Research Infrastructure Track 2 .......... MREFC - 31
Regional Class Research Vessels .......... MREFC - 35
Vera C. Rubin Observatory .......... MREFC - 41

**ORGANIZATIONAL EXCELLENCE** ... **Organizational Excellence - 1**

**Human Capital** ... **Human Capital - 1**

**Travel** ... **Travel - 1**

**Information Technology** ... **Information Technology – 1**

**Administrative Support** ... **Administrative Support – 1**

**Office of Inspector General** ... **OIG - 1**

**Office of the National Science Board** ... **NSB - 1**

**MAJOR FACILITIES** ... **Facilities - 1**
Major Facilities Overview ... Facilities - 3

**Major Facilities**
Academic Research Fleet (ARF) ... Facilities - 7
Antarctic Facilities and Operations (AFO) ... Facilities - 11
Arecibo Observatory (AO) ... Facilities - 15
Geodetic Facility for the Advancement of GEoscience (GAGE) ... Facilities - 20
IceCube Neutrino Observatory (ICNO) ... Facilities - 25
International Ocean Discovery Program (IODP) ... Facilities - 29
Large Hadron Collider (LHC) ... Facilities - 33
Laser Interferometer Gravitational Wave Observatory (LIGO) ... Facilities - 37
National Ecological Observatory Network (NEON) ... Facilities - 41
National High Magnetic Field Laboratory (NHMFL) ... Facilities - 45
Ocean Observatories Initiative (OOI) ... Facilities - 50
Seismological Facility for the Advancement of GEoscience (SAGE) ... Facilities - 55

**Federally Funded Research and Development Centers (FFRDCs)**
Green Bank Observatory (GBO) ... Facilities - 60
National Center for Atmospheric Research (NCAR) ... Facilities - 64
National Radio Astronomy Observatory (NRAO) ... Facilities - 69
National Solar Observatory (NSO) ... Facilities - 74
NSF's National Optical-Infrared Astronomy Research Laboratory (NOIRLab) ... Facilities - 78

Other Facilities Funding ... Facilities - 85

**PERFORMANCE AND MANAGEMENT** ... **Performance & Management - 1**
NSF Performance Framework ... Performance & Management - 3
FY 2020 Strategic Objective Progress Updates ... Performance & Management - 4
FY 2020 Annual Performance Report and FY 2022 Annual Performance Plan ... Performance & Management - 9
FY 2020 Management Challenge Progress Report ... Performance & Management - 27
GAO-IG Act Exhibits ... Performance & Management - 50
Program Evaluation and Monitoring Information ... Performance & Management - 68
Other Information ... Performance & Management - 77

**TECHNICAL INFORMATION** ..................... **Technical Info - 1**
FY 2022 NSF Appropriations Language ..................... Technical Info - 3
Summary of FY 2022 NSF Budgetary Resources by Account ..................... Technical Info - 5
NSF FY 2022 Funding by Program ..................... Technical Info - 8
NSF by Object Classification ..................... Technical Info - 12
NSF Reimbursable Activity ..................... Technical Info - 13
Explanation of FY 2020 Carryover into FY 2021 by Account ..................... Technical Info - 14

**QUANTITATIVE DATA TABLES** ..................... **QDT - 1**

# NSF FY 2022 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..."***

NSF is unique in carrying out its mission by supporting research across all fields of science, technology, engineering, and mathematics, and all levels of STEM education. NSF investments are critical to the economic and national security interests of the nation and development of a future-focused science and engineering workforce that draws on the talents of all Americans.

Last year, NSF celebrated its 70th anniversary. Over the past seven decades, NSF has funded research and researchers, innovations and innovators, and world-class 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 are all examples of the outcomes and benefits of 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's capacity to continue to produce breakthroughs, to innovate, to identify the industries that we cannot even imagine today, to accelerate the translation of research results to practice, and to cultivate the diverse workforce needed to power our country forward, all must be strengthened at speed and scale. NSF has the know-how and energy to create a brighter future for our Nation and is guided by the Director's vision expressed in three pillars that point to opportunities that we must seize:

1. Advancing the frontiers of research into the future
2. Ensuring accessibility and inclusivity
3. Securing global leadership in science and technology

These pillars support the Administration's priorities for the FY 2022 request to Congress to enhance fundamental research and development, improve equity in science and engineering, advance climate science and sustainability research, continue construction of forefront research infrastructure. These priorities, expanded on below, dovetail precisely with the Director's pillars and are addressed by NSF investments at all potential funding levels, appearing repeatedly in the broad portfolio of fundamental research that is the heart of NSF's mission. They animate new and expanded efforts and they connect existing efforts throughout the portfolio of research programs.

*Enhances Fundamental Research and Development*
The FY 2022 request to Congress provides $9.43 billion, an increase of $1.55 billion above the FY 2021 enacted level, to support research across the spectrum of science, engineering and technology, including biological sciences; computer and information sciences; engineering; geosciences; math and physical sciences; social, behavioral, and economic sciences; and education. With this additional funding, NSF will continue to be the champion of basic and fundamental research and will strengthen it at speed and scale.

*<u>Strengthens U.S. Leadership in Emerging Technologies</u>*
We are currently facing a defining moment for the Nation. 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 United States to remain a global leader, we must recommit to investing in breakthrough technologies and innovation, fostering partnerships, and nurturing talent, thereby encouraging the innovative spirit that has been the source of our leadership over the past seven decades.

On March 31, the Administration released the American Jobs Plan, which will create millions of good jobs, rebuild our country's infrastructure, and position the United States for the future. As part of that proposal, the Administration proposes investing $50 billion over eight years in a new directorate for technology at NSF that will collaborate with and build on existing programs across the government. This directorate will closely collaborate with all of NSF's other directorates and offices, as well as with other stakeholders in the Nation's research, innovation, and education enterprise, to advance science and engineering research and innovation leading to breakthrough technologies as well as solutions to national and societal challenges, sustaining and enhancing U.S. competitiveness on a global stage; accelerate the translation of fundamental discoveries from lab to market, advancing the U.S. economy; and create education pathways for every American to pursue new, high-wage jobs, supporting a diverse workforce of researchers, practitioners, and entrepreneurs.

The creation of this new Directorate for Technology, Innovation, and Partnerships (TIP) will allow the agency to continue to support innovation across all disciplines of science and engineering, at the speed that is required in today's rapidly changing landscape.

*<u>Advances Equity in Science and Engineering</u>*
The FY 2022 Request to Congress seeks $100 million, roughly a 50 percent increase, in funding for programs that aim to increase participation in science and engineering of individuals from racial and ethnic groups underrepresented in these fields. Funding will support curriculum design, research on successful recruitment and retention methods, development of outreach or mentorship programs, fellowships, and building science and engineering research and education capacity at HBCUs and other minority-serving institutions. Additionally, through the Established Program to Stimulate Competitive Research (EPSCoR), funded separately, NSF looks to enhance research competitiveness of targeted jurisdictions (states, territories, commonwealth) by strengthening STEM capacity and capability. These STEM-related opportunities are building capacity and infrastructure across the nation, seeding and nurturing innovation clusters with stronger economic outcomes and good quality jobs.

NSF is investing in education research across all levels of learning—from preK-12 through graduate education and beyond—which then informs education and training programs to better develop skill sets in cutting-edge technologies, promote highly collaborative team science, and foster greater diversity in the workforce. NSF will continue to invest robustly across its suite of broadening participation programs. In doing so, NSF will work tirelessly to ensure that there are no barriers to equal opportunity at NSF or in the delivery of its programs. These investments will be central to our ability to achieve those goals.

*<u>Advances Climate Science and Sustainability Research</u>*
The FY 2022 Request to Congress provides $1.20 billion for climate and clean energy-related research. NSF will fund a broad portfolio of research related to climate science and clean energy, including research on atmospheric composition, water and carbon cycles, computational modeling of climate systems, renewable energy technologies, materials sciences, and social, behavioral, and economic research on human responses to climate change.

NSF's investments in basic research, including funding and efforts supported in the Administration's

FY 2022 discretionary request, impact nearly every aspect of America's clean energy future—from fundamental physics, chemistry, and materials science to data and computation including artificial intelligence, to large-scale systems engineering and cyber-infrastructure. NSF's clean energy investments support innovative interdisciplinary basic and translational research and education that may broadly contribute to future sustainability, such as the conversion, storage, and distribution of diverse power and fuel sources (including smart grids); the science and engineering of energy materials, energy use, and energy efficiency; and the ways that people think about and use energy.

*Continues Construction of Forefront Research Infrastructure*

Research infrastructure funded by NSF provides the cutting-edge tools needed to advance fundamental research and development and both contribute to, and benefit from, emerging technology. The Administration's discretionary request invests in the continued construction of major NSF research facilities, including long-term upgrades of NSF's major Antarctic infrastructure and upgrades to the Large Hadron Collider. It also supports construction of the Vera C. Rubin Observatory to enable astronomy research. In addition, the discretionary request seeks funding for the construction and procurement of mid-scale and smaller research facilities and equipment at colleges, universities, and other research institutions across the nation.

The FY 2022 President's Budget Requests $10.17 billion for NSF, an increase of 20 percent from the current budget. NSF stands ready to maximize the impact of this increase in funding and tackle critical challenges to bolster the U.S. economy and our leadership in critical and emerging areas of research and technological advancements.

## FY 2022 ORGANIZING PRINCIPLES

The three pillars of the NSF Director's vision for the future of the agency support the Administration's priorities and give shape to the organizing principles for the Fiscal Year 2022 discretionary request. Examples of specific investments in each pillar follow.

### 1. *Advancing the Frontiers of Science and Engineering*

The first pillar, advancing the frontiers of science and engineering research into the future has been the heart of NSF's mission for over seven decades and will be further strengthened in the years to come. By seeding strategic investments, NSF steers the frontiers of discovery and innovation toward breakthroughs that put the United States at the forefront of global leadership in science and technology.

Since its inception, NSF has been the foundation for new industries. NSF funds the high-risk, high-reward research that has the potential to bring the world new discoveries. Each year, thousands of researchers expand the base of human knowledge and, in doing so, unlock new possibilities. They have built autonomous vehicles; revolutionized our wireless networks; developed life-saving medical technologies; transformed manufacturing; and brought digital tools to agriculture. Curiosity-driven, exploratory research is a critical component to the nation's current and future success. NSF's continued investment in these new and emerging technologies will result in the creation of new, high-wage, good-quality jobs.

The President's Fiscal Year 2022 discretionary request advances the frontiers of research into the future by making critical investments in new industries.

- **Advanced Manufacturing** ($418.51 million) research supported by NSF accelerates advances in manufacturing with emphasis on multidisciplinary research that fundamentally alters and transforms manufacturing capabilities, methods, and practices. NSF investments will make producing next-generation products and services more efficient and sustainable and will lead to advantages such as less time-to-market, new performance attributes, cost savings, energy savings, and reduced environmental impacts. In FY 2022, these investments will support advanced manufacturing research, future manufacturing research, workforce development, and transition to practice. NSF invests in advanced manufacturing to increase future U.S. prosperity, as well as the Nation's competitiveness, security, and quality of life.

- **Advanced Wireless** ($166.61 million) will provide the backbone that connects users, devices, applications, and services that will continue to enrich America's economy. NSF's leadership in advanced wireless research has three inter-related components starting with supporting fundamental research on advanced wireless. In FY 2022, NSF, in partnership with other federal agencies and the private sector, will support the Resilient and Intelligent Next-Generation Systems (RINGS) program, laying the groundwork for next-generation wireless connections that will enable faster service, networks more resilient to natural disasters and service interruptions, and broader access for people across the U.S. NSF will also continue to support the Spectrum and Wireless Innovation enabled by Future Technologies (SWIFT) program and research in artificial intelligence and machine learning techniques that address the diverse, stringent quality-of-service requirements of future wireless applications. The second component supports advanced wireless research testing platforms. Funding in this Request will be dedicated to pursuing a convergent approach to validate advanced wireless research through its PAWR program. The PAWR testbeds will support proofs of concept for dynamic spectrum sharing across diverse geographic and spectrum use cases. The third component is dedicated to developing a diverse workforce trained in advanced wireless technologies.

- **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 not just these areas, but 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. In FY 2022, NSF will increase support for foundational research in AI, including machine learning and deep learning, natural language technologies, knowledge representation and reasoning, robotics, and computer vision, along with the fairness, accountability, transparency, explainability, safety, security, and robustness across all areas of AI. NSF will also support use-inspired research, education and workforce development, and access to data and advanced computing research infrastructure that collectively enhance AI. In FY 2022, NSF will continue support ($69.11 million) for the National AI Research Institutes program. In addition, NSF will emphasize AI research, education and workforce development, and infrastructure activities at minority-serving institutions (MSIs). Specifically, NSF will broaden participation by intentionally focusing on the development of AI research capacity at MSIs, the involvement of populations long underrepresented in AI in research activities, and the formation of partnerships spanning multiple MSIs as well as MSIs and other institution types.

- **Biotechnology** ($382.26 million) comprises the data, tools, research infrastructure, workforce capacity, and innovation that enable the discovery, utilization, and alteration of living organisms, their constituent components, and their biologically related processes. NSF's investment will include research and infrastructure in genomics, proteomics, synthetic biology, chemical biology, bioinformatics, computational biology, data analytics, structural biology, biophysics, tissue engineering, and development of new types of biomaterials, bio-probes, bio-based microelectronics, and biomanufacturing. In addition, NSF invests in educational programs that ensure a trained workforce to support U.S. capabilities in biotechnology, together with research on the ethical, legal, economic, and environmental consequences of synthetic biology and other biotechnologies, contributing to public understanding of product adoption and socially responsible use.

- **Quantum Information Science (QIS)** ($260.0 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. 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. NSF's QIS investments build upon the agency's longstanding 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. NSF will continue the investment in Research Experiences for Undergraduates (REU) and NSF Research Traineeship (NRT) awards related to QIS begun in FY 2021 and will add intentional activities designed to grow the participation of investigators and students from institutions currently underrepresented in QIS.

**Climate Change Activities**

NSF has been investing for several decades in climate and global change issues through a portfolio of programs that advance the 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. NSF is positioned to continue this important work in supporting climate science and sustainability research.

- **U.S. Global Change Research Program (USGCRP)** ($762.0 million) continues to support research that contributes to the USGCRP goal areas to (1) advance scientific knowledge of the integrated natural and human components of the Earth system and (2) inform decisions by providing the scientific basis to inform and enable timely decisions on adaptation and mitigation. In FY 2022, 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 further seek greater integration of social-science research, methodologies, and insights into understanding and supporting responses to global change, improving computing capacity, and maintaining needed observational capabilities over time.

- **Clean Energy Technology (CET)** ($440.0 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. NSF also will support multidisciplinary research in areas such as affordable green housing and sustainable systems for clean water, clean transit, and other infrastructure. Added NSF investments will help build a diverse future clean-energy workforce and advance the translation and deployment of innovative technologies. In FY 2022, NSF will focus on investing in fundamental clean-energy research, research infrastructure enabling sustainable energy generation and distribution and allowing for the creation of more energy-efficient energy systems, the clean energy workforce, and the translation of fundamental discoveries in clean energy into technologies and systems.

**NSF Innovation Corps (I-Corps™)** ($40.0 million) 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. In FY 2022, NSF expects to fund 250-300 teams, partnering with other federal agencies and programs, states, and regional organizations as well as a set of new I-Corps™ Hubs. I-Corps™ Teams are funded at $50,000 per Team with a duration of six months. I-Corps™ Hubs are supported for up to five years, at up to $3.0 million per Hub per year.

**Secure and Trustworthy Cyberspace (SaTC) (**$153.0 million) is a multi-year investment, aiming to develop an organized scientific body of knowledge that informs the theory and practice of cybersecurity and privacy, and an improved understanding of the causes of and mitigations for current threats. Through SaTC, NSF funds a broad and deep multidisciplinary research and education portfolio spanning cybersecurity and privacy, whose results underlie methods for securing critical infrastructure. Further, NSF expects to produce an innovation ecosystem that ensures (a) new and existing technologies are secure from both current threats and potential future threats as technologies evolve, and (b) users' information is protected from violations of privacy despite new attack surfaces that these technologies may present. FY 2022 investments will support foundational research in this space, accelerate transition to practice, and enhance education and preparation of cybersecurity researchers and professionals.

*2. Ensuring Accessibility and Inclusivity*

The second pillar, ensuring accessibility and inclusivity in STEM fields is increasingly important. There is tremendous untapped STEM potential throughout the nation. To meet the needs of the future workforce, every person needs access to a quality STEM education. Every demographic and socioeconomic group in every geographic region of the country is full of talent that must be inspired and motivated to participate in STEM and contribute to the research and innovation enterprise. We must scale up existing pathways into STEM fields and create new tracks into science and engineering.

NSF's commitment to finding talent provides opportunities that build strong STEM pathways which leads to a well-paid workforce and a vibrant U.S. economy. To that end, the following programs are funded in the FY 2022 Budget Request to Congress.

- **ADVANCE** ($20.50 million) seeks to increase the representation and advancement of women in academic science and engineering careers. This program encourages institutions of higher education and the broader STEM community to address aspects of STEM academic culture and institutional structure that may differentially affect women faculty and academic administrators.

- **Historically Black Colleges and Universities Undergraduate Program (HBCU-UP)** ($46.50 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.

- **Historically Black Colleges and Universities Excellence in Research (HBCU-EiR)** ($33.96 million) program supports projects that enable STEM and STEM education faculty to further develop research capacity at HBCUs and to conduct research.

- The **Hispanic-Serving Institutions Program (HSI)** ($56.50 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.

- The **Louis Stokes Alliances for Minority Participation (LSAMP)** ($69.50 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.

- The **Tribal Colleges and Universities Program (TCUP)** ($21.0 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)** ($239.64 million) seeks to advance excellence in science and engineering research and education, enhancing the competitiveness of EPSCoR jurisdictions in the disciplinary domains supported by NSF.

- **Build and Broaden (B2)** ($8.0 million) supports research collaborations between scholars at minority-serving institutions (MSIs) and scholars in other institutions or organizations. B2 is designed to support research projects that builds capacity and enhance research productivity in the SBE sciences at MSIs; provides researchers with new ways to diversify and sustain collaborations; fosters partnerships that strengthen career and research trajectories for faculty at MSIs; and contributes to stronger, more innovative science by diversifying research and widening the STEM pipeline.

- **CISE Minority-Serving Institutions Research Expansion (CISE-MSI) program** ($7.0 million) enhances the capacity at MSIs for computing research, increasing the number of research projects from MSIs funded by CISE and broadening the participation of MSIs in CISE programs.

*3. Securing Global Leadership*

The third pillar is securing global leadership in science and technology. America must lead by our actions and our values. Key tenets of this leadership are transparency, reciprocity and research integrity. NSF will work with like-minded partners who share these values and commitment to advancing scientific progress and prosperity. We will take the necessary steps to safeguard taxpayer investments and to ensure everyone is playing by the same set of rules.

NSF enhances American economic strength and security through partnering with foreign counterparts to promote international collaboration based upon the principles of honesty, openness, transparency, and reciprocal collaboration. Today, our enterprise is put at risk when other governments endeavor to benefit from the global research ecosystem without upholding these principles. Faced with such a risk, securing global leadership is now more important than ever. In March 2020, NSF created a new position of Chief of Research Security Strategy and Policy (CRSSP) as part of its continuing effort to ensure the security of federally funded research while maintaining open international collaborations. In FY 2021, NSF is continuing to refine the CRSSP team efforts and contractor support service capabilities.

As part of the President's Fiscal Year 2022 discretionary request, NSF will build its analytic capabilities to proactively identify conflicts of commitment, vulnerabilities of pre-publication research, and risks to the merit review system. Additionally, NSF will develop external training for the research community to ensure NSF is clearly communicating the benefits of international collaborations as well as the risks from improper foreign government interference.

*Partnerships*

While not an individual pillar, the partnerships NSF cultivates are interwoven through and between each of the pillars. NSF has a rich history of not only pursuing direct partnerships with other agencies, private industry and philanthropy, and like-minded countries, but also fostering environments where partnerships thrive, because they are powerful ways to leverage resources and deliver results.

## RESEARCH INFRASTRUCTURE AND INSTRUMENTATION

The Nation's science and engineering activities rely on instrumentation that is geographically and technically accessible, cost effective, and managed well. To 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.

The **Major Research Instrumentation (MRI)** program is responsible for catalyzing new knowledge and discoveries by helping STEM professionals acquire or develop the instrumentation needed at their institutions. MRI grants support instrumentation in all NSF-supported research disciplines. MRI makes awards of up to $4 million, for projects with total costs (including matching funding) as high as $6.0 million.

In the American Innovation and Competitiveness Act (AICA) enacted in 2017, Congress directed the agency to develop a strategy for supporting research infrastructure with a total project cost above the upper limit for the MRI program and below the **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 2022, NSF will invest a total of $126.25 million in Mid-scale RI, split between two separate tracks, Mid-scale RI-1 ($50.0 million), funded through R&RA, and Mid-scale RI-2 ($76.25 million), funded through MREFC. 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 2022, Mid-scale RI-1 will support projects from its FY 2021 competition.

### NSF Responsiveness to COVID-19 Impacts on Operating Facilities

The primary known impact of COVID-19 on operating facilities at the present time is the loss of science caused by a number of facilities 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 for the Academic Research Fleet due to the reduction in reimbursable science missions, 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 2022 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 (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 2020 Actual | FY 2021 Estimate[1] | FY 2022 Request |
|---|---|---|---|
| Antarctic Infrastructure Recapitalization | $48.78 | $90.00 | $90.00 |
| HL-LHC Upgrade | 33.00 | 33.00 | 36.00 |
| Mid-scale Research Infrastructure | - | 76.25 | 76.25 |
| NEON | 0.74 | - | - |
| RCRV | 25.00 | - | 5.00 |
| Vera C. Rubin Observatory | 46.35 | 40.75 | 40.75 |
| Dedicated Construction Oversight | 0.97 | 1.00 | 1.00 |
| **Total** | **$154.84** | **$241.00** | **$249.00** |

[1] A total of $129.35 million was carried forward from FY 2020 into FY 2021: $29.71 million for AIMS, $9.40 million for DKIST, $65.0 million for Mid-scale RI, $10.97 million for RCRV, $10.07 million for the Rubin Observatory, and $780,000 for Dedicated Construction Oversight.

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 will take place during FY 2021, as the cost and schedule impacts of COVID-19 become better known for FY 2022 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 rescoping of the Antarctic Infrastructure Modernization for Science (AIMS) project. AIMS construction will continue with a focus on meeting near-term needs, and unfunded parts of AIMS will be incorporated into the longer-term AIR program. FY 2022 funding for AIR ($90.0 million) will be used to fund adjusted AIMS scope, if necessary, and 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 2022, funding for **HL-LHC Upgrade** ($36.0 million) will support year three of the five-year project that began in FY 2020, prior to the onset of the COVID-19 impact. Pandemic impacts are likely to result in future, and not yet quantified, changes to upgrade plans. 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.

The **Regional Class Research Vessels** ($5.0 million) are being 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.

**Vera C. Rubin Observatory** ($40.75 million) will be an 8-meter-class wide-field optical telescope capable of carrying out surveys of the entire southern sky. It will collect nearly 40 terabytes of multi-color imaging data every night to produce the deepest, widest-field sky image ever. It will also issue alerts for moving and transient objects within 60 seconds of their discovery. FY 2022 will be the ninth year of a funding profile originally scheduled for nine years, and now likely to extend into a tenth year.

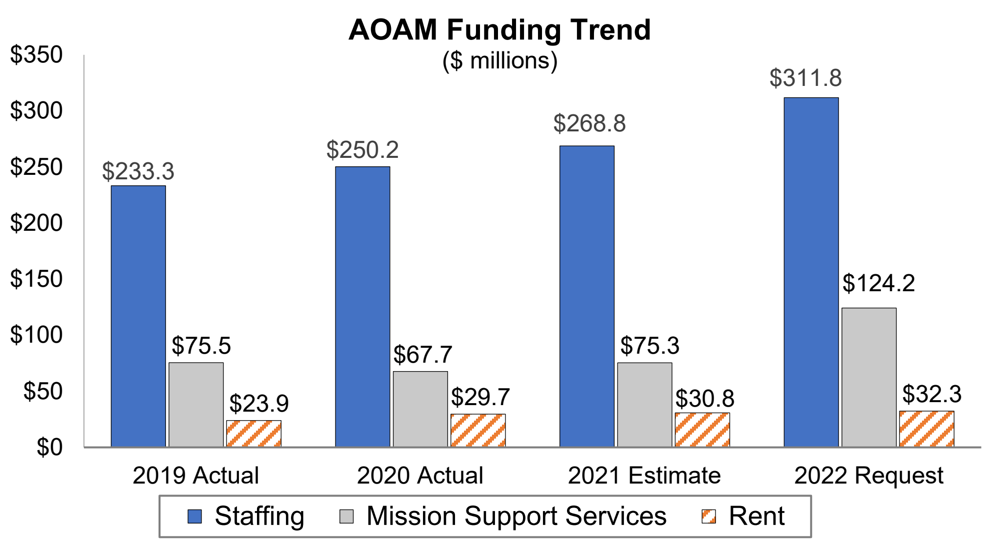
## AGENCY OPERATIONS AND AWARD MANAGEMENT

In FY 2022, funding provides a total of $468.30 million, an increase of $93.37 million or 24.9 percent above the FY 2021 Estimate for the Agency Operations and Award Management (AOAM) account. NSF continues to operate as a lean agency with AOAM costs representing about 5 percent of NSF total FY 2022 budget.

The $9.43 billion in research funding that NSF will support in FY 2022 is managed by the staff at NSF who enable research and steward the taxpayer investment. Investments in the AOAM account provide the fundamental framework through which the Foundation's science and engineering research and education programs are administered. AOAM funds the essential services NSF needs to operate, and investments in the AOAM account continue to be an NSF priority.

The AOAM account is largely the cost of NSF personnel and NSF's headquarters location in Alexandria, VA. In 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. NSF then exercised its transfer authority to restore funding for those reduced activities.

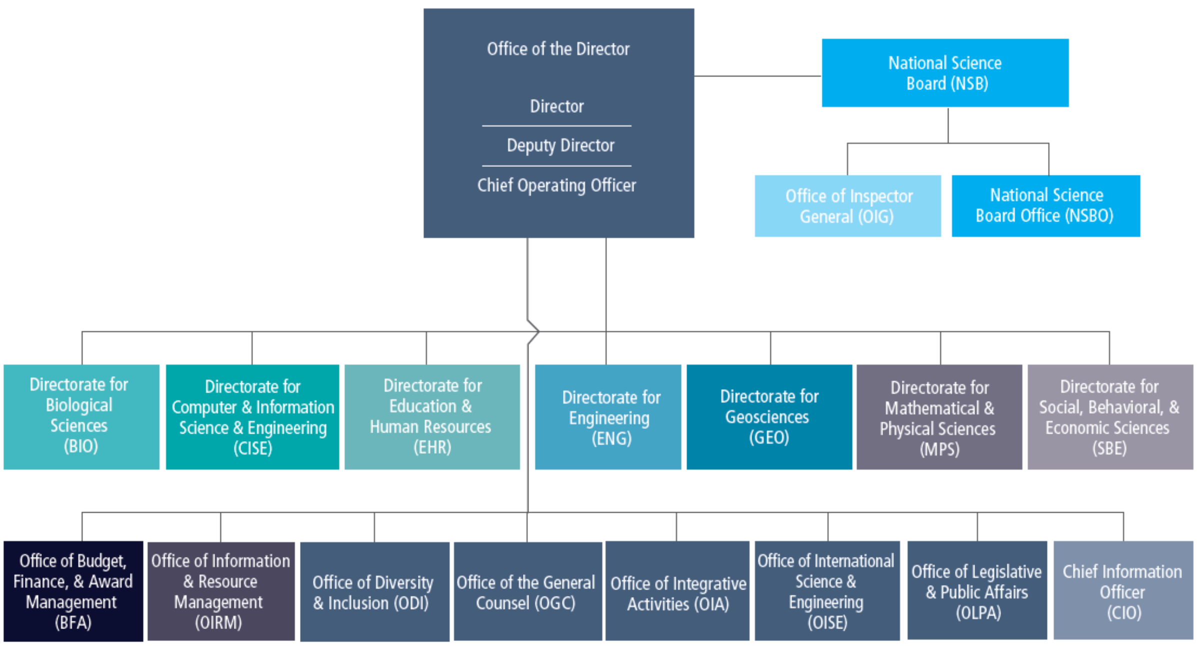
The large increase in AOAM costs in FY 2022 is a course correction aimed at requesting the amount NSF estimates it needs and decreasing the reliance on the transfer authority to cover the full cost of doing business. The requested level also will enable NSF to establish a new directorate as described above, and to grow agency administration and operations, including additional staffing needs, with speed and scale to meet the needs of a $10 billion federal research agency effectively and efficiently. Further, NSF anticipates continuing to move toward a hybrid work environment and the Request therefore includes resources for the necessary additional information technology and training for staff and supervisors to achieve this approach. In addition, NSF requests increases to provide for strategic human capital management, changes at the NSF headquarters building to respond to COVID-19 impacts, establishing a new effort for Science and Security including a Sensitive Compartmentalized Information Facility (SCIF) at the NSF headquarters building, 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).



**ORGANIZATION AND ROLE IN THE FEDERAL RESEARCH ENTERPRISE**

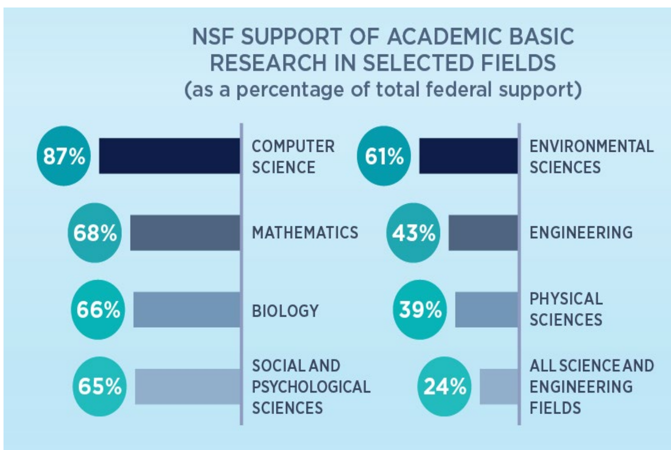
NSF's comprehensive and flexible support of meritorious projects enables the Foundation to identify and foster both fundamental and transformative discoveries and broader impacts within and among fields of inquiry. NSF has the latitude to support emerging fields, high-risk ideas, interdisciplinary collaborations,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

Figure 1.4
**NSF FY 2020 Organization Chart**




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

NSF's annual budget represents approximately 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.

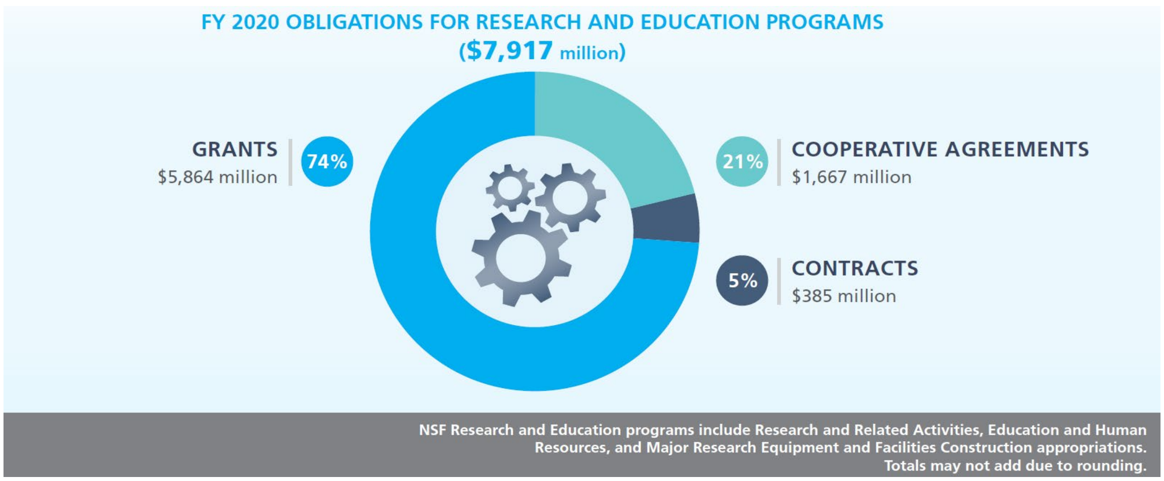



**Note:** Biology includes Biological Science and Environmental Biology. Biology and Psychological Sciences exclude National Institutes of Health funding from the total amount of federal support. *Credit: NSF/National Center for Science and Engineering Statistics, Survey of Federal Funds for Research and Development, FY 2018.*

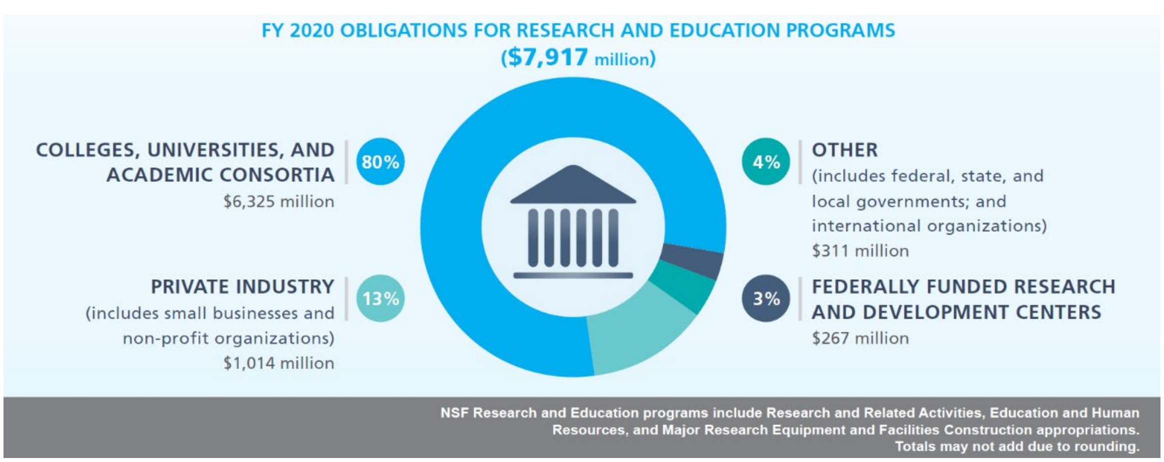
**NSF BY THE NUMBERS**

In FY 2022, NSF expects to evaluate approximately 47,900 proposals through a competitive merit review process and make approximately 13,800 new competitive awards, 11,500 of which will be new research grants and the remainder of which will be contracts and cooperative agreements.

The following two charts show the distribution of NSF's obligations by funding mechanism and institution type. While the data are based on FY 2020, it is expected that the relative shares in FY 2022 will be similar. As shown below, 95 percent of NSF's FY 2020 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 with 80 percent of support for research and education programs ($6,325 million) being awarded to 822 different colleges, universities, and academic consortia. Private industry, including small businesses and non-profit organizations, accounted for 13 percent ($1,014 million), and support to Federally Funded Research and Development Centers accounted for 3 percent, or $267 million. Other recipients (federal, state, and local governments; and international organizations) received 4 percent ($311 million) of support for research and education programs.



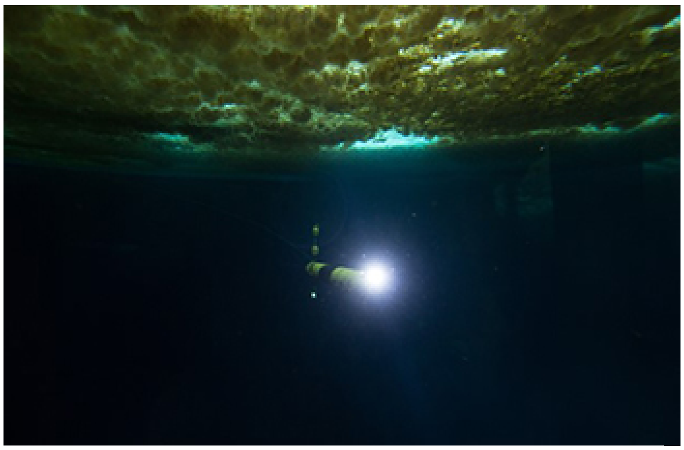
NSF continuously monitors key portfolio, proposal workload, and financial measures to understand short- and long-term trends and to help inform management decisions. The chart below presents a high-level, agency-wide estimate of funding rates, or proposal "success," as a comparison of the number of competitive proposals, new awards, and funding rate between FY 2016 and FY 2020. In FY 2020, there were increases in all three key measures.

## 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.

**Robotic underwater vehicle snaps first images of seafloor beneath Antarctica's Thwaites Glacier**

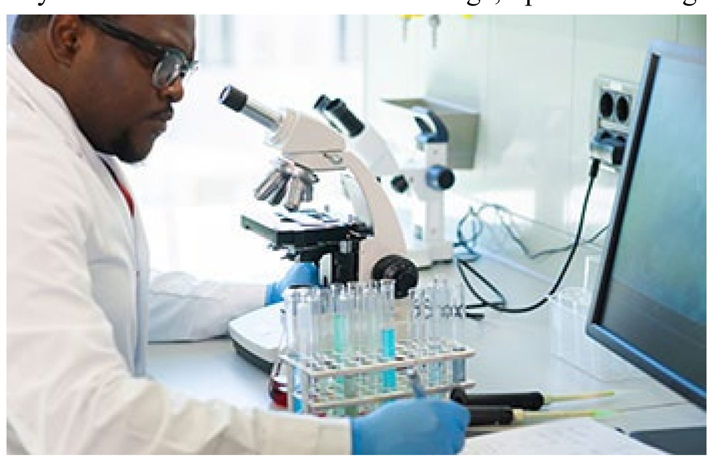
Antarctica is one of the most extreme environments on the planet. Despite the harsh environment and forbidding conditions, researchers funded by NSF are probing Antarctica's secrets above and below the ice. Using an underwater robot called Icefin, researchers with the International Thwaites Glacier Collaboration were able to study the ocean floor beneath the Thwaites Glacier—a fast-moving glacier about the size of Florida flowing into the Pine Island Bay off of West Antarctica. By diving beneath the waves, researchers are hoping to better understand the conditions in the area around the glacier and the changes taking place as it flows into the sea. The information is critical to our understanding of oceanography, sea-levels, and polar phenomena.



Scientists conduct first study beneath Antarctica's Thwaites Glacier.
*Credit: Georgia Tech University.*

**Broadening Participation Research Center: HBCU STEM Undergraduate Success Research Center**

Historically Black Colleges and Universities have a high success rate of graduating their students. NSF is awarding $9 million to establish the center, led by researchers from Morehouse College, Spelman College and Virginia State University. Researchers will study the successful broadening participation practices of 50 HBCUs and develop evidence-based interventions with the aim of transforming mainstream education. The researchers will employ a convergent approach to education and share data to improve student outcomes across the HBCU network and other institutions. "Investing in the institutional capacity of HBCUs and developing diverse STEM talent is part of NSF's longstanding commitment to broaden participation of groups traditionally underrepresented in STEM," said NSF program officer, Claudia Rankins, who manages the HBCU program.



NSF Established New Center to Study Successful Undergraduate STEM Education Practices at Historically Black Colleges and Universities.
*Credit: Maksim Shmeljov/Shutterstock.*

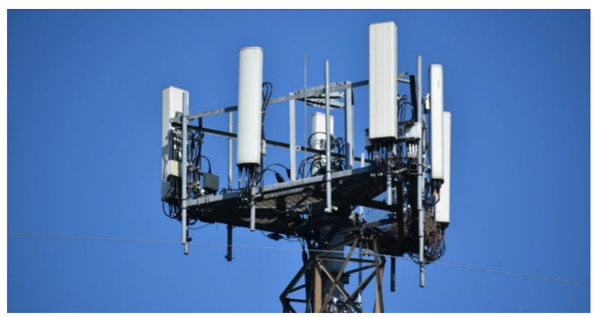
**AI in the classroom**

*Students at work. Credit: Christina S. Murrey, College of Education, University of Texas at Austin.*

Enhancing educational outcomes for all students is a critical part of building a STEM-enabled workforce and bolstering science and technology leadership for future generations. The Institute for Student-AI Teaming is designing new approaches to AI in the classroom to boost educational outcomes, foster deeper student engagement, and foster long-term interest in STEM subjects—especially for students from communities underrepresented in STEM fields. Working closely with a diverse community of K-12 educators, students, parents, and stakeholders, researchers will deploy AI Partners to interact naturally with students and teachers to augment classroom activities. This will give students the guidance they need to learn effectively while ensuring that educators can focus on inspiring and teaching students. By supporting the development of AI-enabled tools that can be deployed in classrooms across the nation—including classrooms that are underrepresented in STEM—NSF is helping ensure that students from every community can develop their STEM talents.

**Platforms for Advanced Wireless Research (PAWR)**

Expanding the reach of high-speed Internet connectivity is critical to boosting economic productivity, educational opportunities, and other benefits to communities around the nation. Through PAWR, NSF is partnering with a consortium of more than 35 companies to stand up four city-scale testing platforms. These platforms are in turn enabling experimentation with novel wireless concepts, protocols, technologies, and applications and services. With platforms currently based in Salt Lake City, New York City, and North Carolina's Research Triangle, PAWR is moving forward with plans for a fourth testing platform to focus on rural broadband technology, with an eye toward reducing access costs for rural communities and integrating multiple wireless technologies in new ways to reach unserved and underserved areas.


Cell tower. *Credit: ArtisticOperations/ Pixabay*.

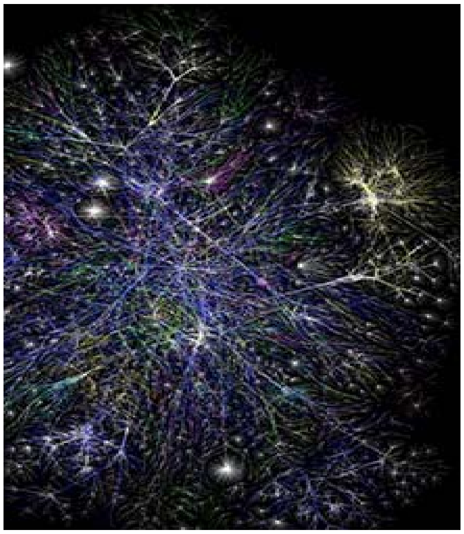
**Developing a potential biofuel, identifying key switchgrass genes**


Scientists' new analysis of switchgrass could be a game-changer for its use as a source of biofuel. *Credit: Jason Bonnette, UT Austin*

As economies move towards renewable fuels, the development of new source of clean energy – including biofuels – continues to be a critical avenue of research. In pursuit of such fuels and building on decades of NSF-supported advances in genomics, researchers have published a complex genome analysis of switchgrass, a promising biofuel crop. The analysis tied different genes to performance in varying climates across North America, enabling the development of a roadmap for breeding high-yielding switchgrass paired to current and future climate conditions across the United States. Increased switchgrass yield would increase its uses as a source of biofuel, a critical component of lowering atmospheric carbon levels and combating climate change.

**Tiny optical cavities could advance quantum networks**

Engineers have reached a new milestone for Quantum Information Science and the quest to create a quantum internet. The internet as we know it today is built on familiar technology like high-power microprocessors that power computation and networking infrastructure that is the backbone of connectivity, but scientists are still designing counterparts for the future of quantum computing. Funded by NSF under the Quantum Leap Big Idea, researchers have answered an important question about how quantum information can be sent and received through a quantum internet. Scientists can encode information in the quantum properties of individual atoms, which can be transmitted to other quantum computers. But how to "read" that information when it is received has been an open question until now. The researchers sculpted microscopic cavities in tiny pieces of crystal capable of holding atoms encoded with quantum information and sensing the atom's quantum properties. Just as technology like floppy disks kickstarted the digital age in 1960s, quantum breakthroughs like this are enabling leaps forward in emerging industries.



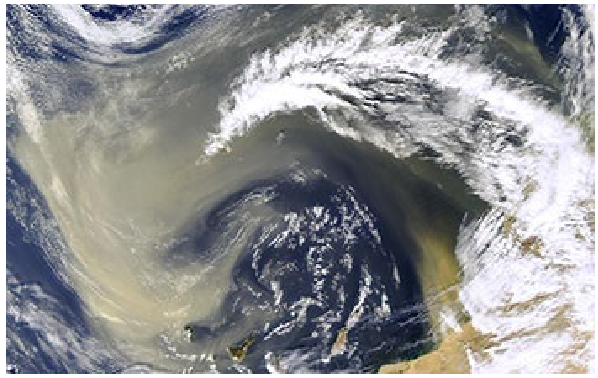
NSF-funded researchers are working to create the building blocks of a quantum network. *Credit: The Opte Project/Wikimedia (CC BY 2.5).*

**Scientists discover how cyanobacteria thrive in low light**

Cyanobacteria are tiny organisms that live virtually everywhere on Earth and use weak, filtered sunlight to generate energy through photosynthesis. They helped create an oxygen-rich atmosphere and continue to provide us with much of the oxygen we need to survive. Now, with funding from NSF, researchers have mapped the structure of the protein complex that allows cyanobacteria to live on such small amounts of light. The results could be used to engineer crops that thrive under low-light conditions, making the production of some crops less energy-intensive and more bountiful.


When cyanobacteria live in low-light conditions, some can switch to using far-red sunlight. *Credit: Shireen Dooling, Graphic Designer, ASU Biodesign Institute.*

**Earth's atmosphere far dustier than previously believed**



Dust in the atmosphere swirls above the Sahara Desert. *Credit: NASA.*

Underestimation of coarse dust skews models that predict global climate. Coarse dust particles warm Earth's climate by absorbing both incoming radiation from the sun and outgoing radiation from Earth's surface. These particles can impact stability and circulation within our atmosphere, which may affect atmospheric phenomena like hurricanes. The National Science Foundation found that Earth's atmosphere contains 17 million metric tons of coarse dust whereas current models only account for 4 million metric tons. "An accurate prediction of global climate change depends on understanding various components in the Earth system," says Chungu Lu, a program director in NSF's Division of Atmospheric and Geospace Sciences. "This research has furthered our understanding of climate change effects by dust, especially coarse dust, in the air."

**Examining the impact of the COVID-19 Pandemic on the rural American West**


The Rural West Covid Project team also plans to examine how rural communities in the West recover from the pandemic and how people’s sense of community has changed. *Credit: Sara Carpenter/Shutterstock.*

Much has been written about the impact of the COVID-19 pandemic on urban centers and suburbs across the United States, but less discussed is its impact on rural America, especially the rural West. The NSF-funded researchers have published a paper with results of their study in the journal Proceedings of the National Academy of Sciences. The scientists present results of their first survey of over 1,000 rural Western residents, which took place from June through July, 2020 by mail, text and phone. The findings show significant impacts on health and well-being across sex, age, ethnicity, and education.

**Seismic network from unlikely source**

How do you detect undersea earthquakes that can potentially cause devastating tsunamis? A team of NSF-funded geoscientists has found a way to use fiber optic communications cables at the bottom of the North Sea as a giant seismic network. While placing permanent seismic monitoring equipment on the seafloor would be prohibitively expensive, the fiber optic cables that already crisscross the ocean floor—carrying telecommunications signals between continents—are a ready-made solution. By sending a beam of light along the fiber optic cable, researchers detect tiny imperfections that reflect light back, which act as “waypoints” along the cable. When a seismic wave jostles the cable, the waypoints shift slightly, changing the way light in the cable is reflected and allowing researchers to take measurements of the seismic wave. By making creative use of existing infrastructure, researchers enhance disaster preparedness while opening up exciting new ways to study the Earth.

Researchers detected an earthquake by using fiber optic cable that connects a wind farm. *Credit: Riekelt Hakvoort/Shutterstock.com.*

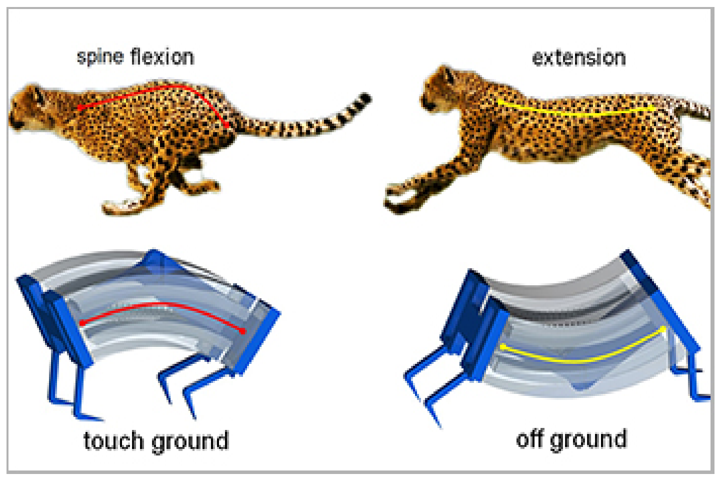
**PuebloConnect: Expanding internet access and content relevance in Tribal communities**


Team member Jennifer Case Nevarez of the Community Learning Network worked with K'e Infoshop to donate supplies and PPE to various groups, communities, and organizations in need during 2020. *Credit: PuebloConnect.*

Rural and Native American reservation communities in northern New Mexico have among the lowest Internet availability rates in the nation. In partnership with non-profit, Native-serving, and community organizations, CISE researchers are actively working to solve these digital inequities. The research team develops novel last-mile Internet connectivity and access solutions in tribal regions, develops community Web skills, and deploys cutting-edge technologies for connectivity and network management. The connectivity enables reservation residents to meaningfully participate in the Internet, as both consumers and producers of Internet content, in order to create new opportunities for economic development. In response to the stay-at-home orders due to COVID-19, the team has recently expanded Internet access on the Santa Clara Pueblo through installation of an innovative new base station and is working on providing a mobile WiFi hotspot to reservation residents.

**Inspired by cheetahs, researchers build fastest soft robots yet**

From navigating forbidding terrain in search-and-rescue missions to rapidly sorting fragile products in a warehouse environment, 'soft robots' have transformative potential in applications and environments that require machine assistants to have flexibility, agility, and a gentle touch. With a grant from NSF, engineers have developed a new type of soft robot that moves more than three times faster than previous designs. Inspired by the way that cheetahs derive their record speed by flexing their spine between two 'bistable' positions, researchers created soft robots that are faster and capable of running up steep inclines that are challenges for existing models. The engineers are already working on the next generation of their high-performing model, envisioning how their breakthrough could pave the way for multi-functional soft robots that may one day assist humans in a variety of environments.




Inspired by the biomechanics of cheetahs, researchers have developed a new type of soft robot. *Credit: Jie Yin, North Carolina State University.*

**LIGO-Virgo finds mystery object in gap between neutron stars and black holes**

When the Laser Interferometer Gravitational-Wave Observatory—known as LIGO—detected gravitational waves for the first time in 2016, it sent shockwaves through the scientific community, confirming predictions made by Albert Einstein a century before in a feat of research that some thought would be impossible to achieve. LIGO is continuing to make breakthroughs, detecting cosmic collisions between black holes and neutron stars, and answering key questions about our universe. One of those questions revolves around the "mass gap"—a blank space in astrophysicists' data between the largest neutron stars ever detected and the smallest black hole. At the end of their lifetimes, larger stars collapse into black holes, while smaller stars leave behind ultra-dense neutron stars. Since normal stars come in a spectrum of sizes, astrophysicists have been puzzled by the gap between neutron stars and black holes. A new LIGO discovery in 2020 provided evidence of an object firmly in the "mass gap" range. Whether it is record-breaking neutron star or a mini-black hole, the discovery is helping scientists get a clearer picture of some of the most exotic phenomena in the universe.

## SUMMARY TABLES

**Total NSF Funding:**

NSF Summary Table ....................Summary Tables - 3

NSF Funding Profile ....................Summary Tables - 4

Number of People Involved in NSF Activities....................Summary Tables - 5

NSF Budget Requests and Appropriations by Account: FY 2000-FY 2022....................Summary Tables - 7

**Major NSF-wide Investments:**

NSF Administration Priorities Summary ....................Summary Tables - 9

NSF NSTC Cross-cuts Summary ....................Summary Tables - 11

NSF Big Ideas Funding ....................Summary Tables - 13

NSF Selected Cross-cutting Programs ....................Summary Tables - 14

NSF Programs to Broaden Participation ....................Summary Tables - 15

**STEM Education Investments:**

NSF Education and Human Resources Funding by Division and Program ....................Summary Tables - 18

CoSTEM Inventory and Postdoctoral Fellowship Programs
by Level of Education ....................Summary Tables - 19

**Research Infrastructure:**

NSF Research Infrastructure Funding by Account and Activity....................Summary Tables - 20

NSF Research Infrastructure Summary....................Summary Tables - 21

**NATIONAL SCIENCE FOUNDATION**
**SUMMARY TABLE**
**FY 2022 BUDGET REQUEST TO CONGRESS**
(Dollars in Millions)

| NSF by Account | FY 2020 Actual | FY 2020 CARES Act Actual | FY 2021 Enacted[1] | FY 2022 Request | FY 2022 Request change over: FY 2020 Actual Amount | Percent | FY 2021 Enacted Amount | Percent |
|---|---|---|---|---|---|---|---|---|
| BIO | $809.31 | $19.00 | - | $948.51 | $139.20 | 17.2% | N/A | N/A |
| CISE | 996.40 | 15.00 | - | 1,116.06 | 119.66 | 12.0% | N/A | N/A |
| ENG | 754.31 | 15.00 | - | 916.79 | 162.48 | 21.5% | N/A | N/A |
| GEO | 993.72 | - | - | 1,194.92 | 201.20 | 20.2% | N/A | N/A |
| MPS | 1,530.12 | 6.00 | - | 1,690.74 | 160.62 | 10.5% | N/A | N/A |
| SBE | 280.35 | 9.50 | - | 319.66 | 39.31 | 14.0% | N/A | N/A |
| TIP[2] | 352.31 | 3.55 | - | 864.87 | 512.56 | 145.5% | N/A | N/A |
| *TIP Programs* | *120.25* | *0.80* | - | *590.23* | *469.98* | *390.8%* | *N/A* | *N/A* |
| *SBIR/STTR, including Operations* | *232.06* | *2.75* | - | *274.64* | *42.58* | *18.3%* | *N/A* | *N/A* |
| OISE | 51.04 | - | - | 75.32 | 24.28 | 47.6% | N/A | N/A |
| OPP | 480.59 | - | - | 506.29 | 25.70 | 5.3% | N/A | N/A |
| IA[3] | 352.97 | 1.95 | - | 504.90 | 151.93 | 43.0% | N/A | N/A |
| U.S. Arctic Research Commission | 1.60 | - | - | 1.65 | 0.05 | 3.1% | N/A | N/A |
| **Research & Related Activities** | **$6,602.70** | **$70.00** | **$6,909.77** | **$8,139.71** | **$1,537.01** | **23.3%** | **$1,229.94** | **17.8%** |
| **Education & Human Resources[3]** | **$1,084.24** | **$5.00** | **$968.00** | **$1,287.27** | **$203.03** | **18.7%** | **$319.27** | **33.0%** |
| **Major Research Equipment & Facilities Construction** | **$154.84** | **-** | **$241.00** | **$249.00** | **$94.16** | **60.8%** | **$8.00** | **3.3%** |
| **Agency Operations & Award Management** | **$347.58** | **$1.00** | **$345.64** | **$468.30** | **$120.72** | **34.7%** | **$122.66** | **35.5%** |
| **Office of Inspector General** | **$16.30** | **-** | **$17.85** | **$20.42** | **$4.12** | **25.2%** | **$2.57** | **14.4%** |
| **Office of the National Science Board** | **$4.43** | **-** | **$4.50** | **$4.60** | **$0.17** | **3.9%** | **$0.10** | **2.2%** |
| **Total, NSF Discretionary Funding** | **$8,210.09** | **$76.00** | **$8,486.76** | **$10,169.30** | **$1,959.21** | **23.9%** | **$1,682.54** | **19.8%** |
| Education and Human Resources - H-1B Visa | 114.78 | - | 157.00 | 162.47 | 47.69 | 41.6% | 5.47 | 3.5% |
| Donations | 21.06 | - | 40.00 | 10.00 | -11.06 | -52.5% | -30.00 | -75.0% |
| **Total, NSF Mandatory Funding** | **$135.83** | **-** | **$197.00** | **$172.47** | **$36.64** | **27.0%** | **-$24.53** | **-12.5%** |
| **Total, NSF Budgetary Resources** | **$8,345.92** | **$76.00** | **$8,683.76** | **$10,341.77** | **$1,995.85** | **23.9%** | **$1,658.01** | **19.1%** |

Totals exclude reimbursable amounts.

[1] Funding amounts below the account level for the FY 2021 Enacted were not available at the time of printing. Not included here are $600.0 million in American Rescue Plan Act of 2021 (ARP) (P.L. 117-2) supplemental mandatory 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.

[2] FY 2020 funding for TIP is shown for comparability across fiscal years.

[3] In FY 2022, funding for Graduate Research Fellowship Program will be consolidated in Education and Human Resources. FY 2020 funding from IA is shown in EHR for comparability across fiscal years.

## 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 2020 Actual Estimate | FY 2021 Estimate | FY 2022 Request Estimate |
|---|---|---|---|
| **Statistics for Competitive Awards** | | | |
| Number of Proposals | 42,400 | 43,200 | 47,900 |
| Number of Awards | 12,100 | 11,500 | 13,800 |
| Regular Appropriation | 11,600 | 11,500 | 13,800 |
| Cares Act | 500 | | |
| Funding Rate | 28% | 27% | 29% |
| **Statistics for Research Grant Awards** | | | |
| Number of Research Grant Proposals | 34,900 | 37,900 | 41,800 |
| Number of Research Grant Awards | 9,600 | 9,700 | 11,500 |
| Regular Appropriation | 9,100 | 9,700 | 11,500 |
| Cares Act | 500 | | |
| Funding Rate | 28% | 26% | 28% |
| Median Annualized Award Size | $153,800 | $155,300 | $176,900 |
| Average Annualized Award Size | $196,600 | $207,100 | $237,600 |
| Average Duration (years) | 2.9 | 2.9 | 3.0 |

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

## NUMBER OF PEOPLE INVOLVED IN NSF ACTIVITIES

NSF estimates that in FY 2022 approximately 366,800 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 2020 Actual Estimate | FY 2020 CARES Act Actual Estimate | FY 2021 Estimate | FY 2022 Request Estimate |
|---|---|---|---|---|
| Senior Researchers | 47,633 | 864 | 48,700 | 57,500 |
| Other Professionals | 12,799 | 191 | 13,200 | 16,100 |
| Postdoctoral Associates | 5,919 | 128 | 6,000 | 7,300 |
| Graduate Students | 42,204 | 501 | 42,800 | 51,600 |
| Undergraduate Students[1] | 39,573 | 333 | 40,500 | 48,700 |
| K-12 Teachers | 40,343 | 2 | 40,500 | 46,500 |
| K-12 Students | 118,047 | 15 | 119,700 | 139,100 |
| **Total Number of People** | **306,519** | **2,034** | **311,400** | **366,800** |

[1] The FY 2020 Actual for Undergraduates is adjusted downward from prior agency reported levels to correct an award reporting error.

**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]

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[1] Science and Engineering Indicators 2020: Chapter 2 Higher Education in Science and Engineering, NCSES *GSS 2017*: Table 1- 7, https://ncsesdata.nsf.gov/gradpostdoc/2017/html/gss17-dt-tab001-7.html and NCSES *GSS 2017*: Table 3-1, https://ncsesdata.nsf.gov/gradpostdoc/2017/html/gss17-dt-tab003-1.html.

**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 2022**

(Millions of Current Dollars)

Click here for complete history

| | Research & Related Activities (R&RA) | | Education & Human Resources (EHR) | | Major Research Equipment & Facilities Construction (MREFC)[1] | | Agency Operations & Award Management (AOAM)[2] | | Office of Inspector General (OIG) | | Office of the National Science Board (NSB) | | NSF, TOTAL | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Fiscal Year** | **Request** | **Appropriation** | **Request** | **Appropriation** | **Request** | **Appropriation** | **Request** | **Appropriation** | **Request** | **Appropriation** | **Request** | **Appropriation** | **Request** | **Appropriation** |
| 2000 | $3,004.00 | $2,972.90 | $678.00 | $690.87 | $85.00 | $93.50 | $149.00 | $149.28 | $5.45 | $5.45 | - | - | $3,921.45 | $3,912.00 |
| 2001 | 3,540.68 | 3,356.29 | 729.01 | 785.60 | 138.54 | 121.33 | 157.89 | 161.09 | 6.28 | 6.27 | - | - | 4,572.40 | 4,430.57 |
| 2002 | 3,326.98 | 3,612.26 | 872.41 | 894.28 | 96.33 | 138.80 | 170.04 | 171.26 | 6.76 | 6.75 | - | - | 4,472.52 | 4,823.35 |
| 2003 | 3,783.21 | 4,069.29 | 908.08 | 903.17 | 126.28 | 148.54 | 210.16 | 189.43 | 8.06 | 9.19 | - | 3.48 | 5,035.79 | 5,323.09 |
| 2004 | 4,106.36 | 4,262.12 | 938.04 | 938.98 | 202.33 | 154.98 | 225.70 | 218.96 | 8.77 | 9.94 | - | 3.88 | 5,481.20 | 5,588.86 |
| 2005 | 4,452.31 | 4,229.98 | 771.36 | 841.42 | 213.27 | 173.65 | 294.00 | 223.45 | 10.11 | 10.03 | 3.95 | 3.97 | 5,745.00 | 5,482.49 |
| 2006 | 4,333.49 | 4,339.21 | 737.00 | 796.69 | 250.01 | 190.88 | 269.00 | 247.06 | 11.50 | 11.35 | 4.00 | 3.95 | 5,605.00 | 5,589.14 |
| 2007 | 4,665.95 | 4,654.24 | 816.22 | 796.59 | 240.45 | 175.61 | 281.82 | 248.50 | 11.86 | 10.97 | 3.91 | 3.97 | 6,020.21 | 5,889.87 |
| 2008 | 5,131.69 | 4,841.73 | 750.60 | 765.60 | 244.74 | 220.74 | 285.59 | 281.79 | 12.35 | 11.43 | 4.03 | 3.97 | 6,429.00 | 6,125.26 |
| *2009* | *5,593.99* | *5,186.17* | *790.41* | *845.26* | *147.51* | *152.01* | *305.06* | *294.15* | *13.10* | *12.00* | *4.03* | *4.03* | *6,854.10* | *6,493.61* |
| *2009 ARRA* | - | *2,500.00* | - | *100.00* | - | *400.00* | | - | - | *2.00* | | - | - | *3,002.00* |
| 2009 Total | 5,593.99 | 7,686.17 | 790.41 | 945.26 | 147.51 | 552.01 | 305.06 | 294.15 | 13.10 | 14.00 | 4.03 | 4.03 | 6,854.10 | 9,495.61 |
| 2010 | 5,733.24 | 5,563.92 | 857.76 | 872.76 | 117.29 | 117.29 | 318.37 | 300.00 | 14.00 | 14.00 | 4.34 | 4.54 | 7,045.00 | 6,872.51 |
| 2011 | 6,018.83 | 5,509.98 | 892.00 | 861.03 | 165.19 | 117.06 | 329.19 | 299.40 | 14.35 | 13.97 | 4.84 | 4.53 | 7,424.40 | 6,805.98 |
| 2012 | 6,253.54 | 5,689.00 | 911.20 | 829.00 | 224.68 | 197.06 | 357.74 | 299.40 | 15.00 | 14.20 | 4.84 | 4.44 | 7,767.00 | 7,033.10 |
| 2013 | 5,983.28 | 5,543.72 | 875.61 | 833.31 | 196.17 | 196.17 | 299.40 | 293.60 | 14.20 | 13.19 | 4.44 | 4.12 | 7,373.10 | 6,884.11 |
| 2014 | 6,212.29 | 5,808.92 | 880.29 | 846.50 | 210.12 | 200.00 | 304.29 | 298.00 | 14.32 | 14.20 | 4.47 | 4.30 | 7,625.78 | 7,171.92 |
| 2015 | 5,807.46 | 5,933.65 | 889.75 | 866.00 | 200.76 | 200.76 | 338.23 | 325.00 | 14.43 | 14.43 | 4.37 | 4.37 | 7,255.00 | 7,344.21 |
| 2016 | 6,186.30 | 5,989.68 | 962.57 | 878.97 | 200.31 | 218.31 | 354.84 | 357.00 | 15.16 | 15.16 | 4.37 | 4.37 | 7,723.55 | 7,463.49 |
| 2017 | 6,425.44 | 6,005.65 | 952.86 | 873.05 | 193.12 | 214.86 | 373.02 | 359.09 | 15.20 | 15.20 | 4.38 | 4.37 | 7,964.02 | 7,472.22 |
| 2018[3] | 5,361.65 | 6,334.48 | 760.55 | 902.00 | 182.80 | 182.80 | 328.51 | 328.51 | 15.01 | 15.20 | 4.37 | 4.37 | 6,652.89 | 7,767.36 |
| 2019 | 6,150.68 | 6,504.51 | 873.37 | 922.00 | 94.65 | 295.74 | 333.63 | 333.03 | 15.35 | 15.35 | 4.32 | 4.37 | 7,472.00 | 8,075.00 |
| 2020[4] | 5,662.96 | 6,789.80 | 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[5] | 6,213.02 | 6,909.77 | 930.93 | 968.00 | 229.75 | 241.00 | 345.64 | 345.64 | 17.85 | 17.85 | 4.21 | 4.50 | 7,741.40 | 8,486.76 |
| 2022 | 8,139.71 | - | 1,287.27 | - | 249.00 | - | 468.30 | - | 20.42 | - | 4.60 | - | 10,169.30 | - |

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

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

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

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

[4] FY 2020 appropriations 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.

[5] FY 2021 Appropriations are Enacted appropriations. Not included here are $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.

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**NATIONAL SCIENCE FOUNDATION**
**NSF ADMINISTRATION PRIORITIES SUMMARY**
**FY 2022 BUDGET REQUEST TO CONGRESS**
(Dollars in Millions)

| | **Advanced Manufacturing** | | | | | **Advanced Wireless** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **FY 2020 Actual** | **FY 2021 Estimate** | **FY 2022 Request** | **FY 2022 Request change over FY 2021 Estimate Amount** | **Percent** | **FY 2020 Actual** | **FY 2021 Estimate** | **FY 2022 Request** | **FY 2022 Request change over FY 2021 Estimate Amount** | **Percent** |
| BIO | $8.48 | $7.16 | $17.16 | $10.00 | 139.7% | - | - | - | - | N/A |
| CISE | 42.37 | 42.22 | 42.22 | - | - | 88.76 | 88.76 | 93.26 | 4.50 | 5.1% |
| ENG | 127.99 | 117.37 | 174.37 | 57.00 | 48.6% | 24.36 | 23.45 | 25.80 | 2.35 | 10.0% |
| GEO | - | - | - | - | N/A | - | - | - | - | N/A |
| MPS | 160.62 | 123.03 | 123.13 | 0.10 | 0.1% | 17.00 | 17.00 | 17.00 | - | - |
| SBE | 0.75 | 0.50 | 3.50 | 3.00 | 600.0% | - | - | - | - | N/A |
| TIP[1] | 26.58 | 24.63 | 54.63 | 30.00 | 121.8% | 0.60 | 0.55 | 30.55 | 30.00 | 5454.5% |
| OISE | 0.50 | 0.50 | 0.50 | - | - | - | - | - | - | N/A |
| OPP | - | - | - | - | N/A | - | - | - | - | N/A |
| IA | 5.06 | 1.00 | 1.00 | - | - | - | - | - | - | N/A |
| **R&RA** | **$372.35** | **$316.41** | **$416.51** | **$100.10** | **31.6%** | **$130.72** | **$129.76** | **$166.61** | **$36.85** | **28.4%** |
| **EHR** | **$1.45** | **$2.00** | **$2.00** | **-** | **-** | **-** | **-** | **-** | **-** | **N/A** |
| **Total, NSF** | **$373.80** | **$318.41** | **$418.51** | **$100.10** | **31.4%** | **$130.72** | **$129.76** | **$166.61** | **$36.85** | **28.4%** |

| | **Artificial Intelligence** | | | | | **Biotechnology** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **FY 2020 Actual** | **FY 2021 Estimate** | **FY 2022 Request** | **FY 2022 Request change over FY 2021 Estimate Amount** | **Percent** | **FY 2020 Actual** | **FY 2021 Estimate** | **FY 2022 Request** | **FY 2022 Request change over FY 2021 Estimate Amount** | **Percent** |
| BIO | $13.78 | $20.00 | $20.00 | - | - | $110.00 | $110.00 | $130.00 | $20.00 | 18.2% |
| CISE | 329.80 | 329.80 | 349.80 | 20.00 | 6.1% | 9.04 | 6.00 | 6.00 | - | - |
| ENG | 91.47 | 87.15 | 95.80 | 8.65 | 9.9% | 92.76 | 90.94 | 101.50 | 10.56 | 11.6% |
| GEO | 5.00 | 5.00 | 5.00 | - | - | 8.00 | 10.00 | 10.00 | - | - |
| MPS | 71.67 | 62.48 | 71.67 | 9.19 | 14.7% | 73.48 | 51.20 | 52.20 | 1.00 | 2.0% |
| SBE | 16.04 | 14.59 | 19.59 | 5.00 | 34.3% | 1.93 | 1.50 | 1.50 | - | - |
| TIP[1] | 67.66 | 61.55 | 121.55 | 60.00 | 97.5% | 9.27 | 9.06 | 69.06 | 60.00 | 662.3% |
| OISE | - | - | - | - | N/A | - | - | - | - | N/A |
| OPP | - | - | - | - | N/A | 2.11 | 1.60 | 2.00 | 0.40 | 25.0% |
| IA | 2.97 | 1.00 | 1.00 | - | - | 1.95 | 1.00 | 1.00 | - | - |
| **R&RA** | **$598.39** | **$581.57** | **$684.41** | **$102.84** | **17.7%** | **$308.54** | **$281.30** | **$373.26** | **$91.96** | **32.7%** |
| **EHR** | **$6.76** | **$30.00** | **$50.00** | **$20.00** | **66.7%** | **$16.07** | **$9.00** | **$9.00** | **-** | **-** |
| **Total, NSF** | **$605.15** | **$611.57** | **$734.41** | **$122.84** | **20.1%** | **$324.61** | **$290.30** | **$382.26** | **$91.96** | **31.7%** |

[1] FY 2020 and FY 2021 funding for TIP is shown for comparability across fiscal years.

**NATIONAL SCIENCE FOUNDATION**
**NSF ADMINISTRATION PRIORITIES SUMMARY**
**FY 2022 BUDGET REQUEST TO CONGRESS**
(Dollars in Millions)

| | Clean Energy Technology | | | | | Microelectronics and Semiconductors | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | FY 2022 Request change over FY 2021 Estimate: Amount | Percent | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | FY 2022 Request change over FY 2021 Estimate: Amount | Percent |
| BIO | $18.00 | $45.00 | $59.28 | $14.28 | 31.7% | $3.00 | - | - | - | N/A |
| CISE | 18.50 | 23.50 | 31.12 | 7.62 | 32.4% | $18.46 | $18.46 | $23.46 | 5.00 | 27.1% |
| ENG | 113.54 | 123.03 | 178.57 | 55.54 | 45.1% | 30.43 | 34.77 | 40.00 | 5.23 | 15.0% |
| GEO | - | - | - | - | N/A | - | - | - | - | N/A |
| MPS | 92.62 | 90.00 | 118.56 | 28.56 | 31.7% | 35.07 | 15.20 | 25.20 | 10.00 | 65.8% |
| SBE | - | - | - | - | N/A | - | - | - | - | N/A |
| TIP[1] | 48.47 | 52.47 | 52.47 | - | - | 17.71 | 20.23 | 50.23 | 30.00 | 148.3% |
| OISE | - | - | - | - | N/A | - | - | - | - | N/A |
| OPP | - | - | - | - | N/A | - | - | - | - | N/A |
| IA | - | - | - | - | N/A | - | - | - | - | N/A |
| **R&RA** | **$291.13** | **$334.00** | **$440.00** | **$106.00** | **31.7%** | **$104.67** | **$88.66** | **$138.89** | **$50.23** | **56.7%** |
| **EHR** | **-** | **-** | **-** | **-** | **N/A** | **-** | **-** | **-** | **-** | **N/A** |
| **Total, NSF** | **$291.13** | **$334.00** | **$440.00** | **$106.00** | **31.7%** | **$104.67** | **$88.66** | **$138.89** | **$50.23** | **56.7%** |

| | Quantum Information Science | | | | | U.S. Global Change Research Program | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | FY 2022 Request change over FY 2021 Estimate: Amount | Percent | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | FY 2022 Request change over FY 2021 Estimate: Amount | Percent |
| BIO | $3.28 | $3.28 | $3.28 | - | - | $90.00 | $145.00 | $212.15 | $67.15 | 46.3% |
| CISE | 17.59 | 19.28 | 24.28 | 5.00 | 25.9% | - | - | - | - | N/A |
| ENG | 23.83 | 27.89 | 32.89 | 5.00 | 17.9% | - | - | - | - | N/A |
| GEO | - | - | - | - | N/A | 294.17 | 329.23 | 481.70 | 152.47 | 46.3% |
| MPS | 125.46 | 136.13 | 146.13 | 10.00 | 7.3% | - | 10.00 | 14.63 | 4.63 | 46.3% |
| SBE | 0.37 | - | - | - | N/A | 19.61 | 17.18 | 25.14 | 7.96 | 46.3% |
| TIP[1] | 15.47 | 18.42 | 48.42 | 30.00 | 162.9% | - | - | - | - | N/A |
| OISE | 2.21 | 1.00 | 1.00 | - | - | - | - | - | - | N/A |
| OPP | - | - | - | - | N/A | 15.40 | 19.40 | 28.38 | 8.98 | 46.3% |
| IA | 2.33 | - | - | - | N/A | - | - | - | - | N/A |
| **R&RA** | **$190.54** | **$206.00** | **$256.00** | **$50.00** | **24.3%** | **$419.18** | **$520.81** | **$762.00** | **$241.19** | **46.3%** |
| **EHR** | **$3.98** | **$4.00** | **$4.00** | **-** | **-** | **-** | **-** | **-** | **-** | **N/A** |
| **Total, NSF** | **$194.52** | **$210.00** | **$260.00** | **$50.00** | **23.8%** | **$419.18** | **$520.81** | **$762.00** | **$241.19** | **46.3%** |

[1] FY 2020 and FY 2021 funding for TIP is shown for comparability across fiscal years.

**NATIONAL SCIENCE FOUNDATION**
**NSTC CROSS-CUTS SUMMARY**
**FY 2022 BUDGET REQUEST TO CONGRESS**
(Dollars in Millions)

**National Nanotechnology Initiative (NNI)**

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | FY 2022 Request change over: FY 2020 Actual Amount | FY 2020 Actual Percent | FY 2021 Estimate Amount | FY 2021 Estimate Percent |
|---|---|---|---|---|---|---|---|
| BIO | $42.50 | $39.95 | $39.95 | -$2.55 | -6.0% | - | - |
| CISE | 14.36 | 14.05 | 14.05 | -0.31 | -2.2% | - | - |
| ENG | 221.52 | 190.95 | 219.99 | -1.53 | -0.7% | 29.04 | 15.2% |
| MPS | 330.70 | 183.50 | 183.50 | -147.20 | -44.5% | - | - |
| SBE | 0.40 | 0.40 | 0.40 | - | - | - | - |
| TIP[1] | 11.67 | 10.05 | 10.05 | -1.62 | -13.9% | - | - |
| OISE | 0.10 | 0.10 | 0.10 | - | - | - | - |
| **R&RA** | **$621.25** | **$439.00** | **$468.04** | **-$153.21** | **-24.7%** | **$29.04** | **6.6%** |
| **EHR** | **$13.74** | **$2.50** | **$2.50** | **-$11.24** | **-81.8%** | **-** | **-** |
| **NSF Total** | **$634.99** | **$441.50** | **$470.54** | **-$164.45** | **-25.9%** | **$29.04** | **6.6%** |

[1] FY 2020 and FY 2021 funding for TIP is shown for comparability across fiscal years.

**Networking & Information Technology R&D (NITRD)**

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | FY 2022 Request change over: FY 2020 Actual Amount | FY 2020 Actual Percent | FY 2021 Estimate Amount | FY 2021 Estimate Percent |
|---|---|---|---|---|---|---|---|
| BIO | $79.00 | $79.00 | $79.00 | - | - | - | - |
| CISE | 996.40 | 1,005.49 | 1,116.06 | 119.66 | 12.0% | 110.57 | 11.0% |
| ENG | 134.75 | 154.98 | 179.26 | 44.51 | 33.0% | 24.28 | 15.7% |
| GEO | 27.00 | 27.00 | 27.00 | - | - | - | - |
| MPS | 228.42 | 191.62 | 200.81 | -27.61 | -12.1% | 9.19 | 4.8% |
| SBE | 31.86 | 29.44 | 37.44 | 5.58 | 17.5% | 8.00 | 27.2% |
| TIP[1] | 73.76 | 76.11 | 398.11 | 324.35 | 439.7% | 322.00 | 423.1% |
| IA | 2.97 | 1.00 | 1.00 | -1.97 | -66.3% | - | - |
| **R&RA** | **$1,574.16** | **$1,564.64** | **$2,038.68** | **$464.52** | **29.5%** | **$474.04** | **30.3%** |
| **EHR** | **$17.00** | **$17.59** | **$27.59** | **$10.59** | **62.3%** | **$10.00** | **56.9%** |
| **NSF Total** | **$1,591.16** | **$1,582.23** | **$2,066.27** | **$475.11** | **29.9%** | **$484.04** | **30.6%** |

[1] FY 2020 and FY 2021 funding for TIP is shown for comparability across fiscal years.

**Quantum Information Science (QIS)**

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | FY 2022 Request change over: FY 2020 Actual Amount | FY 2020 Actual Percent | FY 2021 Estimate Amount | FY 2021 Estimate Percent |
|---|---|---|---|---|---|---|---|
| BIO | $3.28 | $3.28 | $3.28 | - | - | - | - |
| CISE | 17.59 | 19.28 | 24.28 | 6.69 | 38.0% | 5.00 | 25.9% |
| ENG | 23.83 | 27.89 | 32.89 | 9.06 | 38.0% | 5.00 | 17.9% |
| MPS | 125.46 | 136.13 | 146.13 | 20.67 | 16.5% | 10.00 | 7.3% |
| SBE | 0.37 | - | - | -0.37 | -100.0% | - | N/A |
| TIP[1] | 15.47 | 18.42 | 48.42 | 32.95 | 213.0% | 30.00 | 162.9% |
| OISE | 2.21 | 1.00 | 1.00 | -1.21 | -54.8% | - | - |
| IA | 2.33 | - | - | -2.33 | -100.0% | - | N/A |
| **R&RA** | **$190.54** | **$206.00** | **$256.00** | **$65.46** | **34.4%** | **$50.00** | **24.3%** |
| **EHR** | **$3.98** | **$4.00** | **$4.00** | **$0.02** | **0.5%** | **-** | **-** |
| **NSF Total** | **$194.52** | **$210.00** | **$260.00** | **$65.48** | **33.7%** | **$50.00** | **23.8%** |

[1] FY 2020 and FY 2021 funding for TIP is shown for comparability across fiscal years.

**NATIONAL SCIENCE FOUNDATION**
**NSTC CROSS-CUTS SUMMARY**
**FY 2022 BUDGET REQUEST TO CONGRESS**
(Dollars in Millions)

**U.S. Global Change Research Program (USGCRP)**

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | FY 2022 Request change over: FY 2020 Actual | | FY 2022 Request change over: FY 2021 Estimate | |
|---|---|---|---|---|---|---|---|
| | | | | Amount | Percent | Amount | Percent |
| BIO | $90.00 | $145.00 | $212.15 | $122.15 | 135.7% | $67.15 | 46.3% |
| GEO | 294.17 | 329.23 | 481.70 | 187.53 | 63.7% | 152.47 | 46.3% |
| MPS | - | 10.00 | 14.63 | 14.63 | N/A | 4.63 | 46.3% |
| SBE | 19.61 | 17.18 | 25.14 | 5.53 | 28.2% | 7.96 | 46.3% |
| OPP | 15.40 | 19.40 | 28.38 | 12.98 | 84.3% | 8.98 | 46.3% |
| **R&RA** | **$419.18** | **$520.81** | **$762.00** | **$342.82** | **81.8%** | **$241.19** | **46.3%** |
| **EHR** | **-** | **-** | **-** | **-** | **N/A** | **-** | **N/A** |
| **NSF Total** | **$419.18** | **$520.81** | **$762.00** | **$342.82** | **81.8%** | **$241.19** | **46.3%** |

**NATIONAL SCIENCE FOUNDATION**
**NSF BIG IDEAS FUNDING**
**FY 2022 BUDGET REQUEST TO CONGRESS**
(Dollars in Millions)

| NSF Big Ideas | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|
| **Research Ideas** | **$177.15** | **$150.00** | **$150.00** |
| Harnessing the Data Revolution for 21st Century Science and Engineering (HDR) | 30.00 | 30.00 | 30.00 |
| The Future of Work at the Human-Technology Frontier (FW-HTF) | 30.00 | 30.00 | 30.00 |
| Navigating the New Arctic (NNA) | 27.20 | 30.00 | 30.00 |
| The Quantum Leap (QL)[1] | 30.00 | - | - |
| Understanding the Rules of Life (URoL) | 29.95 | 30.00 | 30.00 |
| Windows on the Universe (WoU) | 30.00 | 30.00 | 30.00 |
| **Enabling Big Ideas** | **$73.43** | **$144.92** | **$196.92** |
| Growing Convergence Research (GCR) | 15.90 | 16.00 | 24.17 |
| Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science (NSF INCLUDES) | 20.75 | 20.00 | 46.50 |
| Mid-scale Research Infrastructure | 30.37 | 108.92 | 126.25 |
| *Mid-scale RI Track 1* | *30.37* | *32.67* | *50.00* |
| *Mid-scale RI Track 2* | - | *76.25* | *76.25* |
| NSF 2026[1] | 6.42 | - | - |
| **Total** | **$250.59** | **$294.92** | **$346.92** |

[1] Starting in FY 2021, all Quantum Leap stewardship activities are managed with the broader Quantum Information Science (QIS) portfolio. See the NSF-Wide Investments chapter for detail on QIS.

**NATIONAL SCIENCE FOUNDATION**
**SELECTED CROSS-CUTTING PROGRAMS**
**FY 2022 BUDGET REQUEST TO CONGRESS**
(Dollars in Millions)

| Selected Cross-Cutting Programs | | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | FY 2022 Request change over: FY 2020 Actual Amount | FY 2020 Actual Percent | FY 2021 Estimate Amount | FY 2021 Estimate Percent |
|---|---|---|---|---|---|---|---|---|
| ADVANCE | Research & Related Activities | - | - | - | - | N/A | - | N/A |
| | Education & Human Resources | 18.00 | 18.00 | 20.50 | 2.50 | 13.9% | 2.50 | 13.9% |
| | **Total, NSF** | **$18.00** | **$18.00** | **$20.50** | **$2.50** | **13.9%** | **$2.50** | **13.9%** |
| Faculty Early Career Development - CAREER | Research & Related Activities | 387.95 | 333.46 | 365.02 | -22.93 | -5.9% | 31.56 | 9.5% |
| | Education & Human Resources | - | - | - | - | N/A | - | N/A |
| | **Total, NSF** | **$387.95** | **$333.46** | **$365.02** | **-$22.93** | **-5.9%** | **$31.56** | **9.5%** |
| Long-Term Ecological Research Sites - LTERs | Research & Related Activities | 31.45 | 32.29 | 33.54 | 2.09 | 6.6% | 1.25 | 3.9% |
| | Education & Human Resources | - | - | - | - | N/A | - | N/A |
| | **Total, NSF** | **$31.45** | **$32.29** | **$33.54** | **$2.09** | **6.6%** | **$1.25** | **3.9%** |
| National Nanotechnology Coordinated Infrastructure - NNCI | Research & Related Activities | 15.65 | 15.46 | 15.46 | -0.19 | -1.2% | - | - |
| | Education & Human Resources | - | - | - | - | N/A | - | N/A |
| | **Total, NSF** | **$15.65** | **$15.46** | **$15.46** | **-$0.19** | **-1.2%** | **-** | **-** |
| Research Experiences for Undergraduates - REU - Sites Only | Research & Related Activities | 74.48 | 60.63 | 67.17 | -7.31 | -9.8% | 6.54 | 10.8% |
| | Education & Human Resources | - | - | - | - | N/A | - | N/A |
| | **Total, NSF** | **$74.48** | **$60.63** | **$67.17** | **-$7.31** | **-9.8%** | **$6.54** | **10.8%** |
| Research Experiences for Undergraduates - REU - Supplements Only | Research & Related Activities | 24.16 | 21.65 | 17.37 | -6.79 | -28.1% | -4.28 | -19.8% |
| | Education & Human Resources | - | - | - | - | N/A | - | N/A |
| | **Total, NSF** | **$24.16** | **$21.65** | **$17.37** | **-$6.79** | **-28.1%** | **-$4.28** | **-19.8%** |
| Total, Research Experiences for Undergraduates - REU | Research & Related Activities | 98.64 | 82.28 | 84.54 | -14.10 | -14.3% | 2.26 | 2.7% |
| | Education & Human Resources | - | - | - | - | N/A | - | N/A |
| | **Total, NSF** | **$98.64** | **$82.28** | **$84.54** | **-$14.10** | **-14.3%** | **$2.26** | **2.7%** |
| Research in Disabilities Education - RDE | Research & Related Activities | 0.22 | - | - | -0.22 | -100.0% | - | N/A |
| | Education & Human Resources | 15.35 | 6.50 | 6.50 | -8.85 | -57.7% | - | - |
| | **Total, NSF** | **$15.57** | **$6.50** | **$6.50** | **-$9.07** | **-58.3%** | **-** | **-** |
| Research in Undergraduate Institutions - RUI | Research & Related Activities | 43.40 | 32.64 | 32.99 | -10.41 | -24.0% | 0.35 | 1.1% |
| | Education & Human Resources | - | - | - | - | N/A | - | N/A |
| | **Total, NSF** | **$43.40** | **$32.64** | **$32.99** | **-$10.41** | **-24.0%** | **$0.35** | **1.1%** |

**NATIONAL SCIENCE FOUNDATION**
**PROGRAMS TO BROADEN PARTICIPATION**
**FY 2022 BUDGET REQUEST TO CONGRESS**
(Dollars in Millions)

| | Amount of Funding Captured | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|---|
| **Total, Broadening Participation Programs** | | **$1,105.15** | **$1,212.21** | **$1,407.92** | **$195.71** | **16.1%** |

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

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

## Focused Programs

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

(Dollars in Millions)

| | Amount of Funding Captured | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|---|
| **Focused Programs** | | | | | | |
| ADVANCE | 100% | 18.00 | 18.00 | 20.50 | 2.50 | 13.9% |
| Alliances for Graduate Education & the Professoriate (AGEP) | 100% | 8.00 | 8.00 | 12.00 | 4.00 | 50.0% |
| AGEP Graduate Research Supplements (AGEP-GRS) | 100% | 3.17 | 6.64 | 6.64 | - | - |
| Broadening Participation in Biology Fellowships | 100% | 5.00 | 3.50 | 5.00 | 1.50 | 42.9% |
| Broadening Participation in Engineering (BPE) | 100% | 4.72 | 7.50 | 9.00 | 1.50 | 20.0% |
| Career-Life Balance (CLB)[1] | 100% | 0.69 | 0.28 | 0.28 | - | - |
| Centers of Research Excellence in Science & Technology (CREST) | 100% | 24.00 | 24.00 | 39.00 | 15.00 | 62.5% |
| CISE Education and Workforce | 100% | 11.00 | 12.75 | 12.75 | - | - |
| CISE-MSI Research Expansion Program | 100% | - | - | 7.00 | 7.00 | N/A |
| Coastlines and People (CoPe) | 100% | 4.41 | 18.00 | 28.00 | 10.00 | 55.6% |
| Disability and Rehabilitation Engineering (DARE) | 100% | 5.07 | 5.10 | 6.00 | 0.90 | 17.6% |
| Excellence Awards in Science & Engineering (EASE)[2] | 100% | 7.33 | 5.00 | 7.64 | 2.64 | 52.8% |
| Historically Black Colleges & Universities Undergraduate Program (HBCU-UP) | 100% | 35.00 | 36.50 | 46.50 | 10.00 | 27.4% |
| HBCU Excellence in Research (HBCU-EiR) | 100% | 18.05 | 20.50 | 33.96 | 13.46 | 65.7% |
| Improving Undergraduate STEM Education (IUSE): Hispanic Serving Institutions (HSI) program | 100% | 45.00 | 46.50 | 56.50 | 10.00 | 21.5% |
| Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science (NSF INCLUDES) | 100% | 20.75 | 20.00 | 46.50 | 26.50 | 132.5% |
| Louis Stokes Alliances for Minority Participation (LSAMP) | 100% | 47.49 | 49.50 | 69.50 | 20.00 | 40.4% |
| Mathematical and Physical Sciences Ascending Postdoctoral Research Fellowships (MPS-Ascend) | 100% | - | 10.00 | 10.00 | - | - |
| NSF Scholarships in STEM (S-STEM)[3] | 100% | 79.91 | 132.75 | 121.85 | -10.90 | -8.2% |
| Partnerships for Research & Education in Materials (PREM) | 100% | 6.38 | 9.00 | 9.00 | - | - |
| Partnerships in Astronomy & Astrophysics Res. Ed. (PAARE) | 100% | - | - | 0.50 | 0.50 | N/A |
| SBE Build and Broaden | 100% | 1.37 | 8.00 | 8.00 | - | - |
| SBE Postdoctoral Research Fellowships-Broadening Participation (SPRF-BP) | 100% | 1.49 | 3.00 | 3.00 | - | - |
| Science of Broadening Participation | 100% | 1.73 | 1.50 | 1.50 | - | - |
| Tribal Colleges & Universities Program (TCUP) | 100% | 15.00 | 16.50 | 21.00 | 4.50 | 27.3% |
| **Subtotal, Focused Programs** | | **\$363.56** | **\$462.52** | **\$581.62** | **\$119.10** | **25.8%** |

[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] NSF Scholarships in Science, Technology, Engineering, and Mathematics (S-STEM) and Innovative Technology Experiences for Students and Teachers (ITEST) 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.

(Dollars in Millions)

| | Amount of Funding Captured | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|---|
| Emphasis Programs | | | | | | |
| Advancing Informal STEM Learning (AISL) | 58% | 36.24 | 36.25 | 40.60 | 4.35 | 12.0% |
| Computer Science for All (CSforAll) | 62% | 18.89 | 15.19 | 15.19 | - | - |
| CyberTraining | 51% | 2.53 | 3.06 | 3.06 | - | - |
| Discovery Research PreK-12 (DRK-12) | 56% | 53.20 | 53.20 | 53.20 | - | - |
| EHR Core Research | 62% | 41.43 | 47.52 | 60.15 | 12.63 | 26.6% |
| Graduate Research Fellowship Program (GRFP) | 67% | 189.48 | 189.49 | 212.13 | 22.64 | 11.9% |
| Improving Undergraduate STEM Education (IUSE) | 64% | 70.11 | 71.36 | 69.50 | -1.86 | -2.6% |
| Innovative Technology Experiences for Students and Teachers (ITEST)[3] | 74% | 25.80 | 32.75 | 30.06 | -2.69 | -8.2% |
| International Research Experiences for Students (IRES) | 54% | 6.36 | 6.62 | 6.48 | -0.14 | -2.0% |
| Research Experiences for Teachers (RET) Sites in Engineering and Computer Science | 72% | 5.90 | 4.54 | 5.18 | 0.65 | 14.3% |
| Research Experiences for Undergraduates (REU) - Sites and Supplements | 61% | 60.17 | 50.19 | 51.57 | 1.38 | 2.7% |
| Robert Noyce Teacher Scholarship Program (NOYCE) | 59% | 41.16 | 39.53 | 39.53 | - | - |
| **Subtotal, Emphasis Programs** | | **$551.27** | **$549.69** | **$586.66** | **$36.97** | **6.7%** |

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

## Geographic Diversity Programs

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

(Dollars in Millions)

| | Amount of Funding Captured | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|---|
| Geographic Diversity Programs | | | | | | |
| EPSCoR | 100% | 190.32 | 200.00 | 239.64 | 39.64 | 19.8% |
| **Subtotal, Geographic Diversity Programs** | | **$190.32** | **$200.00** | **$239.64** | **$39.64** | **19.8%** |

**NATIONAL SCIENCE FOUNDATION**
**EDUCATION AND HUMAN RESOURCES FUNDING BY DIVISION AND PROGRAM**
**FY 2022 BUDGET REQUEST TO CONGRESS**
(Dollars in Millions)

| | | | | FY 2022 Request change over: | | | |
|---|---|---|---|---|---|---|---|
| | | | | FY 2020 Actuals | | FY 2021 Request | |
| | FY 2020 Actuals | FY 2021 Estimate | FY 2022 Request | Amount | Percent | Amount | Percent |
| **Division of Research on Learning in Formal and Informal Settings (DRL)** | | | | | | | |
| Advancing Informal STEM Learning (AISL) | $62.48 | $62.50 | $70.00 | $7.52 | 12.0% | $7.50 | 12.0% |
| Artificial Intelligence Research Institutes, National | 2.03 | 7.59 | 17.59 | 15.56 | 766.5% | 10.00 | 131.8% |
| Computer Science for All (CSforAll) | 15.00 | 10.00 | 10.00 | -5.00 | -33.3% | - | - |
| Discovery Research PreK-12 (DRK-12) | 95.00 | 95.00 | 95.00 | - | - | - | - |
| EHR Core Research (ECR): STEM Learning | 24.11 | 29.07 | 37.07 | 12.96 | 53.8% | 8.00 | 27.5% |
| **DRL Subtotal** | **$198.62** | **$204.16** | **$229.66** | **$31.04** | **15.6%** | **$25.50** | **12.5%** |
| **Division of Graduate Education (DGE)** | | | | | | | |
| Cybercorps®: Scholarship for Service (SFS) | 55.00 | 60.00 | 70.00 | 15.00 | 27.3% | 10.00 | 16.7% |
| EHR Core Research (ECR): STEM Professional Workforce Preparation | 16.45 | 18.12 | 20.11 | 3.66 | 22.2% | 1.99 | 11.0% |
| Graduate Research Fellowship Program (GRFP)[2] | 284.51 | 284.52 | 318.52 | 34.01 | 12.0% | 34.00 | 11.9% |
| NSF Research Traineeship (NRT) | 49.52 | 58.00 | 58.00 | 8.48 | 17.1% | - | - |
| **DGE Subtotal** | **$405.48** | **$420.64** | **$466.63** | **$61.15** | **15.1%** | **$45.99** | **10.9%** |
| **Division of Human Resource Development (HRD)** | | | | | | | |
| ADVANCE | 18.00 | 18.00 | 20.50 | 2.50 | 13.9% | 2.50 | 13.9% |
| Alliances for Graduate Education and the Professoriate (AGEP) | 8.00 | 8.00 | 12.00 | 4.00 | 50.0% | 4.00 | 50.0% |
| Big Idea: NSF INCLUDES | 20.75 | 20.00 | 46.50 | 25.75 | 124.1% | 26.50 | 132.5% |
| Centers for Research Excellence in Science and Technology (CREST) | 24.00 | 24.00 | 39.00 | 15.00 | 62.5% | 15.00 | 62.5% |
| EHR Core Research (ECR): Broadening Participation and Institutional Capacity in STEM | 12.71 | 14.61 | 16.99 | 4.28 | 33.7% | 2.38 | 16.3% |
| Excellence Awards in Science and Engineering (EASE) | 7.33 | 5.00 | 7.64 | 0.31 | 4.2% | 2.64 | 52.8% |
| Historically Black Colleges and Universities Undergraduate Program (HBCU-UP) | 35.00 | 36.50 | 46.50 | 11.50 | 32.9% | 10.00 | 27.4% |
| IUSE: Hispanic Serving Institutions (HSI) Program | 22.50 | 23.25 | 28.25 | 5.75 | 25.6% | 5.00 | 21.5% |
| Louis Stokes Alliances for Minority Participation (LSAMP) | 47.49 | 49.50 | 69.50 | 22.01 | 46.3% | 20.00 | 40.4% |
| Tribal Colleges and Universities Program (TCUP) | 15.00 | 16.50 | 21.00 | 6.00 | 40.0% | 4.50 | 27.3% |
| **HRD Subtotal** | **$210.77** | **$215.36** | **$307.88** | **$97.11** | **46.1%** | **$92.52** | **43.0%** |
| **Division of Undergraduate Education (DUE)** | | | | | | | |
| Advanced Technological Education (ATE) | 73.53 | 75.00 | 75.00 | 1.47 | 2.0% | - | - |
| EHR Core Research (ECR): STEM Learning Environments | 13.56 | 14.85 | 22.85 | 9.29 | 68.5% | 8.00 | 53.9% |
| Improving Undergraduate STEM Education (IUSE) | 90.00 | 90.00 | 90.00 | - | - | - | - |
| IUSE: Hispanic Serving Institutions (HSI) Program | 22.50 | 23.25 | 28.25 | 5.75 | 25.6% | 5.00 | 21.5% |
| Robert Noyce Teacher Scholarship Program (Noyce)[1] | 69.77 | 67.00 | 67.00 | -2.77 | -4.0% | - | - |
| **DUE Subtotal** | **$269.37** | **$270.10** | **$283.10** | **$13.73** | **5.1%** | **$13.00** | **4.8%** |
| **Total, EHR** | **$1,084.24** | **$1,110.26** | **$1,287.27** | **$203.03** | **18.7%** | **$177.01** | **15.9%** |

[1] Decreases reflected in FY 2021 Estimate and FY 2022 Request as compared to the FY 2020 Actuals are due to FY 2020 spending, which includes no year recoveries funding and two year funding.

[2] 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.

**NATIONAL SCIENCE FOUNDATION**
**CoSTEM INVENTORY AND POSTDOCTORAL FELLOWSHIP PROGRAMS**
**BY LEVEL OF EDUCATION**
**FY 2022 BUDGET REQUEST TO CONGRESS**
(Dollars in Millions)

| | | | | | FY 2022 Request change over: | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | FY 2020 Actual | | FY 2021 Estimate | |
| | | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Amount | Percent | Amount | Percent |
| **Minority-Serving Institutions** | | | | | | | | |
| UG | Hispanic Serving Institutions Program (HSI) Program | 45.00 | 46.50 | 56.50 | 11.50 | 25.6% | 10.00 | 21.5% |
| UG | Historically Black Colleges and Universities Undergraduate Program (HBCU-UP) | 35.00 | 36.50 | 46.50 | 11.50 | 32.8% | 10.00 | 27.4% |
| UG | Tribal Colleges and Universities Program (TCUP) | 15.00 | 16.50 | 21.00 | 6.00 | 40.0% | 4.50 | 27.3% |
| **Minority-Serving Institutions Subtotal** | | **$95.00** | **$99.50** | **$124.00** | **$29.00** | **30.5%** | **$24.50** | **24.6%** |
| **Fellowships and Scholarships** | | | | | | | | |
| UG | NSF Scholarships in STEM (S-STEM) (H-1B) | 79.91 | 132.75 | 121.85 | 41.94 | 52.5% | -10.90 | -8.2% |
| UG | Robert Noyce Scholarship (Noyce) Program | 69.77 | 67.00 | 67.00 | -2.77 | -4.0% | - | - |
| G | CyberCorps®: Scholarship for Service (SFS) | 54.99 | 60.00 | 70.00 | 15.01 | 27.3% | 10.00 | 16.7% |
| G | Graduate Research Fellowship Program (GRFP) | 284.51 | 284.52 | 318.52 | 34.01 | 12.0% | 34.00 | 11.9% |
| G | NSF Research Traineeship (NRT) | 49.63 | 58.00 | 58.00 | 8.37 | 16.9% | - | - |
| **Fellowships and Scholarships Subtotal** | | **$538.82** | **$602.27** | **$635.37** | **$96.55** | **17.9%** | **$33.10** | **5.5%** |
| **Other Grant Programs** | | | | | | | | |
| K-12 | Computer Science for All (CSforAll) | 30.46 | 24.50 | 24.50 | -5.96 | -19.6% | - | - |
| K-12 | Discovery Research PreK-12 (DRK-12) | 95.00 | 95.00 | 95.00 | 0.00 | 0.0% | - | - |
| K-12 | Innovative Technology Experiences for Teachers and Students (ITEST) (H1-B) | 34.87 | 44.25 | 40.62 | 5.75 | 16.5% | -3.63 | -8.2% |
| UG | Advanced Technological Education (ATE) | 73.53 | 75.00 | 75.00 | 1.47 | 2.0% | - | - |
| UG | Emerging Frontiers in Research and Innovation (EFRI) Research Experience and Mentoring (REM) | 0.49 | 0.80 | 1.00 | 0.51 | 104.1% | 0.20 | 25.0% |
| UG | Harnessing the Data Revolution : Data Science Corps | 3.00 | 6.00 | 3.00 | - | - | -3.00 | -50.0% |
| UG | Improving Undergraduate STEM Education (IUSE) | 109.54 | 111.50 | 108.60 | -0.94 | -0.9% | -2.90 | -2.6% |
| UG | International Research Experiences for Students (IRES) | 11.77 | 12.25 | 12.00 | 0.23 | 1.9% | -0.25 | -2.0% |
| UG | Louis Stokes Alliances for Minority Participation (LSAMP) | 47.49 | 49.50 | 69.50 | 22.01 | 46.4% | 20.00 | 40.4% |
| UG | Research Experiences for Undergraduates (REU) - Sites and Supplements | 98.64 | 82.28 | 84.54 | -14.10 | -14.3% | 2.26 | 2.7% |
| UG | Research Experiences for Teachers (RET) in Engineering and Computer Science | 8.19 | 6.30 | 7.20 | -0.99 | -12.1% | 0.90 | 14.3% |
| G | Alliances for Graduate Education and the Professoriate | 8.00 | 8.00 | 12.00 | 4.00 | 50.0% | 4.00 | 50.0% |
| G | Training-based Workforce Development for Advanced Cyberinfrastructure (CyberTraining) | 4.97 | 6.00 | 6.00 | 1.03 | 20.8% | - | - |
| O&I | Advancing Informal STEM Learning (AISL) | 62.48 | 62.50 | 70.00 | 7.52 | 12.0% | 7.50 | 12.0% |
| O&I | Excellence Awards in Science and Engineering (EASE) | 7.33 | 5.00 | 7.64 | 0.31 | 4.2% | 2.64 | 52.8% |
| O&I | Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science (NSF INCLUDES) | 20.75 | 20.00 | 46.50 | 25.75 | 124.1% | 26.50 | 132.5% |
| O&I | EHR Core Research (ECR) | 66.83 | 76.65 | 97.02 | 30.19 | 45.2% | 20.37 | 26.6% |
| **Other Grant Programs Subtotal** | | **$683.34** | **$685.53** | **$760.12** | **$76.78** | **11.2%** | **$74.59** | **10.9%** |
| **Subtotal, Above Categories (CoSTEM Inventory Programs)** | | **$1,317.16** | **$1,387.30** | **$1,519.49** | **$202.33** | **15.4%** | **$132.19** | **9.5%** |
| **NSF Postdoctoral Programs** | | | | | | | | |
| G | Astronomy and Astrophysics Postdoctoral Fellowships | 2.28 | 2.40 | 2.40 | 0.12 | 5.5% | - | - |
| G | Entrepreneurial Fellowships[1] | - | - | 20.00 | 20.00 | N/A | 20.00 | N/A |
| G | Geosciences Postdoctoral Fellowships | 3.95 | 7.90 | 9.95 | 6.00 | 152.0% | 2.05 | 25.9% |
| G | Mathematical Sciences Postdoctoral Research Fellowships | 6.15 | 9.15 | 9.15 | 3.00 | 48.8% | - | - |
| G | MPS ASCEND Postdoctoral Research Fellowships | - | 10.00 | 10.00 | 10.00 | N/A | - | - |
| G | Postdoctoral Research Fellowships in Biology | 19.05 | 16.80 | 16.80 | -2.25 | -11.8% | - | - |
| G | SPRF-Broadening Participation | 1.49 | 3.00 | 3.00 | 1.51 | 101.8% | - | - |
| G | SPRF-Fundamental Research | 1.92 | 3.00 | 1.50 | -0.42 | -21.9% | -1.50 | -50.0% |
| **NSF Postdoctoral Programs Subtotal** | | **$34.83** | **$52.25** | **$72.80** | **$37.97** | **109.0%** | **$20.55** | **39.3%** |
| **K-12 STEM Education Programs (K-12) Subtotal** | | **$160.33** | **$163.75** | **$160.12** | **-$0.21** | **-0.1%** | **-$3.63** | **-2.2%** |
| **Undergraduate STEM Education Programs - (UG) Subtotal** | | **$597.34** | **$642.88** | **$673.69** | **$76.35** | **12.8%** | **$30.81** | **4.8%** |
| **Graduate and Professional STEM Education Programs - (G)** | | **$436.93** | **$468.77** | **$537.32** | **$100.39** | **23.0%** | **$68.55** | **14.6%** |
| **Outreach and Informal STEM Education Programs - (O&I) Subtotal** | | **$157.39** | **$164.15** | **$221.16** | **$63.77** | **40.5%** | **$57.01** | **34.7%** |
| **Total, NSF STEM Education** | | **$1,351.99** | **$1,439.55** | **$1,592.29** | **$240.30** | **17.8%** | **$152.74** | **10.6%** |

[1] Entrepreneurial Fellowships is a new postdoctoral program for FY 2022 in the new TIP directorate.

**NATIONAL SCIENCE FOUNDATION**
**RESEARCH INFRASTRUCTURE (RI) FUNDING, BY ACCOUNT AND ACTIVITY**
**FY 2022 BUDGET REQUEST TO CONGRESS**
(Dollars in Millions)

| | FY 2020 Actual | FY 2020 Actual RI Funding | FY 2021 Estimate | FY 2021 Estimate RI Funding | FY 2022 Request | FY 2022 Request RI Funding | FY 2022 Request RI change over: FY 2020 Actual RI | | FY 2021 Estimate RI | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Amount | Percent | Amount | Percent |
| BIO | $809.31 | **$129.10** | $818.14 | **$118.22** | $948.51 | **$129.00** | -$0.10 | -0.1% | $10.78 | 9.1% |
| CISE | 996.40 | **199.37** | 1,005.49 | **175.60** | 1,116.06 | **182.09** | -17.28 | -8.7% | 6.49 | 3.7% |
| ENG | 754.31 | **24.96** | 761.85 | **23.58** | 916.79 | **23.83** | -1.13 | -4.5% | 0.25 | 1.1% |
| GEO | 993.72 | **407.46** | 1,004.18 | **414.64** | 1,194.92 | **442.93** | 35.47 | 8.7% | 28.29 | 6.8% |
| MPS | 1,530.12 | **409.48** | 1,580.48 | **403.75** | 1,690.74 | **392.26** | -17.22 | -4.2% | -11.49 | -2.8% |
| SBE | 280.35 | **67.56** | 282.06 | **64.77** | 319.66 | **70.70** | 3.14 | 4.6% | 5.93 | 9.2% |
| TIP[1] | 352.31 | **-** | 364.87 | **-** | 864.87 | **-** | - | N/A | - | N/A |
| OISE | 51.04 | **0.10** | 51.32 | **0.10** | 75.32 | **0.10** | - | - | - | - |
| OPP | 480.59 | **355.63** | 483.35 | **355.44** | 506.29 | **371.23** | 15.60 | 4.4% | 15.79 | 4.4% |
| IA | 495.23 | **108.65** | 527.14 | **110.97** | 504.90 | **143.13** | 34.48 | 31.7% | 32.16 | 29.0% |
| USARC | 1.60 | **-** | 1.60 | **-** | 1.65 | **-** | - | N/A | - | N/A |
| R&RA | $6,744.96 | **$1,702.32** | $6,880.48 | **$1,667.07** | $8,139.71 | **$1,755.27** | $52.95 | 3.1% | $88.20 | 5.3% |
| EHR | $941.98 | **-** | $968.00 | **-** | $1,287.27 | **-** | - | N/A | - | N/A |
| MREFC | $154.84 | **$153.87** | $241.00 | **$240.00** | $249.00 | **$248.00** | $94.13 | 61.2% | $8.00 | 3.3% |
| AOAM | $347.58 | **-** | $374.93 | **-** | $468.30 | **-** | - | N/A | - | N/A |
| OIG | $16.30 | **-** | $17.85 | **-** | $20.42 | **-** | - | N/A | - | N/A |
| NSB | $4.43 | **-** | $4.50 | **-** | $4.60 | **-** | - | N/A | - | N/A |
| **Total, NSF** | **$8,210.09** | **$1,856.19** | **$8,486.76** | **$1,907.07** | **$10,169.30** | **$2,003.27** | **$147.08** | **7.9%** | **$96.20** | **5.0%** |

[1] FY 2020 and FY 2021 funding for TIP is shown for comparability across fiscal years.

**NATIONAL SCIENCE FOUNDATION**
**RESEARCH INFRASTRUCTURE SUMMARY**
**FY 2022 BUDGET REQUEST TO CONGRESS**
(Dollars in Millions)

| | | | | FY 2022 Request change over: | | | |
|---|---|---|---|---|---|---|---|
| | FY 2020 | FY 2021 | FY 2022 | FY 2020 Actual | | FY 2021 Estimate | |
| | Actual | Estimate | Request | Amount | Percent | Amount | Percent |
| **Operations and Maintenance of Major Facilities[1]** | **$912.77** | **$947.27** | **$950.21** | **$37.44** | **4.1%** | **$2.94** | **0.3%** |
| **Major Research Facilities Construction Investments** | **$162.30** | **$169.15** | **$183.35** | **$21.05** | **13.0%** | **$14.20** | **8.4%** |
| Construction, Acquisition, and Commissioning (MREFC)[2] | 153.87 | 163.75 | 171.75 | 17.88 | 11.6% | 8.00 | 4.9% |
| Design Stage Activities[3] | 8.43 | 5.40 | 11.60 | 3.17 | 37.6% | 6.20 | 114.8% |
| **Mid-scale Research Infrastructure[4]** | **$102.21** | **$160.98** | **$179.99** | **$77.78** | **76.1%** | **$19.01** | **11.8%** |
| MREFC Mid-scale Research Infrastructure | - | 76.25 | 76.25 | 76.25 | N/A | - | - |
| NSF-wide Mid-scale Research Infrastructure (R&RA) | 30.37 | 32.67 | 50.00 | 19.63 | 64.6% | 17.33 | 53.0% |
| Directorate Midscale Research Infrastructure Programs | 71.84 | 52.06 | 53.74 | -18.10 | -25.2% | 1.68 | 3.2% |
| **Major Research Instrumentation (MRI)** | **$75.37** | **$75.00** | **$89.85** | **$14.48** | **19.2%** | **$14.85** | **19.8%** |
| **Polar Logistical and Infrastructure Support[5]** | **$135.79** | **$137.30** | **$143.10** | **$7.31** | **5.4%** | **$5.80** | **4.2%** |
| **CISE Networking and Computational Resources Infrastructure and Services (NCRIS)[6]** | **$146.78** | **$130.65** | **$140.65** | **-$6.13** | **-4.2%** | **$10.00** | **7.7%** |
| **Research Resources[7]** | **$217.73** | **$187.43** | **$211.67** | **-$6.06** | **-2.8%** | **$24.24** | **12.9%** |
| BIO | 61.75 | 51.87 | 57.65 | -4.10 | -6.6% | 5.78 | 11.1% |
| CISE | 48.49 | 40.75 | 37.24 | -11.25 | -23.2% | -3.51 | -8.6% |
| GEO | 74.21 | 64.83 | 82.50 | 8.29 | 11.2% | 17.67 | 27.3% |
| MPS | 18.15 | 15.10 | 18.40 | 0.25 | 1.4% | 3.30 | 21.9% |
| SBE | 13.01 | 9.59 | 9.59 | -3.42 | -26.3% | - | - |
| OPP | 2.12 | 5.29 | 6.29 | 4.17 | 196.5% | 1.00 | 18.9% |
| **Other Research Infrastructure** | **$104.68** | **$100.73** | **$106.85** | **$2.17** | **2.1%** | **$6.12** | **6.1%** |
| **Subtotal, Research Infrastructure Support** | **$1,857.62** | **$1,908.51** | **$2,005.67** | **$148.05** | **8.0%** | **$97.16** | **5.1%** |
| Research Infrastructure Stewardship Offset | -1.44 | -1.44 | -2.40 | -0.96 | 66.8% | -0.96 | 66.7% |
| **RESEARCH INFRASTRUCTURE TOTAL** | **$1,856.19** | **$1,907.07** | **$2,003.27** | **$147.08** | **7.9%** | **$96.20** | **5.0%** |

[1] For facility level detail on operations and maintenance, see the Research Facilities and Other Research Infrastructure O&M funding table in the Summary Tables chapter.

[2] Construction, Acquisition, and Commissioning are for implementation support provided through the MREFC account. MREFC funding is included for the Antarctic Infrastructure Modernization for Science (AIMS) project of the Antarctic Infrastructure Recapitalization (AIR) program, ($47.78 million in FY 2020, $90.0 million in FY 2021 and FY 2022); Vera C. Rubin Observatory ($46.35 million in FY 2020 and $40.75 million in FY 2021 and FY 2022); the High Luminosity-Large Hadron Collider Upgrade (HL-LHC) ($33.0 million in FY 2020 and FY 2021 and $36.0 million in FY 2022), the National Ecological Observatory Network (NEON) ($740,000 in FY 2020), Regional Class Research Vessels (RCRV) ($25.0 million in FY 2020 and $5.0 million in FY 2022) and Mid-scale Research Infrastructure ($65.0 million in FY 2020 (carried over into FY 2021) and $76.25 million in FY 2021 and FY 2022, 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 2020 funding of $3.50 million and $3.60 million in FY 2021 and FY 2022 for the potential Leadership Class Computing Facility, and $4.93 million in FY 2020 for the Antarctic Infrastructure Modernization for Science (AIMS) project of the Antarctic Infrastructure Recapitalization (AIR) program, and $1.80 million in FY 2021 and $8.0 million in FY 2022 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). For more information, please refer to the Mid-scale Research Infrastructure narrative in the NSF-wide Investfments chapter.

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

[6] Funding for Networking and Computational Resources Infrastructure and Services excludes support for the potential Leadership Class Computing Facility in FY 2020 ($3.50 million), and in FY 2021 and FY 2022 ($3.60 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

NSF Current Authorizations........................................................................ Authorizations - 3

Computer Science Education Research Report in Compliance with
Public Law 114-329............................................................................ Authorizations - 9

EPSCoR Report in Compliance with Public Law 114-329...................................... Authorizations - 13

**NATIONAL SCIENCE FOUNDATION CURRENT AUTHORIZATIONS**

(Dollars in Millions)

| LEGISLATION | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Authorization Levels FY 2020 | Authorization Levels FY 2021 | Authorization Levels FY 2022 |
|---|---|---|---|---|---|---|
| **National Science Foundation Act of 1950, P.L. 81-507**[1] | | | | | | |
| *Scholarships and Graduate Fellowships* | | | | *within limits of funds made available for this purpose* | | |
| *General Authority* | | | | *within the limits of available appropriations* | | |
| *Administering Provisions* | | | | *to make such expenditures as may be necessary* | | |
| *International Cooperation and Coordination with Foreign Policy* | | | | *within the limit of appropriated funds* | | |
| *Contract Arrangements* | | | | *utilize appropriations available* | | |
| **American Innovation and Competitiveness Act, P.L. 114-329** | | | | *(Does not authorize appropriations)* | | |
| *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 children and students with dyslexia, professional development for teachers and administrators of students with dyslexia, curricula and educational tools needed for children with dyslexia, and implementation and scaling of successful models of dyslexia intervention.*[4] *For each of fiscal years 2016 through 2021, there are authorized out of funds appropriated to the National Science Foundation, $5,000,000.* | | | | | | |
| **Promoting Women in Entrepreneurship Act, P.L. 115-6** | | | | *(Does not authorize appropriations)* | | |
| *Amends the Science and Engineering Equal Opportunities Act to authorize the National Science Foundation to encourage its entrepreneurial programs to recruit and support women to extend their focus beyond the laboratory and into the commercial world.* | | | | | | |

**NATIONAL SCIENCE FOUNDATION CURRENT AUTHORIZATIONS**

(Dollars in Millions)

| LEGISLATION | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Authorization Levels FY 2020 | FY 2021 | FY 2022 |
|---|---|---|---|---|---|---|
| **Women in Aerospace Education Act, P.L. 115-303**<br>*Amends the National Science Foundation Authorization Act of 2002 to permit certain grants awarded by the National Science Foundation (NSF) to be used to provide internships that include research experiences at national laboratories and National Aeronautics and Space Administration (NASA) centers. NSF Master Teaching Fellows and undergraduate freshman and sophomore students studying to become mathematics and science teachers under the Robert Noyce Teacher Scholarship Program are eligible for the internships.* | | | | *(Does not authorize appropriations)* | | |
| **National Earthquake Hazards Reduction Program Reauthorization Act of 2018, P.L. 115-307**<br>*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.*<br><br>*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] | **$53.35** | **$54.00** | **$54.00** | *$54.00* | *$54.00* | *$54.00* |
| **National Quantum Initiative Act, P.L. 115-368**<br>*Authorizes the National Science Foundation to carry out a basic research and education program on quantum information science and engineering, and award grants for the establishment of at least 2 but not more than 5 Multidisciplinary Centers for Quantum Research and Education up to $10 million each for each of fiscal years 2019 through 2023.* | | | | *(Does not authorize appropriations)* | | |

**NATIONAL SCIENCE FOUNDATION CURRENT AUTHORIZATIONS**
(Dollars in Millions)

| LEGISLATION | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Authorization Levels FY 2020 | FY 2021 | FY 2022 |
|---|---|---|---|---|---|---|
| **H.R. 3196 - Vera Rubin Survey Telescope Designation Act, P.L. 116-97**<br>*Renames the Large Synoptic Survey Telescope as the Vera C. Rubin Observatory.* | | | | *(Does not authorize appropriations)* | | |
| **S. 737 - Building Blocks of STEM Act, P.L. 116-102**<br>*A bill to direct the National Science Foundation to support STEM education research focused on early childhood. This includes an increase the participation of underrepresented populations in STEM fields may be used for research into various subjects regarding female students in prekindergarten through elementary school, including the role of teachers and caregivers. Also, offer female-inclusive computer science enrichment programs, and acquainting female students in prekindergarten through elementary school with careers in computer science.* | | | | *(Does not authorize appropriations)* | | |
| **S. 153 - Supporting Veterans in STEM Careers Act, P.L. 116-115**<br>*Requires NSF to develop a veteran outreach plan and tracking of veteran participation, include data on veterans in annual STEM indicators report, and updates Noyce Teacher Scholarship program, NSF fellowship programs, and cyber grant programs to all include outreach to veterans.* | | | | *(Does not authorize appropriations)* | | |
| **S. 881 - Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow (PROSWIFT) Act, P.L. 116-181**<br>*Establishes an interagency working group on space weather where NSF is a member. The Director of the National Science Foundation shall maintain and improve ground-based observations of the Sun,and continue to provide space weather data.* | | | | *(Does not authorize appropriations)* | | |
| **S. 2904 - IOGAN Act P.L. 116-258**<br>*Directs NSF and the NIST to support research on generative adversarial networks. A generative adversarial network is a software system designed to be trained with authentic inputs (e.g., photographs) to generate similar, but artificial, outputs (e.g., deepfakes). NSF must support research on manipulated or synthesized content and information authenticity.* | | | | *(Does not authorize appropriations)* | | |

**NATIONAL SCIENCE FOUNDATION CURRENT AUTHORIZATIONS**
(Dollars in Millions)

| LEGISLATION | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Authorization Levels FY 2020 | Authorization Levels FY 2021 | Authorization Levels FY 2022 |
|---|---|---|---|---|---|---|
| **S. 461 - HBCU PARTNERS Act, P.L. 116-270** | | | | | *(Does not authorize appropriations)* | |
| *To strengthen the capacity and competitiveness of historically Black colleges and universities through robust public-sector, private-sector, and community partnerships and engagement, and for other purposes. Calls on NSF to submit to the Secretary of Education, the Executive Director of the White House Initiative on Historically Black Colleges and Universities, the Committee on Health, Education, Labor, and Pensions of the Senate, the Committee on Education and Labor of the House of Representatives, and the President's Board of Advisors an annual Agency Plan describing efforts to strengthen the capacity of HBCUs to participate or be eligible to participate in the programs and initiatives under the jurisdiction of NSF.* | | | | | | |
| **S. 914 - Coordinated Ocean Observations and Research Act of 2019, P.L. 116-271** | | | | | *(Does not authorize appropriations)* | |
| *A bill[6] that clarifies the authority of the Administrator of the National Oceanic and Atmospheric Administration with respect to post-storm assessments, and to require the establishment of a National Water Center, and for other purposes. Amends Section 12407(a) of the Federal Ocean Acidification Research And Monitoring Act of 2009 (33 U.S.C. 3706(a)) stating that the Director of NSF shall continue to carry out research activities on ocean acidification.* | | | | | | |
| **National Defense Authorization Act for Fiscal Year 2021, P.L. 116-283** | | | | | | |
| *Sec. 5105 Directs NSF to enter into a contract with the National Research Council of the National Academies to conduct a study of the current and future impact of Artificial Intelligence (AI) on the workforce of the U.S. across sectors.* | | | | | *(Does not authorize appropriations)* | |
| *Sec. 5106 Establishes a task force, in coordination with the OSTP, to investigate the feasibility and advisability of establishing and sustaining a National AI Research Resource and to propose a roadmap detailing how such resource should be established and sustained.* | | | | | *(Does not authorize appropriations)* | |
| *Sec. 5201 Authorizes NSF to award AI Institutes and establishes an AI Leadership Network.* | | | | | *(Does not authorize appropriations)* | |

**NATIONAL SCIENCE FOUNDATION CURRENT AUTHORIZATIONS**
(Dollars in Millions)

| LEGISLATION | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Authorization Levels FY 2020 | FY 2021 | FY 2022 |
|---|---|---|---|---|---|---|
| **National Defense Authorization Act for Fiscal Year 2021, P.L. 116-283 *continued*** | | | | | | |
| *Sec. 5401(a-e) Authorizes NSF to carry out research and education on AI; requires a report on potential options for requiring an ethics statement in all or a subset of NSF applications for research funding; establishes Faculty Recruitment Fellowships to retain tenure-track or tenured faculty in AI and related fields; establishes Faculty Technology Ethics Fellowships to enable researchers in social and behavioral sciences, ethics, law, and related fields to establish new research and education partnerships with researchers in AI and related fields; updates the Noyce teacher scholarship program to include "artificial intelligence"; and updates the ATE program to establish national centers of scientific and technical education to advance education and workforce development in areas related to AI.* | | | | *(Does not authorize appropriations)* | | |
| *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.* [3,7] | | * | * | *NA* | *$868.00* | *$911.40* |
| *Sec 9405 Updates the American Innovation and Competitiveness Act, the Scientific and Advanced-Technology Act of 1992, and the American Competitiveness and Workforce Improvement Act of 1998 to include "Cybersecurity" and ensures that educators and mentors in fields related to cybersecurity are considered for Presidential Awards for Excellence in Mathematics and Science Teaching and Presidential Awards for Excellence in STEM Mentoring.* | | | | *(Does not authorize appropriations)* | | |
| **H.R. 8810 - National Landslide Preparedness Act, P.L. 116-323** | | * | * | *NA* | *$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.* [3] | | | | | | |
| **H.R. 3153 - EFFORT Act P.L. 116-335** | | | | *(Does not authorize appropriations)* | | |
| *This bill directs the National Science Foundation to support merit-reviewed and competitively awarded research on the science of opioid addiction.* | | | | | | |

**NATIONAL SCIENCE FOUNDATION CURRENT AUTHORIZATIONS**
(Dollars in Millions)

| LEGISLATION | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Authorization Levels FY 2020 | FY 2021 | FY 2022 |
|---|---|---|---|---|---|---|
| **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 2020 Actuals funding includes $3.40 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] Reauthorizes the Integrated Coastal and Ocean Observation System Act of 2009 through 2025.

[7] Authorizes appropriation of funds for the Pilot Program of Grants for Research in Rapidly Evolving, High Priority Topics. Outyear funding is $956,970,000 for fiscal year 2023; $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)**
**FISCAL YEAR 2020**

## 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]. In 2020, Computer Science for All (CSforAll: Research and RPPs) became a stand-alone program and NSF issued an updated solicitation, NSF 20-539[3]. As the new acronym 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 to the educational field new knowledge about the teaching and learning of introductory computer science concepts. The Research Strand aligns the program with the mission of NSF to produce knowledge in service of societal needs.

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 populations targeted in the awards. CSforAll considers 'short-term' metrics to be those 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 is reasonable to expect individual projects to achieve within three years of award. This is the first 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 Monitoring Group within NSF's Directorate for Education and Human Resources 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 CSforAll: RPP projects using these longer-term metrics.

<u>Report on the Success of the Program as Measured by the Short-Term Metrics</u>

During fiscal year (FY) 2020, the program made 37 new awards to proposals submitted pursuant to NSF 20-539. These awards addressed the first three research topics listed in Sec. 310 of the Act as follows. Because some awards address more than one of the goals addressed in (b)(2) A, B, and C, the number of awards sums to more than 37:

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[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

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

With respect to subsection (b)(2) D, all 37 new awards explicitly stated that they address at least one underrepresented or underserved group. The specific groups addressed by these 37 awards are detailed in the following table. Because some awards serve more than one underrepresented group, the number of awards sums to more than 37.

**Underrepresented or Underserved Group Served by Backbone Organizations**

| Category | Number of awards serving |
|---|---|
| African-Americans | 21 |
| Latino/a | 17 |
| Women/Girls | 11 |
| Low Socio-Economic Status | 9 |
| Rural | 7 |
| Disabilities | 6 |
| Native Americans | 4 |
| English Language Learners | 1 |
| Pacific Islanders | 0 |

<u>Report on the Success of the Program as Measured by the Mid-Term Metrics</u>
Mid-term metrics assess progress that individual awards have made at least three years after the award start date, based on information contained in projects' annual reports. Given that the program began in FY 2017, mid-term metrics are possible only for the awards that NSF issued in that first year.

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 have been making satisfactory progress for each year of the project duration.

**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 2020**

This report summarizes fiscal year (FY) 2020 NSF funding to institutions and entities in EPSCoR jurisdictions, as required by the American Innovation and Competitiveness Act Sec. 103(d)(1-3). Specifically, the report itemizes

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

**Introduction**

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

EPSCoR's strategies and objectives in FY 2020 remain the same as those described in the FY 2019 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." Thus, EPSCoR's goals are:

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

government, and private sector levels.

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

In FY 2020, NSF EPSCoR invested a total of $191.57 million in support of its programmatic activities. Of this, $148.57 million (77.6 percent) was directed to RII, $41.85 million (21.8 percent) to co-funding, and $1.76 million (0.6 percent) to outreach activities and workshops. Within the FY 2020 EPSCoR co-funding total, $1.25 million of support was provided through the Coronavirus Aid, Relief, and Economic Security Act (CARES Act) (P.L. 116-136). The table below details the investments from EPSCoR resources and EPSCoR investments in co-funding actions.

**FY 2020 EPSCoR Funding by Jurisdiction**

(Dollars in Millions)

| EPSCoR Jurisdiction | RII Program | Outreach & Workshops | EPSCoR Co-Funding | EPSCoR Co-Funding CARES Act | EPSCoR Total |
|---|---|---|---|---|---|
| AK | $0.75 | - | $0.69 | - | $1.44 |
| AL | 8.52 | 0.10 | 2.89 | 0.15 | 11.66 |
| AR | 6.67 | 0.05 | 1.42 | - | 8.14 |
| DE | 4.64 | - | 5.43 | - | 10.07 |
| GU | 4.14 | - | - | - | 4.14 |
| HI | 4.33 | - | 1.50 | - | 5.83 |
| IA | 0.29 | - | 1.69 | 0.18 | 2.16 |
| ID | 6.34 | - | 1.71 | 0.06 | 8.11 |
| KS | 5.44 | - | 2.28 | 0.07 | 7.79 |
| KY | 11.82 | - | 2.55 | 0.11 | 14.48 |
| LA | 7.21 | - | 2.04 | 0.15 | 9.40 |
| ME | 9.47 | 0.70 | 0.68 | - | 10.85 |
| MS | 4.09 | - | 1.29 | - | 5.38 |
| MT | 5.18 | - | 1.29 | - | 6.47 |
| ND | 5.88 | - | 0.92 | - | 6.80 |
| NE | 4.15 | - | 0.80 | - | 4.95 |
| NH | 10.41 | - | 1.27 | - | 11.68 |
| NM | 4.19 | - | 0.90 | 0.09 | 5.18 |
| NV | 1.03 | - | 1.09 | - | 2.12 |
| OK | 5.35 | - | 2.12 | 0.07 | 7.54 |
| PR | 3.07 | - | 0.74 | - | 3.81 |
| RI | 0.36 | - | 1.15 | 0.10 | 1.61 |
| SC | 4.32 | - | 2.35 | 0.22 | 6.89 |
| SD | 8.45 | 0.10 | 0.41 | 0.05 | 9.01 |
| VI | 5.38 | - | - | - | 5.38 |
| VT | 6.42 | - | 1.56 | - | 7.98 |
| WV | 3.27 | - | 0.95 | - | 4.22 |
| WY | 4.81 | - | 0.61 | - | 5.42 |
| Admin | 2.59 | 0.20 | 0.27 | - | 3.06 |
| **Total** | **$148.57** | **$1.15** | **$40.60** | **$1.25** | **$191.57** |

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

In FY 2020, NSF invested a total of $982.64 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 2020 NSF Funding Made Available to All EPSCoR Jurisdictions**

(Dollars in Millions)

| EPSCoR Jurisdiction | NSF Funding |
|---|---|
| AK | $61.17 |
| AL | 69.10 |
| AR | 27.03 |
| DE | 44.31 |
| GU | 4.49 |
| HI | 49.02 |
| IA | 51.74 |
| ID | 25.43 |
| KS | 44.24 |
| KY | 41.42 |
| LA | 46.39 |
| ME | 29.24 |
| MS | 19.83 |
| MT | 38.54 |
| ND | 19.93 |
| NE | 25.17 |
| NH | 42.90 |
| NM | 59.65 |
| NV | 26.78 |
| OK | 37.21 |
| PR | 23.62 |
| RI | 51.05 |
| SC | 55.75 |
| SD | 19.57 |
| VI | 8.15 |
| VT | 17.36 |
| WV | 17.22 |
| WY | 26.33 |
| **Total** | **$982.64** |

**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 2020, 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 2020 EPSCoR Annual Principal Investigator (PI) Meeting virtually during the week of May 18-22. The EPSCoR community and NSF program officers shared best 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 was a poster session that showcased jurisdictional gains in the areas of academic research competitiveness. The agenda also included open houses for PIs to meet with Program Officers from all NSF Directorates to discuss program-specific funding opportunities. There were approximately 350 participants, almost three times the usual attendance for the annual meeting.
- Encouraged proposal submissions from EPSCoR jurisdictions for mid-scale research infrastructure projects through targeted emails and a community webinar.
- Committed $4.5 million in co-funding support towards a new $18 million Materials Research Science and Engineering Center (MRSEC) led by the University of Delaware. The Center for Hybrid, Active, and Responsive Materials (CHARM) intends to harness the integrated power of computational design, innovative synthetic and manufacturing processes, and nanoscale characterization to unlock the substantial promise of complex synthetic materials.
- Provided $1.5 million in support of new awards under the Louis Stokes Alliances for Minority Participation (LSAMP) program. These projects, based in Arkansas, Kentucky, Puerto Rico, and South Carolina, will help diversify the STEM workforce by increasing the number of STEM baccalaureate and graduate degrees awarded to populations historically underrepresented in these disciplines.
- Continued to support physical research infrastructure nationwide via co-funding support for the Major Research Instrumentation (MRI) program. A total of $2.8 million of EPSCoR funds were committed in FY 2020 to support MRI projects nationwide.
- Granted $500,000 in late-year co-funding support for two Future Manufacturing Seed projects that will catalyze activities in this priority area at Iowa State University and Montana State University.
- Provided co-funding for 25 COVID-19 RAPID awards, using both CARES Act funds ($1.25 million) as well as around $1 million of EPSCoR regular appropriations. These awards enabled researchers in EPSCoR jurisdictions to pursue research on a variety of topics focused on understanding and

responding to the COVID-19 pandemic.

- Partnered with NSF INCLUDES to introduce the NSF INCLUDES First2 Network Alliance, which endeavors to improve the college enrollment rates and success of undergraduate STEM students, with emphasis on rural, first generation students by providing STEM research experiences, peer mentoring and student advocacy. It is particularly focused on students in EPSCoR states. This project is funded by NSF INCLUDES with co-funding from EPSCoR.
- Co-funded a collaborative research project with NSF INCLUDES: Cultivating Indigenous Research Communities for Leadership in Education and STEM (CIRCLES). The alliance is a partnership between six states in the western half of the U.S. (Idaho, Montana, New Mexico, North Dakota, South Dakota, and Wyoming) to address the under representation of American Indian and Alaska Native (AI/AN) students in STEM disciplines and workforce.
- Encouraged EPSCoR-supported faculty to participate in NSF committee and review panels across NSF (e.g., COVs, site visits, and merit review panels).
- Continued the RII Track-2: Focused EPSCoR Collaborations (RII Track-2 FEC) solicitation. RII Track-2 FEC builds interjurisdictional collaborative teams of EPSCoR investigators in scientific focus areas consistent with NSF priorities. In addition, these awards have a particular focus on the development of early career/junior faculty. In FY 2020, proposals were invited on the topic of "Harnessing big data to solve problems of national importance," aligned with NSF's Harnessing the Data Revolution Big Idea.
- Continued the RII Track-4, EPSCoR Research Fellows solicitation, which provides opportunities for early career researchers to further develop their individual research potential through extended collaborative visits to the Nation's premier private, governmental, or academic research centers. Proposals in all areas of science and engineering supported by NSF were invited.
- Convened two meetings with the EPSCoR Interagency Coordinating Committee (EICC) to share relevant program information and identify opportunities for coordination.
- Presented at EPSCoR PI meetings for Department of Defense and National Aeronautics and Space Administration (NASA) awardees. Attending and presenting at these meetings helps to increase NSF EPSCoR visibility and to capitalize on federal agency investments in EPSCoR, providing opportunities for interactions between NSF EPSCoR and cross-agency grantees.

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

Demographics of all reviewers who evaluated EPSCoR proposals or the program in FY 2020 are as follows: of the 184 reviewers, 22 percent were underrepresented minorities, 40 percent were female, 13 percent were from EPSCoR jurisdictions.

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

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

In FY 2020, there were 377 institutional collaborations within EPSCoR jurisdictions; 539 institutional collaborations between EPSCoR jurisdictions and other EPSCoR and non-EPSCoR jurisdictions; and 212 collaborations between institutions in EPSCoR jurisdictions and in foreign countries. These collaborative efforts highlight the vast network of institutional involvement among EPSCoR jurisdictions and their partners in RII projects.

Among the 220 awards co-funded by EPSCoR in FY 2020, 162 involved collaborative research between multiple institutions. Of those 162 collaborative awards, 90 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.

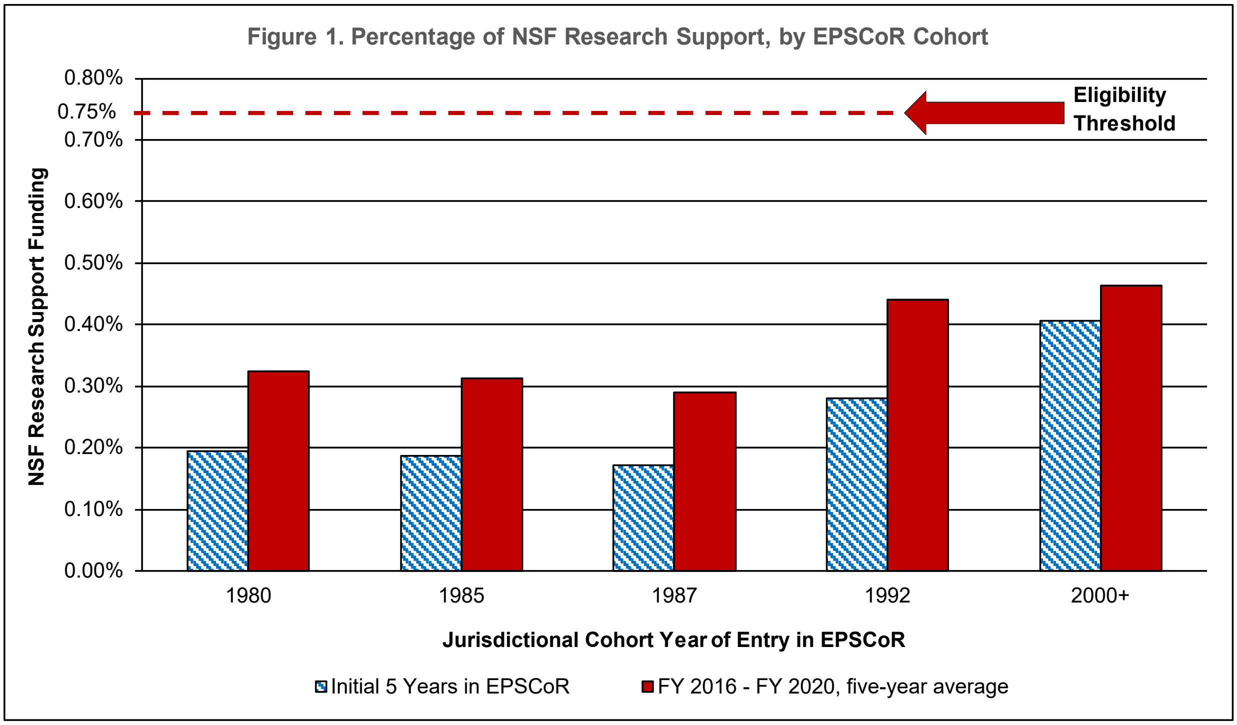
Given EPSCoR's aim to stimulate research that is fully competitive in NSF's disciplinary and multidisciplinary research programs, increases in the ability to capture NSF research funds serve as a proxy for gains in research competitiveness. In FY 2019, both Iowa and New Mexico, which had both been ineligible in FY 2018, fell back below the 0.75 percent eligibility threshold and were eligible to compete in FY 2020 RII competitions.

In FY 2019, EPSCoR re-examined its eligibility methodology and implemented changes to ensure that it is simple, transparent, fair, and stable. These changes incorporate stakeholder feedback and are supported by robust data analyses. The new eligibility methodology was announced at the EPSCoR National Conference in FY 2020 and is effective for the FY 2021 EPSCoR competitions.

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 2020.

Each cohort shows an increase in competitiveness over the periods of participation. For example, the 1980 cohort shows a 66 percent increase in NSF research funding over the past 40 years of EPSCoR activity. The 1985 cohort (Alabama, Kentucky, Nevada, North Dakota, Oklahoma, Puerto Rico, Vermont, and Wyoming) demonstrates a 68 percent increase during its 35 years of participation in EPSCoR. The 1987 cohort (Idaho, Louisiana, Mississippi, and South Dakota) shows a 69 percent increase over the past 33 years, while the 1992 cohort (Kansas and Nebraska) has a 57 percent increase in competitiveness over its 28 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 14 percent increase in research funding.

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



**Percentage of NSF Funding, by Jurisdiction and EPSCoR Cohort**

| | Initial 5 Years in EPSCoR* | Most Recent 5 Year Period (FY 2016-2020)** |
|---|---|---|
| 1980 Cohort | 0.19% | 0.32% |
| Arkansas | 0.10% | 0.25% |
| Maine | 0.27% | 0.26% |
| Montana | 0.13% | 0.37% |
| South Carolina | 0.41% | 0.58% |
| West Virginia | 0.07% | 0.16% |
| 1985 Cohort | 0.19% | 0.31% |
| Alabama | 0.33% | 0.72% |
| Kentucky | 0.22% | 0.38% |
| Nevada | 0.14% | 0.28% |
| North Dakota | 0.06% | 0.17% |
| Oklahoma | 0.30% | 0.40% |
| Puerto Rico | 0.15% | 0.20% |
| Vermont | 0.10% | 0.12% |
| Wyoming | 0.20% | 0.23% |
| 1987 Cohort | 0.17% | 0.29% |
| Idaho | 0.08% | 0.27% |
| Louisiana | 0.36% | 0.49% |
| Mississippi | 0.16% | 0.26% |
| South Dakota | 0.09% | 0.14% |
| 1992 Cohort | 0.28% | 0.44% |
| Kansas | 0.34% | 0.48% |
| Nebraska | 0.22% | 0.40% |
| 2000+ Cohort | 0.41% | 0.46% |
| Alaska | 0.55% | 0.65% |
| Delaware | 0.41% | 0.45% |
| Guam | 0.02% | 0.01% |
| Hawaii | 0.56% | 0.61% |
| Iowa*** | N/A | 0.72% |
| New Hampshire | 0.44% | 0.46% |
| New Mexico | 0.58% | 0.64% |
| Rhode Island | 0.70% | 0.61% |
| Virgin Islands | - | 0.03% |

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

**Percentages based on current eligibility guidelines.

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

The following tables demonstrates the quantifiable outputs of NSF EPSCoR's RII Track-1 and RII Track-2 programs 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. Please note, NSF EPSCoR began collecting and tracking data on participant involvement and project outcomes for RII Track-2 awards in FY 2015. Though it may appear that there are increasing totals of aggregate outputs and human resources over time, this is not the case.

**RII Track-1 Aggregate of EPSCoR Outputs**

| | FY 2016 | FY 2017 | FY 2018 | FY 2019 | FY 2020 | Total |
|---|---|---|---|---|---|---|
| Number of Active Awards* | 30 | 27 | 28 | 27 | 26 | |
| Publications | 1,336 | 985 | 1,044 | 732 | 638 | **4,735** |
| Grants Awarded | 675 | 455 | 505 | 451 | 326 | **2,412** |
| Value of Grants Awarded (Dollars in Millions) | $379.10 | $492.10 | $269.13 | $214.40 | $146.87 | **$1,501.60** |
| Patents Awarded | 14 | 17 | 8 | 17 | 10 | **66** |
| Patents pending | 34 | 29 | 15 | 44 | 38 | **160** |

*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.

**RII Track-2 Aggregate of EPSCoR Outputs**

| | FY 2016 | FY 2017 | FY 2018 | FY 2019 | FY 2020 | Total |
|---|---|---|---|---|---|---|
| Number of active awards* | 16 | 27 | 35 | 44 | 54 | |
| Partial Support Publications | 84 | 191 | 371 | 404 | 334 | **1,384** |
| Grants Awarded | 48 | 87 | 159 | 175 | 113 | **582** |
| Value of Grants Awarded (Dollars in Millions) | $29.30 | $70.76 | $129.22 | $213.67 | $119.23 | **$562.18** |
| Patents Awarded | - | 3 | 3 | 5 | 4 | **15** |
| Patents pending | 6 | 17 | 13 | 13 | 11 | **60** |

*The number of active RII Track-2 awards in a given fiscal year for which data was available. Outputs 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 the RII Track-2 Data Outcomes Portal, as part of their annual reporting requirement.

The tables below indicate EPSCoR's ongoing support of human resource development over the last five fiscal years in the RII Track-1 and RII Track-2 programs. The number of faculty and students involved in these projects signifies a 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 2016 | FY 2017 | FY 2018 | FY 2019 | FY 2020 | Total |
|---|---|---|---|---|---|---|
| Faculty Supported | 1,552 | 1,183 | 1,126 | 1,062 | 891 | **N/A*** |
| Post-Docs Supported | 200 | 156 | 179 | 165 | 170 | **N/A*** |
| Graduate Students Supported | 1,332 | 1,056 | 1,128 | 992 | 834 | **N/A*** |
| Undergraduates Supported | 1,861 | 1,220 | 1,187 | 1,168 | 870 | **N/A*** |
| New Faculty Hired | 84 | 54 | 27 | 40 | 35 | **240** |
| Graduate Degrees Conferred | 258 | 254 | 262 | 202 | 166 | **1,142** |
| Undergraduate Degrees Conferred | 404 | 634 | 357 | 297 | 183 | **1,875** |

* 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.

**RII Track-2 Human Resource Development**

| | FY 2016 | FY 2017 | FY 2018 | FY 2019 | FY 2020 | Total |
|---|---|---|---|---|---|---|
| Faculty Supported | 264 | 393 | 505 | 675 | 710 | **N/A*** |
| Post-Docs Supported | 64 | 100 | 138 | 167 | 172 | **N/A*** |
| Graduate Students Supported | 240 | 481 | 623 | 751 | 761 | **N/A*** |
| Undergraduates Supported | 185 | 404 | 628 | 781 | 732 | **N/A*** |
| Graduate Degrees Conferred | 11 | 25 | 43 | 69 | 39 | **187** |
| Undergraduate Degrees Conferred | 18 | 58 | 74 | 80 | 24 | **254** |

* 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 the RII Track-2 Data Outcomes Portal, as part of their annual reporting requirement.

The Committee of Visitors (COV) for NSF's EPSCoR met virtually in 2020 to review NSF EPSCoR for the period spanning FY 2015 to FY 2019. This review focused on (1) the integrity and efficiency of the program's processes and management practices, including quality and effectiveness of merit review processes, selection of reviewers, portfolio of awards, and management of the program; and (2) other aspects of the program structure and management, including EPSCoR's responsiveness to recommendations from previous COVs and other external evaluations. The report prepared by the COV reflects careful examination and insightful evaluation of the program. The COV found no significant programmatic gaps or needs for significant improvement. However, the Committee did provide four specific recommendations for how EPSCoR could further improve its performance, and EPSCoR is taking actions on those recommendations. The full COV report and EPSCoR's responses to the recommendations are available on the NSF COV website.[1]

In FY 2020, EPSCoR established a memorandum of understanding with NASA EPSCoR with the goal of providing a new NSF/NASA track within the existent RII Track-4: EPSCoR Research Fellows program. This new opportunity, RII Track-4 Fellows Advancing in Science and Technology (RII Track-4 FAST) is intended to allow non-tenured PIs to further develop their individual research potential through extended collaborative visits to NASA research facilities located at NASA Centers throughout the United States. This solicitation targets faculty at minority-serving institutions, women's colleges, and primarily undergraduate institutions. Through this opportunity, the RII Track-4: FAST Fellows will learn new techniques, initiate new collaborations or advance existing partnerships, benefit from access to unique equipment and facilities, and/or shift their research toward potentially transformative new directions in NASA-related research. The experiences gained through the fellowships are intended to have lasting impacts that will enhance the

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

Fellows' research trajectories and skills well beyond the award period. In turn, these benefits to the Fellows are also expected to improve the research capacity of their institutions and jurisdictions more broadly.

NSF EPSCoR is continuing to refine and implement a cohesive research competitiveness evaluation framework for the program. This evaluation, completed in 2020, helps to address the legislative objective of increasing the research competitiveness of jurisdictions receiving EPSCoR funding by (1) developing a flexible framework to explore, define, and measure research competitiveness in relation to each unique jurisdictional context, and (2) using evidence of jurisdictional progress toward research competitiveness over time for strategic program improvement. The evaluation builds on the findings and recommendations from the EPSCoR retrospective evaluation completed by the Science and Technology Policy Institute (STPI) in 2012. This activity has been underway since 2017. Key activities to date include descriptive and correlational analyses, development of a logic model for the research competitiveness framework, and refinement of a high-level theory of change model for the EPSCoR program. Further planned activities include:

- Developing briefing summaries for use by jurisdictional stakeholders to enhance their jurisdictional research competitiveness.
- Working with the Evaluation and Assessment Capability (EAC) section to address learning agenda questions in NSF's evidence building plan:
    - What are the most appropriate and useful implementation and performance indicators for monitoring progress of EPSCoR jurisdictions? How might a monitoring data system be developed leveraging easily accessible existing information and minimizing burden on jurisdictions?
    - How do EPSCoR funding strategies (infrastructure, co-funding, and outreach) contribute to increasing academic research competitiveness (ARC) across jurisdictions?
- Hosting a focused stakeholder meeting to (1) help identify potential impactful programmatic changes with respect to achieving the overall mission and increasing academic research competitiveness, (2) Produce a revised set of strategic priorities and an implementation plan that will leverage the current staffing capacity, and (3) Complement ongoing efforts with EAC and the ARC framework.

# NSF-WIDE INVESTMENTS

**Administration Priorities:**


**Climate:**

U.S. Global Change Research Program ........ NSF-Wide Investments - 3
Clean Energy Technology ........ NSF-Wide Investments - 6

**Economy:**

Advanced Manufacturing ........ NSF-Wide Investments - 9
Advanced Wireless ........ NSF-Wide Investments - 12
Artificial Intelligence ........ NSF-Wide Investments - 14
Biotechnology ........ NSF-Wide Investments - 18
National Nanotechnology Initiative ........ NSF-Wide Investments - 21
Networking and Information Technology R&D ........ NSF-Wide Investments - 27
Quantum Information Sciences ........ NSF-Wide Investments - 32

**NSF Research Big Ideas:**

Harnessing the Data Revolution for 21st-Century Science and Engineering ........ NSF-Wide Investments - 35
The Future of Work at the Human-Technology Frontier ........ NSF-Wide Investments - 37
Navigating the New Arctic ........ NSF-Wide Investments - 40
Understanding the Rules of Life ........ NSF-Wide Investments - 43
Windows on the Universe ........ NSF-Wide Investments - 45

**NSF Enabling Big Ideas:**

Growing Convergence Research ........ NSF-Wide Investments - 47
Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science ........ NSF-Wide Investments - 49
Mid-scale Research Infrastructure ........ NSF-Wide Investments - 52

**Ongoing Major FY 2021 Investments:**

NSF Innovation Corps ........ NSF-Wide Investments - 55
NSF Centers ........ NSF-Wide Investments - 57
Secure and Trustworthy Cyberspace ........ NSF-Wide Investments - 67
Selected Crosscutting Programs ........ NSF-Wide Investments - 70
Spectrum Innovation Initiative ........ NSF-Wide Investments - 73

**STEM Education and Workforce:**

Improving Undergraduate STEM Education ........ NSF-Wide Investments - 75
Major Investments in Science, Technology, Engineering, and Mathematics (STEM) Graduate Students and Graduate Education ........ NSF-Wide Investments - 77

## U.S. GLOBAL CHANGE RESEARCH PROGRAM (USGCRP)

**Total Funding for USGCRP**[1]

(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|
| BIO | $90.00 | $145.00 | $212.15 |
| GEO | 294.17 | 329.23 | 481.70 |
| MPS | - | 10.00 | 14.63 |
| SBE | 19.61 | 17.18 | 25.14 |
| OPP | 15.40 | 19.40 | 28.38 |
| **Total** | **$419.18** | **$520.81** | **$762.00** |

[1] Funding displayed may have overlap with other topics and programs.

### Overview

NSF investments in climate and global change research span climate science, climate impacts, climate adaptation and mitigation strategies and climate solutions. As part of NSF's holistic approach to addressing global change, NSF's USGCRP investments are complemented by investments in research to advance America's clean energy future—from fundamental physics, chemistry, and materials science to large-scale systems engineering and cyber-infrastructure. 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 approaches to studying Earth system processes and the consequences of change, including how humans respond to changing environments and the impacts on ecosystems and the essential services they provide.

NSF has been investing in the fundamental research at the heart of global change issues for several decades. Long-term, continuous, and consistent observational records are essential for testing hypotheses quantitatively and are thus a cornerstone of global change research. NSF supports a variety of research observing networks that complement, and are dependent on, the climate monitoring systems maintained by its federal partners. The results of NSF investments have helped communities address challenges associated with mitigation, adaptation, and other responses to a changing and variable environment.

NSF funding for USGCRP in the FY 2022 Request is $762.0 million. NSF's investments will continue to support research that contributes to the USGCRP Goal Areas to (1) advance scientific knowledge of the integrated natural and human components of the Earth system and (2) inform decisions by providing the scientific basis to inform and enable timely decisions on adaptation and mitigation. In FY 2022, 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 further seek greater integration of social-science research, methodologies, and insights into understanding and supporting responses to global change, improving computing capacity, and maintaining needed observational capabilities over time.

Past investments have helped inform the National Climate Assessment and several other technical reports mandated by the Global Climate Research Act of 1990. Investments have also aided U.S. communities to develop mitigation and adaptation strategies to address both challenges and opportunities derived from a changing environment. The fundamental knowledge gained through NSF disciplinary and cross-cutting programs focusing on the coupled natural-human system are critical in developing effective solutions to these challenges and opportunities.

**FY 2022 Investments by Program Component Area (PCA)**

Advance Scientific Knowledge of The Integrated Natural and Human Components of the Earth System

*Earth System Understanding*: NSF participates in the Earth System Understanding PCA to improve our knowledge of the Earth's past and present climate variability and change through activities to document and understand long-term climate cycles across the globe, as well as to better understand the natural variability of climate and the processes responsible for global changes using a range of paleoclimate and instrumental data and modeling approaches. NSF also supports activities to improve our understanding of the frequency and intensity of extreme climate events, particularly wet and dry extremes of the water cycle, their causes, and how those may be manifested in the future. Upgrading and expanding critical environmental observing systems are vital to these efforts.

NSF also supports Earth System Understanding through activities spanning a broad range of disciplines and topics that seek to better understand the physical, geological, chemical, biological, and human components of the Earth system and their interactions. Examples of major foci include fundamental research on all aspects of the carbon cycle, the water cycle, atmospheric composition and greenhouse gas processes, marine and terrestrial ecosystems, and ocean and atmospheric circulations that both drive and respond to climate and global change. Human drivers of change include urbanization, population growth, and economic and technological development over a range of temporal scales and NSF has a strong commitment to fostering new interdisciplinary research approaches that allow exploration of the interdependencies across these areas.

*Integrated Observations*: NSF contributes to the Integrated Observations PCA through its advanced capabilities to observe the physical, chemical, biological, and human components of the Earth system over multiple space and time scales. Facilities such as the Academic Research Fleet and the National Ecological Observatory Network assist the Nation in gaining a fundamental scientific understanding of the Earth as well as monitor important variations and trends that allow the research community to examine major feedback processes between the climate and natural and human systems.

*Integrated Modeling*: NSF will continue to devote significant resources to advancing climate modeling capabilities from global and centennial to regional and decadal scales. Since there is increasingly deep interplay among observations and modeling at multiple spatial and temporal scales, a high priority will be given to developing more complete representations—models of coupled interactive atmospheric chemistry, terrestrial and marine ecosystems, biogeochemical cycling, and middle atmospheric processes. In addition, NSF is encouraging the development of ecosystem and water models at regional scales, as well as models that integrate human system components such as risk, vulnerability, and decision-making.

Inform Decisions: Provide the Scientific Basis to Inform and Enable Timely Decisions on Adaptation and Mitigation

*Inform Adaptation and Mitigation*: A key focus of the USGCRP is developing better means of assessing and responding to the impacts of global change as well as the vulnerability and resilience of both human and natural systems to those changes, particularly in highly sensitive regions such as the Arctic. In addition to supporting research that will inform adaptation decisions, NSF will also support fundamental research regarding the science of adaptation, defined as the adjustment in natural or human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects. This research ranges from developing the theoretical framework for evaluating adaptation options (and avoiding unintended consequences of adaptation choices) to risk assessment and decision-making. NSF will continue interdisciplinary research (including human factors) in water sustainability, resiliency, biodiversity, ocean acidification, and vulnerable areas, particularly in the rapidly changing Arctic.

**USGCRP Funding by Program Component Area**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|
| Integrated Observations | $148.12 | $157.89 | $179.87 |
| Multidisciplinary Earth and Human System Understanding | 232.26 | 309.25 | 504.37 |
| Integrated Modeling | 25.65 | 40.47 | 63.06 |
| Science of Adaptation and Science to Inform Adaptation Decisions | 13.15 | 13.20 | 14.70 |
| **Total** | **$419.18** | **$520.81** | **$762.00** |

## CLEAN ENERGY TECHNOLOGY

**Clean Energy Technology Funding**[1]
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|
| BIO | $18.00 | $45.00 | $59.28 |
| CISE | 18.50 | 23.50 | 31.12 |
| ENG | 113.54 | 123.03 | 178.57 |
| MPS | 92.62 | 90.00 | 118.56 |
| TIP[2] | 48.47 | 52.47 | 52.47 |
| **Total** | **$291.13** | **$334.00** | **$440.00** |

[1] Funding displayed may have overlap with other topics and programs.

[2] FY 2020 and FY 2021 funding for TIP is shown for comparability across fiscal years.

### Overview

NSF's clean-energy investments create new understanding and innovations for increasing energy efficiency, enhancing sustainability and resilience, and reducing and mitigating climate change. NSF-supported areas of fundamental research and education include the production, conversion, storage, and distribution of diverse electricity and fuel sources; the science and engineering of energy materials, energy use, and energy efficiency, including novel data and computational approaches to advance these frontiers; and the ways that people think about and use energy. Clean-energy investments also create vital research and education partnerships in response to national and international developments in sustainability science.

NSF's investments in clean energy span longstanding programs as well as focused new solicitations. For example, NSF has made long-term investments in multidisciplinary clean-energy research centers through the Centers for Chemical Innovation, Expeditions in Computing, Engineering Research Centers, and Industry-University Cooperative Research Centers programs. To serve researchers and students across the country, NSF has established research infrastructure, such as the Grid-Connected Testing Infrastructure for Networked Control of Distributed Energy Resources (DERConnect).

NSF's future investments will continue to advance the fundamental science and engineering underlying clean-energy technologies and infrastructure, including:

- Generation of renewable and alternative energy sources for electricity (solar, wind, geothermal, harvesting, and ocean waves, currents and tides), fuels (chemical, biomass, and biofuels), and energy-conversion technologies (e.g., advanced fuel cells);
- Manufacture, storage, distribution, and management of renewable and alternative energy sources and systems, including smart grids, efficient power transmission and conversion systems, grid-scale energy storage, and carbon capture;
- Energy materials, use and efficiency, including research on low-power and green electronics, energy-intelligent and sustainable computing and communication systems (including wireless systems), eco-manufacturing of diverse products (including materials and chemicals), and the remediation and reduction of legacy pollution; and
- Societal and environmental aspects of clean energy, such as research on sustainable energy systems that preserve essential ecosystems and environmental services, promote positive and equitable social and economic outcomes, and prepare individuals and communities to responsibly adopt them.

The above advances require related investments in novel data and computational approaches; for example, new computational modeling techniques to simulate renewable and alternative energy sources, transmission, and storage; novel materials supporting energy efficiency and sustainability; sustainable computing and communication; and societal aspects.

NSF also will support multidisciplinary research in areas such as affordable green housing, and sustainable systems for clean water, clean transit, and other infrastructure. Added NSF investments will help build the future clean-energy workforce and advance the translation and deployment of innovative technologies.

**Goals**

1. *Foundational Research:* Support foundational research in science and engineering that will fuel innovations in clean-energy supply, distribution, and use.
2. *Clean-Energy Infrastructure:* Development of energy generation and distribution infrastructure, as well as the associated computing and communications infrastructure, necessary to generate fundamental knowledge and development of accompanying clean-energy technology.
3. *Workforce Development*: Attract, educate, train and reskill/upskill workers, from K-12 to college and industry, for the clean-energy workforce of the future.

**FY 2022 Investments**

Foundational Research
NSF will invest in fundamental clean-energy research related to increasing the efficiency of generation, conversion, storage, and distribution of electricity and fuel; clean-energy sources that are renewable or alternatives to traditional fossil fuels; energy materials, use, and efficiency; and related infrastructure and systems, such as sustainable transit and vehicle technologies that improve engine efficiency and fuel economy, building efficiency, more effective transmission of electricity, decarbonized manufacturing, ecosystem services, and interconnected natural, human-built, and social systems.

Clean-Energy Infrastructure
Investments in research infrastructure enabling sustainable energy generation and distribution will allow for the creation of more energy-efficient energy systems, from generation to distribution, for all uses spanning industry, transportation, and buildings. 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. This investment will support full-stack hardware and software research to consider increased energy sustainability and reduced e-waste through innovations in recyclable materials and manufacturing; and develop more energy-efficient technologies for communications systems. Importantly, computing research infrastructure will also support data and computation affording insights into energy-efficient and sustainable approaches and techniques more generally.

Workforce Development
To prepare the clean energy workforce, NSF invests in the Advanced Technological Education, Faculty Early Career Development, Grant Opportunities for Academic Liaison with Industry, 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) and NSF Innovation Corp (I-Corps™) provides students with industrial and entrepreneurship experience.

Transition to Practice

NSF speeds translation of fundamental discoveries in clean and renewable energy into technologies and systems through its Centers for Chemical Innovation, Expeditions in Computing, Engineering Research Centers, Industry-University Cooperative Research Centers, and Partnerships for Innovation programs, as well as through Transition-to-Practice, Innovation Transitions, and Small Business Innovation Research and Small Business Technology Transfer investments. In addition, NSF coordinates with other agencies such as the Department of Energy and the Department of Defense to transition fundamental research further towards application.

## ADVANCED MANUFACTURING

**Advanced Manufacturing Funding**[1]

(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|
| BIO | $8.48 | $7.16 | $17.16 |
| CISE | 42.37 | 42.22 | 42.22 |
| EHR | 1.45 | 2.00 | 2.00 |
| ENG | 127.99 | 117.37 | 174.37 |
| MPS | 160.62 | 123.03 | 123.13 |
| SBE | 0.75 | 0.50 | 3.50 |
| TIP[2] | 26.58 | 24.63 | 54.63 |
| OISE | 0.50 | 0.50 | 0.50 |
| IA | 5.06 | 1.00 | 1.00 |
| **Total** | **$373.80** | **$318.41** | **$418.51** |

[1] Funding displayed may have overlap with other topics and programs.

[2] FY 2020 and 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, from medicine to information technology to transportation. Breakthroughs in manufacturing spur the economy by increasing productivity, enabling new products, opening new industries, and creating well-paying jobs. 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.

NSF invests in advanced manufacturing to increase future U.S. prosperity, as well as the Nation's competitiveness, security, and quality of life. NSF support will:

- Advance competitiveness through groundbreaking discoveries that lead to manufacturing innovations;
- Secure the supply chain by growing and maximizing the use of U.S. resources (including raw materials, knowledge, and workforce);
- Grow the manufacturing workforce by broadening pathways and fostering communities; and
- Rapidly translate discoveries into useful products and create jobs through collaborations between researchers, entrepreneurs, and industry.

Since its founding in 1950, NSF has pushed the frontiers of manufacturing, sparking breakthroughs from nanomaterials and computer-aided design to 3D printing and blockchain, as well as tools for real-time, in situ feedback and sensing.

Today, NSF invests 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 environmental impact than plastics; distributed and smart manufacturing systems; safe, productive, and collaborative worker-technology interactions; and many other areas related to advanced manufacturing. NSF invests in communities and experiential programs to grow and nurture a STEM-enabled manufacturing workforce.

NSF also invests in industry partnerships and entrepreneurship to speed manufacturing innovations to the marketplace.

NSF's advanced manufacturing research intersects, builds upon, and contributes to related investments in biotechnology, synthetic biology, sustainability, artificial intelligence, robotics, sensing technologies, the Internet of Things, data science, and computational modeling. Similarly, NSF's investments in the FW-HTF, HDR, and URoL Big Ideas are bolstered by advanced manufacturing research.

In FY 2020, NSF launched the Future Manufacturing effort to enable leadership in the new manufacturing sectors of bio-manufacturing, cyber-manufacturing, and eco-manufacturing by creating knowledge that enables a new generation of manufacturing industries.

**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 workers, from K-12 to college and industry, for the manufacturing workforce of the future.
4. *Transition to Practice*: Leverage industry partnerships to advance research and transition research results to practice.

**FY 2022 Investments**

NSF investments accelerate advances in manufacturing with emphasis on multidisciplinary research that fundamentally alters and transforms manufacturing capabilities, methods, and practices. NSF investments will make producing next-generation products and services more efficient and sustainable and will lead to advantages such as less time-to-market, new performance attributes, cost savings, energy savings, and reduced environmental impacts.

<u>Advanced Manufacturing Research</u>
Continued investments in advanced manufacturing include fundamental research on highly-connected, adaptable, resilient, safe, and secure cyber-physical systems, i.e., engineered systems that are built from, and depend upon, seamless integration of computation and physical components. Investments also support activities that develop new methods, processes, analyses, tools, or equipment for new or existing manufacturing products, supply-chain components, or chemicals and materials, including replacements for mainstay materials such as plastics that cause environmental harm. NSF plans to support advanced manufacturing 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.

Workforce Development

To prepare the advanced manufacturing workforce, NSF invests in the Advanced Technological Education, Faculty Early Career Development, Grant Opportunities for Academic Liaison with Industry, Research Experiences for Undergraduates Sites and Supplements, and Research Experiences for Teachers Sites and Supplements programs, as well as in manufacturing engineering education in research projects. NSF support for Non-Academic Research Internships for Graduate Students (INTERN) and NSF Innovation Corps (I-Corps™) provides individuals with industrial and entrepreneurial experiences. These programs help equip workers with the knowledge and skills needed for well-paying careers in high-technology industries.

Transition to Practice

NSF speeds translation of fundamental discoveries in advanced manufacturing into products and processes through its Engineering Research Centers, Industry-University Cooperative Research Centers, and Partnerships for Innovation programs, as well as through the NSF Small Business Innovation Research and Small Business Technology Transfer programs. In addition, NSF coordinates with other agencies and participates in the Manufacturing USA Institutes, particularly by connecting them to universities and community colleges.

## ADVANCED WIRELESS RESEARCH

**Advanced Wireless Research Funding**[1]

(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|
| CISE | $88.76 | $88.76 | $93.26 |
| ENG | 24.36 | 23.45 | 25.80 |
| MPS | 17.00 | 17.00 | 17.00 |
| TIP[2] | 0.60 | 0.55 | 30.55 |
| **Total** | **$130.72** | **$129.76** | **$166.61** |

[1] Funding displayed may have overlap with other topics and programs.

[2] FY 2020 and 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, including the Federal Communications Commission and National Institute of Standards and Technology, and collaborates extensively with 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; mobile edge computing; distributed machine learning, and inferences across mobile devices; and fine-grained and real-time dynamic spectrum allocation and sharing. The 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.

In addition, by deepening public-private partnerships such as those enabling the 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 commercial products and services.

### 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.
3. *Education and Workforce Development:* Catalyze academic, industry, and community leaders to work together to nurture the next generation of the wireless networking workforce, including researchers, engineers, technicians, and practitioners, as well as to increase public awareness of advanced wireless.

### FY 2022 Investments

<u>Fundamental Advanced Wireless Research</u>

- Through core 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. The core research programs are also investing in technologies beyond 5G systems, looking at more efficient uses of spectrum bands, higher-order spectrum, sensing using wireless communications, novel codes for highly-efficient device-to-device communications and self-healing of secure wireless networks. These investments will continue to support the foundations of U.S. leadership in advanced wireless R&D.
- In FY 2022, in partnership with other federal agencies and the private sector, NSF will support the Resilient and Intelligent Next-Generation Systems (RINGS) program, laying the groundwork for next-generation wireless connections that will enable faster service, networks more resilient to natural disasters and service interruptions, and broader access for people across the U.S.
- In FY 2022, 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, improving access to underserved areas, distributed machine learning, intelligent transportation systems, wireless-enabled smart manufacturing, and beyond-5G wireless components and systems.
- In FY 2022, NSF will continue to support research in artificial intelligence and machine learning techniques that address the diverse, stringent quality-of-service requirements of future wireless applications such as learning from a continuous stream of new data in real time and enabling efficient operations with limited radio and network resources. Research integrating AI, machine learning, and advanced wireless will enable self-organizing, self-managing, scalable wireless networks that can support large numbers of people, devices and diverse applications.
- 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).

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; and Research Triangle, NC, 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. A fourth platform in this program, expected to start in FY 2021, will support robust and rigorous experimentation on diverse ways to deliver affordable, high-speed broadband to the wide-spread rural regions of the country. FY 2022 will be the first 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 2022, 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 2022, 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.

## ARTIFICIAL INTELLIGENCE (AI)

**Artificial Intelligence Funding[1]**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|
| BIO | $13.78 | $20.00 | $20.00 |
| CISE | 329.80 | 329.80 | 349.80 |
| EHR | 6.76 | 30.00 | 50.00 |
| ENG | 91.47 | 87.15 | 95.80 |
| GEO | 5.00 | 5.00 | 5.00 |
| MPS | 71.67 | 62.48 | 71.67 |
| SBE | 16.04 | 14.59 | 19.59 |
| TIP[2] | 67.66 | 61.55 | 121.55 |
| IA | 2.97 | 1.00 | 1.00 |
| **Total** | **$605.15** | **$611.57** | **$734.41** |

[1] Funding displayed may have overlap with other topics and programs.

[2] FY 2020 and 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 e-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, biomedicine, 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 2022, NSF will increase 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, 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, 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.

**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 2022 Investments**

Fundamental AI Research

- In FY 2022, NSF will emphasize AI research, education and workforce development, and infrastructure activities at minority-serving institutions (MSIs). Specifically, NSF will broaden participation by intentionally focusing on the development of AI research capacity at MSIs, the involvement of populations long underrepresented in AI in research activities, and the formation of partnerships spanning multiple minority-serving institutions and other institution types.
- In FY 2022, NSF and Amazon will continue to jointly support research on fairness in AI at the level of $7.60 million, with the goal of contributing to trustworthy AI systems that are readily accepted and deployed to tackle the grand challenges facing society. Specific topics of interest include, but are not limited to, transparency, explainability, accountability, potential adverse biases and effects, mitigation strategies, validation of fairness, and advances in broad accessibility and utility of AI systems.
- In FY 2022, NSF will continue support ($69.11 million) 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, NSF funded five institutes in the areas of foundations of ML; trustworthy AI; AI-augmented learning; AI for accelerating molecular synthesis and manufacturing; and AI for discovery in physics. Each institute is expected to receive up to $20.0 million over five years. NSF also partnered with the U.S. Department of Agriculture's National Institute of Food and Agriculture (USDA NIFA) to establish two other institutes in FY 2020 for AI-driven innovation in agriculture and food systems, to be fully supported by USDA NIFA. In FY 2020, NSF and USDA NIFA also funded several teams to lay plans for future institutes. In FY 2021, NSF plans to establish seven more institutes in the areas of human-AI interaction and collaboration; AI for advances in optimization; AI and advanced cyberinfrastructure; AI and computer and network systems; AI in dynamic systems; AI to advance biology; and AI-augmented learning. USDA NIFA anticipates fully funding an additional AI Institute in agriculture and food systems.
- In FY 2022, 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 2022, 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 2022, 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 2021, the foundational CISE and ENG robotics programs were merged into a new jointly-administered program, Foundational Research in Robotics (Robotics) to support robotics research that combines advances in engineering with advances in computer science. This program, along with the multi-agency National Robotics Initiative 3.0 program that funds larger-scale integrative projects, will continue in FY 2022, investing 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 plans to establish an additional five-year National AI Research Institute in this area. NSF is particularly interested in adult learning in the context of technologies and work environments of the future, including the spectrum of AI fields.
- 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 as well as the CyberCorps®: Scholarship for Service (SFS) program.
- In FY 2022, GRFP will continue to encourage applications from students who want to conduct AI-related research. The NSF GRFP recognizes and supports outstanding graduate students in NSF-supported STEM disciplines who are pursuing research-based master’s and doctoral degrees at accredited 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 2022, NRT will continue to include a special focus on traineeships in AI and other emerging industries.
- In FY 2022, 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]

<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.

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

- In FY 2020, the NSF Convergence Accelerator (CA) emphasized AI through themes relating to HDR and FW-HTF; this focus is continuing in FY 2021 and FY 2022. 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 2022, Phase I awardees will compete for larger-scale Phase II funding.
- For FY 2022, 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 will build upon a FY 2021 workshop that is scheduled to explore 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 rules and regulations.

## BIOTECHNOLOGY

**Biotechnology Funding**[1]

(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|
| BIO | $110.00 | $110.00 | $130.00 |
| CISE | 9.04 | 6.00 | 6.00 |
| EHR | 16.07 | 9.00 | 9.00 |
| ENG | 92.76 | 90.94 | 101.50 |
| GEO | 8.00 | 10.00 | 10.00 |
| MPS | 73.48 | 51.20 | 52.20 |
| SBE | 1.93 | 1.50 | 1.50 |
| OPP | 2.11 | 1.60 | 2.00 |
| IA | 1.95 | 1.00 | 1.00 |
| TIP[2] | 9.27 | 9.06 | 69.06 |
| **Total** | **$324.61** | **$290.30** | **$382.26** |

[1] Funding displayed may have overlap with other topics and programs.

[2] FY 2020 and FY 2021 funding for TIP is shown for comparability across fiscal years.

### Overview

Advances in genomics, proteomics, metabolomics, glycomics, cell biology, synthetic biology, chemical biology and computational methods 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. Biotechnology comprises the data, tools, research infrastructure, workforce capacity, and innovation that enable the discovery, utilization, and alteration of living organisms, their constituent components, and their biologically related processes. NSF investments to advance biotechnology serve to accelerate scientific discovery and to enable the harnessing of biological systems to create goods and services that contribute to agriculture, health, security, manufacturing, and environmental sectors of the United States.

NSF has long supported the fundamental biological research that catalyzed the development of modern biotechnology. Current investments include research and infrastructure in genomics, proteomics, synthetic biology, chemical biology, bioinformatics, computational biology, data analytics, structural biology, biophysics, tissue engineering, and development of new types of biomaterials, bio-probes, bio-based microelectronics, and biomanufacturing. In addition, NSF invests in educational programs that ensure a trained workforce to support U.S. capabilities in biotechnology, together with research on the ethical, legal, economic, and environmental consequences of synthetic biology and other biotechnologies, contributing to public understanding of product adoption and socially responsible use. These investments enhance biotechnology beyond the current state of the art and enable innovation that addresses climate change, food security, clean energy, and other important societal problems and ensures the development of a robust supply chain of biologically-derived materials that can increase U.S. resilience to global interruptions. Biotechnology promises to enable new modes of information storage, retrieval, and processing, as well as computation; foods and feedstocks that will provide raw materials for new bioindustries; new organs and organisms engineered to solve problems, from sensing of emerging infectious agents to development of self-healing materials for sustainable infrastructure; and other unimagined products inspired by life forms. Biotechnology advances will enable new predictive tools and platform technologies that empower the U.S.

to rapidly react to new and emerging biological threats, addressing economic and societal challenges and also responding with solutions for unanticipated challenges.

The importance of investment in synthetic biology and other biotechnologies was first highlighted by the Office of Science and Technology Policy (OSTP) in 2012[1] and was underscored recently as a key driver of the U.S. bioeconomy by the National Academies of Sciences, Engineering and Medicine in 2020.[2] In response to recommendations from the Government Accountability Office[3] and in collaboration with OSTP, NSF plays a lead role in coordinating interagency activities to promote synthetic biology and to develop next-generation tools to advance biotechnology. New investments at NSF in FY 2021 that catalyze biotechnology innovations include programs in Designing Synthetic Cells Beyond the Bounds of Evolution; Sentinel Cells for Surveillance and Response to Emergent Infectious Diseases; and Molecular Foundations for Biotechnology. The National Artificial Intelligence (AI) Research Institutes program includes a focus that effectively integrate biotechnology innovation and AI. These new investments complement existing programs in research, infrastructure, workforce development and translation that advance biotechnology and the bioeconomy.

**Goals**

1. *Foundational Research:* Support foundational 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 Development:* Deliver proof-of-concept processes, devices, applications, tools, and systems that exploit emerging discoveries and drive advances in biotechnology for scientific and societal 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 2022 Investments**

<u>Foundational Research</u>
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 will serve to leverage biodiversity to motivate bio-inspired design and stimulate use-inspired solutions, including through the NSF Big Idea, Understanding the Rules of Life that supports relevant convergent research. Social-science researchers will engage to address issues of risk tolerance, public acceptance, and ethical considerations associated with new biotechnology discoveries and innovations.

<u>Computing and Physical Infrastructure</u>
NSF will continue to invest in bioinformatics and computational biology to solve the computational and data-science challenges inherent in biotechnology research. NSF will leverage investments in data analytics and computation, artificial intelligence and machine learning, and physical infrastructure–including distributed networks of biofoundries and regional mid-scale facilities–to support growth of U.S. biotechnology innovation.

[1] www.obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/national_bioeconomy_blueprint_april_2012.pdf
[2] www.nationalacademies.org/our-work/safeguarding-the-bioeconomy-finding-strategies-for-understanding-evaluating-and-protecting-the-bioeconomy-while-sustaining-innovation-and-growth
[3] www.gao.gov/products/gao-18-656

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 and biomanufacturing technologies to address many of today's challenges.

Education and Workforce Development
To prepare a diverse biotechnological workforce, NSF will invest in students at multiple levels, through programs such as the International Genetically Engineering Machine competition open to high school students, the Advanced Technological Education program at two-year institutions, and sites and supplements for Research Experiences for Undergraduates as well as 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, including in those outside academia.

## NATIONAL NANOTECHNOLOGY INITIATIVE (NNI)

**Total Funding for NNI**[1]
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|
| BIO | $42.50 | $39.95 | $39.95 |
| CISE | 14.36 | 14.05 | 14.05 |
| EHR | 13.74 | 2.50 | 2.50 |
| ENG | 221.52 | 190.95 | 219.99 |
| MPS | 330.70 | 183.50 | 183.50 |
| SBE | 0.40 | 0.40 | 0.40 |
| TIP[2] | 11.67 | 10.05 | 10.05 |
| OISE | 0.10 | 0.10 | 0.10 |
| **Total** | **$634.99** | **$441.50** | **$470.54** |

[1] Funding displayed may have overlap with other topics and programs.

[2] FY 2020 and 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; 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 intelligent (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 for reducing and mitigating climate change including research on capture, sequestration, and reuse of $CO_2$. A new research thrust has emerged in 2021 and will expand in 2022 that is focused on understanding the structure and nanoscale behavior of the novel SARs-COV2 virus and supporting foundational concepts for vaccine developments. NSF contributes to the NNI goals and five Program Component Areas (PCAs) outlined in the current draft of 2021 NNI Strategic Plan.[1] Funding by PCA is shown at the end of this discussion.

### FY 2022 NNI Funding

NSF supports nanoscale science and engineering throughout all the research and education directorates as a means to advance discovery, invention, and innovation and to integrate various fields of research. NNI enables increased interdisciplinarity in areas of atomic and molecular research in about 6,000 active awards with full or partial contents on nanoscale science and engineering (NSE). Approximately 10,000 students and teachers will be educated and trained in NSE in FY 2022.

Overall, NSF's total NNI funding in the FY 2022 Request is $470.54 million. Several new directions planned for FY 2022 include research connected to COVID-19, mitigation of global change, advanced

[1] www.nano.gov

manufacturing, AI systems including using artificial intelligence for creating smart materials and systems, the bioeconomy, sustainability, and quantum information science and engineering including 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 industries 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 2022, NSF support will increasingly focus on convergence research and education activities in confluence with other priority areas. NSF will strengthen partnerships of the Nanoscale Engineering Research Centers (NERCs) with small businesses in the areas of nanomanufacturing and commercialization and will support an industrial internship program (INTERN) in emerging areas. NSF will continue its contributions to translational innovation programs, including Grant Opportunities for Academic Liaison with Industry (GOALI); Industry-University Cooperative Research Centers (IUCRC); the NSF Innovation Corps (I-Corps™) program; and the Partnerships for Innovation (PFI). The NSF Small Business Innovation Research (SBIR) program has an ongoing nanotechnology topic with subtopics for nanomaterials, nanomanufacturing, nanoelectronics and active nanostructures, nanotechnology for biological and medical applications, and instrumentation for nanotechnology.

Various assessments and reports have assisted with informing plans for NNI going into the future. NSF sponsored an international study on long-term research entitled *Nanotechnology Research Directions for Societal Needs in 2020,*[3] which provides a vision of the field to 2020 and beyond. With the National Institutes of Health (NIH), National Aeronautics and Space Administration (NASA), Environmental Protection Agency (EPA), Office of Naval Research (ONR), and the U.S. Department of Agriculture (USDA), NSF co-sponsored the study entitled *Converging Knowledge, Technology, and Society*[4] evaluating the convergence of nanotechnology with other emerging areas by 2030. Other reports address aspects of fundamental research for energy-efficient sensing and computing, data storage, real-time communication ecosystem, multi-level and scalable security, a new fabrication paradigm, and insight computing.[5,6,7]

National Academies (NASEM) 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 have emerged from these coordination efforts, including the recent formation of the NQI."[8,9]

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.

<u>PCA 1: Foundational Research ($306.30 million)</u>
The first PCA will be funded at a total of $306.30 million. 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

[2] 2020 Nanoscale Science and Engineering Grantees Conference: www.nsf.gov/nano and www.nseresearch.org/2020/
[3] NSF/WTEC 2010, Springer, available on www.nsf.gov/nano and www.wtec.org/nano2/
[4] NSF/WTEC 2013, Springer, available on www.nsf.gov/nano and www.wtec.org/NBIC2-Report/
[5] www.nsf.gov/nano
[6] 1.usa.gov/1Fg90Dw; www.src.org/nri/energy-efficient-computing-workshop.pdf
[7] www.semiconductors.org/issues/research/research/
[8] www.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

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; 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 global 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 ERCs, Science and Technology Centers (STCs), Centers for Chemical Innovation (CCIs) and other center program 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 and Chemistry (Chemistry of Living Processes). NSF will expand its efforts in 2022 in nanobiotechnology associated with synthetic biology and synthetic cells through a new solicitation, Designing Synthetic Cells Beyond the Bounds of Evolution, a new Dear Colleague Letter, Sentinel Cells for Surveillance and Response to Emergent Infectious Diseases, and through core programs in BIO/MCB and ENG/CBET.

This PCA includes foundational research supporting the NSI (Nanotechnology Signature Initiative) on: Sustainable Nanomanufacturing, Nanoelectronics including semiconductors, Nanotechnology for Sensors and Sensors for Nanotechnology, the Water Sustainability through Nanotechnology NSI (to continue until end of FY 2021), and the Nanotechnology-Inspired Grand Challenge for Future Computing.

- *Sustainable Nanomanufacturing:* Support foundational concepts for new nanomanufacturing methods at confluence with digitization, biotechnology, AI, and cognitive sciences. A new activity in Designing Synthetic Cells beyond the bounds of Evolution, that will have enabled novel nanomanufacturing applications and Reproducible Cells and Organoids via Directed-Differentiation Encoding (RECODE) that 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 increase coordinated research on quantum-related research and the FW-HTF.
- *Nanotechnology for Sensors and Sensors for Nanotechnology*: Research is aimed at 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 ENG’s Division of Chemical, Bioengineering, Environmental, and Transport Systems (CBET) will 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” (ICA). Two examples of active centers are 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.

Even though the Water NSI has graduated in 2020, research continues to take advantage of the unique properties of engineered nanomaterials and systems to increase water availability; improve the efficiency of water delivery; and enable next-generation water monitoring systems.

PCA 2: Nanotechnology-Enabled Applications, Devices, and Systems ($96.97 million)
The FY 2022 Request includes $96.97 million for research that applies the principles of nanoscale science and engineering to create novel devices and systems. This includes the incorporation of nanoscale or nanostructured materials and the processes required to achieve improved performance or new functionality, including metrology, scale up, manufacturing technology, and nanoscale reference materials and standards. Core programs in the ENG, MPS, and CISE directorates support development of new principles, design methods, and constructive solutions for nanomaterials and nanodevices. A special focus is on smart, autonomous nanoscale-based devices and systems. The 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. A new Future Manufacturing Solicitation was announced in 2020 and is continuing into 2021 and 2022.[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. The Real Time Machine Learning (RTML) 3-year NSF/CISE-ENG program[12] started in FY 2019 in collaboration with the Defense Advanced Research Projects Agency (DARPA) ($10.0 million from NSF and $10.0 million from DARPA) and will continue through 2022.

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

PCA 3: Research Infrastructure and Instrumentation ($25.68 million)
The FY 2022 Request includes $25.68 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.

While student support to perform research is captured in other categories, dedicated educational and workforce efforts, ranging from curriculum development to advanced training, are included here as resources supporting the human infrastructure of the NNI. NSF has funded an award of about $16 million per year for the NNCI sites for FY 2015–2024, with a national coordination office added in FY 2016. Five-year renewal of NNCI has been completed in FY 2020. Other STCs, ERCs, CCIs, 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), two NERCs, 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. NSF will increase coordinated research on its Mid-scale Research Infrastructure priority area. The Major Research Instrumentation (MRI) Program[13] 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.

[11] www.nsf.gov/funding/pgm_summ.jsp?pims_id=505737
[12] www.nsf.gov/pubs/2019/nsf19566/nsf19566.htm
[13] www.nsf.gov/funding/pgm_summ.jsp?pims_id=5260

PCA 4: Education and Workforce Development ($20.50 million)
In FY 2022, NSF will fund education and workforce development activities in all areas of nanoscale science and engineering at $20.50 million. Typical activities supported by the Directorate for Education and Human Resources, the Directorate for Engineering's Division of Engineering Education and Centers, and other divisions are fellowships, single investigator awards and centers. Illustrations of projects at the undergraduate and graduate levels are "Supporting micro and nano technicians through hybrid teaching methods" and "Nano-makerspace to make and explore in the world of the small". Super Small Science or hosting a nationwide communication competition with the Boston Museum of Science for undergraduate and graduate students.[14]

PCA 5: Environment, Health, and Safety ($21.09 million)
In FY 2022, NSF will continue its funding for the Environment, Health, and Safety (EHS), ELSI, and diversity/equity/inclusion/access, as well as nanotechnology research integrity, safety, and reproducibility at $21.09 million, representing roughly 4.5 percent of its overall NNI budget. Requests for research are primarily directed at understanding nano-bio phenomena and processes, as well as environment, health, and safety implications and methods for reducing the respective risks of nanotechnology development. ENG's nano EHS program has changed to *Nanoscale Interactions*. MPS supports the CCI: Center for Sustainable Nanotechnology. NSF continues to sponsor the Center for Sustainable Nanotechnology at University of Wisconsin.[15] Support of diversity and equity by inclusion and access will be advanced for minorities, women, and persons with handicaps 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).
- Collaboration with NIST, Air Force Office of Scientific Research (AFOSR), and DARPA will continue in 2020 with a focus on "Brain-like Computing".
- 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.
- NSF collaboration with NIOSH, NIH's National Cancer Institute (NCI), NIST, Pacific Northwest National Laboratory, and DOD, and many public- and private-sector partners with the Nanoinformatics Consortium: UCLA, the National Nanomanufacturing Network, nanoHUB, RTI International, MIT, and the NanoBusiness Commercialization Association.
- OECD (Working Group on Bio, Nano, and other Converging Technologies) and other international forum activities—participation by NSF in collaboration with State Department and other NNI agencies.

[14] www.mos.org/quantum-matters-competition
[15] www.susnano.wisc.edu/

**NNI Funding by Program Component Area**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|
| Foundational Research | $396.89 | $293.30 | $306.30 |
| Nanotechnology-Enabled Applications, Devices, and Systems | 115.13 | 83.97 | 96.97 |
| Research Infrastructure and Instrumentation | 43.02 | 25.68 | 25.68 |
| Education and Workforce Development | 31.74 | 19.00 | 20.50 |
| Responsible Development | 48.21 | 19.55 | 21.09 |
| **Total** | **$634.99** | **$441.50** | **$470.54** |

**NETWORKING AND INFORMATION TECHNOLOGY RESEARCH AND DEVELOPMENT (NITRD)**

**NITRD Funding**

(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|
| BIO | $79.00 | $79.00 | $79.00 |
| CISE | 996.40 | 1,005.49 | 1,116.06 |
| EHR | 17.00 | 17.59 | 27.59 |
| ENG | 134.75 | 154.98 | 179.26 |
| GEO | 27.00 | 27.00 | 27.00 |
| MPS | 228.42 | 191.62 | 200.81 |
| SBE | 31.86 | 29.44 | 37.44 |
| IA | 2.97 | 1.00 | 1.00 |
| TIP[1] | 73.76 | 76.11 | 398.11 |
| **Total** | **$1,591.16** | **$1,582.23** | **$2,066.27** |

[1] FY 2020 and 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.

NSF's FY 2022 Budget Request includes support for NITRD at a level of $2,066.27 million. NITRD activities represent approximately 20.3 percent of NSF's FY 2022 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. No major changes were made to the PCAs for FY 2022.

## FY 2022 NSF Investments by Program Component Area (PCA)

The following information focuses on FY 2022 NSF investments, both new and continuing, by PCA.

PCA 1: AI R&D ($518.34 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 critical gap in America's AI research and education portfolio by accelerating AI innovations, training AI researchers and innovators, and transitioning outcomes across a range of sectors.

Through this PCA, NSF will emphasize AI research, education and workforce development, and infrastructure activities at minority-serving institutions (MSIs). Specifically, NSF will broaden participation by intentionally focusing on the development of AI research capacity at MSIs, the involvement of populations long underrepresented in AI in research activities, and the formation of partnerships spanning multiple MSIs and other institution types.

Additionally, this PCA will include CISE investments in foundational research in AI, including knowledge representation and reasoning, multi-agent systems, planning, machine and deep learning, computer vision, and human language technologies; ENG investments in advanced manufacturing and the mind, machine, and motor nexus; SBE investments to integrate machine learning advances with learning mechanisms developed in cognitive science, develop new statistical inferences and algorithms for the analysis of large data sets, and understand the legal and ethical implications of AI; BIO investments in ML, natural language processing, computer vision, and genetic algorithms applied to solve problems such as genome sequence alignment, prediction of protein structure, reconstruction of evolutionary relationships, extraction of quantitative information from multi-media data sources, and the bioeconomy more generally; 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 a set of innovation accelerators that bring together multiple disciplines, institutions, and sectors, and are focused on specific societal grand challenges, such as artificial intelligence, biotechnology, and climate science.

<u>PCA 2: Computing-Enabled Human Interaction, Communications, Augmentation (CHuman) ($110.08 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>PCA 3: Computing-Enabled Networked Physical Systems (CNPS) ($142.22 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 Smart and Connected Communities (S&CC) program, which will support interdisciplinary, integrative research that deeply engages local residents, stakeholders, and governments to improve understanding, design, and long-term sustainability of intelligent infrastructure for American communities, thereby leading to enhanced quality of life for residents. CNPS will additionally include BIO 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>PCA 4: Cyber Security and Privacy (CSP) ($127.76 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. CSP will additionally include CISE, ENG, and SBE investments in research to analyze the flow of information and to mitigate the impacts of false or misleading information in online and other computer-mediated systems; topics will include detecting, mitigating, and countering threats to accurate information, and understanding the interactions of people with information systems.

PCA 5: Education and Workforce (EdW) ($125.15 million)
EdW will include CISE and EHR investments in IUSE: Computing in Undergraduate Education, to support efforts to re-envision the role of computing in interdisciplinary collaboration within American institutions of higher education and in Computer Science for All: Researcher-Practitioner Partnerships, to support the R&D needed to bring computer science and computational thinking to all schools at the preK-12 levels. It will also include CISE and EHR investments supporting workforce development in cybersecurity, enabling a growing pipeline of researchers, educators, and practitioners, and allowing all Americans to understand the security and privacy of the digital systems on which their lives increasingly depend. EdW will additionally include BIO investments in advancing America's ability to incorporate and apply biological knowledge to economic development and other issues of societal importance. 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. NSF holds as a core value that the inclusion of all people in STEM is vital to the nation's health, security, and prosperity.

PCA 6: Enabling-R&D for High-Capability Computing Systems (EHCS) ($205.19 million)
EHCS will include investments in strategic computing activities initiated under the recently updated National Strategic Computing Initiative,[1] which will support research advances in new computing technologies, architectures, and platforms for the future, as well as the development of advanced computing systems and services, including maximizing the benefits of these systems and services through deep integration with science and engineering research. EHCS will also include CISE and MPS investments that advance computational algorithms and data analytics to address scientific and engineering opportunities presented by data emerging from digital and observational data sources. It will also include CISE and MPS investments in fundamental research on innovative materials integration and novel phenomena associated with quantum information science, optical computing, and neuro-computing.

PCA 7: High Capability Computing Infrastructure and Applications (HCIA) ($205.42 million)
HCIA will include CISE investments on the development of software and algorithms for advanced computing systems and services. For example, HCIA will include CISE and MPS investments in new computational methods, algorithms, scientific databases, and other computational tools to support researchers in the mathematical and physical sciences as well as engineering through programs such as Computational and Data-Enabled Science and Engineering; CISE and GEO investments in EarthCube, a 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.

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

PCA 8: Intelligent Robotics and Autonomous Systems (IRAS) ($65.28 million)
IRAS will include CISE and ENG investments in robotics and autonomous systems that exhibit significant levels of both computational capability and physical complexity, including research related to the design, application, and use of robotics to augment human function, promote human-robot interaction, and increase robot autonomy. As part of the next generation of robotics, collaborative robotics (co-robot) systems, i.e., robotic systems that work beside or cooperatively with people, will be characterized by their flexibility and resourcefulness. They will use a variety of modeling or reasoning approaches, along with real-time, real-world data, demonstrating a level of intelligence and adaptability seen in humans and animals. As development of this next generation of co-robotics proceeds in application domains such as advanced manufacturing, emergency response, and health care, complete confidence in these systems becomes increasingly important.

PCA 9: Large-Scale Data Management and Analysis (LSDMA) ($254.68 million)
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 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.

PCA 10: Large-Scale Networking (LSN) ($216.48 million)
LSN will include CISE investments in the NSF-wide S&CC program as well as on a set of Platforms for Advanced Wireless Research that enable research on topics ranging from dynamic spectrum sharing to measurement and monitoring, thus advancing the next generation of high-performance, robust wireless networks. LSN will also include NSF investments in the Spectrum Innovation Initiative supporting foundational spectrum research in increased spectrum efficiencies, flexibility, and adaptability and leading to the creation of advanced wireless technologies and systems beyond 5G. Additionally, LSN will include NSF investments, in collaboration with other federal agencies and the private sector, on Resilient and Intelligent Next-Generation (NextG) Systems (RINGS), transforming emerging NextG wireless and mobile communication, networking, sensing, and computing.

PCA 11: Software Productivity, Sustainability and Quality (SPSQ) ($95.67 million)
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 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.

**NITRD Funding by Program Component Area**

(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|
| Artificial Intelligence R&D | $315.62 | $357.81 | $518.34 |
| Computing-Enabled Human Interaction, Communications, Augmentation | 98.58 | 96.01 | 110.08 |
| Computing-Enabled Networked Physical Systems | 77.06 | 74.68 | 142.22 |
| Cyber Security and Privacy | 108.21 | 107.23 | 127.76 |
| Education and Workforce | 98.80 | 98.49 | 125.15 |
| Enabling-R&D for High-Capability Computing Systems | 181.29 | 176.01 | 205.19 |
| High Capability Computing Infrastructure and Applications | 208.80 | 190.59 | 205.42 |
| Intelligent Robotics and Autonomous Systems | 47.11 | 46.09 | 65.28 |
| Large-Scale Data Management and Analysis | 206.01 | 186.16 | 254.68 |
| Large Scale Networking | 179.27 | 178.31 | 216.48 |
| Software Productivity, Sustainability and Quality | 70.41 | 70.85 | 95.67 |
| **Total** | **$1,591.16** | **$1,582.23** | **$2,066.27** |

## QUANTUM INFORMATION SCIENCE (QIS)

**QIS Funding**[1]
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|
| BIO | $3.28 | $3.28 | $3.28 |
| CISE | 17.59 | 19.28 | 24.28 |
| EHR | 3.98 | 4.00 | 4.00 |
| ENG | 23.83 | 27.89 | 32.89 |
| MPS | 125.46 | 136.13 | 146.13 |
| SBE | 0.37 | - | - |
| TIP[2] | 15.47 | 18.42 | 48.42 |
| OISE | 2.21 | 1.00 | 1.00 |
| IA | 2.33 | - | - |
| **Total** | **$194.52** | **$210.00** | **$260.00** |

[1] Funding displayed may have overlap with other topics and programs.

[2] FY 2020 and 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 2022, NSF will continue the investment in multidisciplinary centers for quantum research and education at the level of $50.0 million, including Quantum Leap Challenge Institutes funded in FY 2020 and FY 2021, continue the investment in REU and NRT awards related to QIS begun in FY 2021 and will add targeted activities designed to grow the participation of investigators and students from institutions currently under-represented in QIS.

**Goals**

1. Answer key science and engineering questions in order to facilitate the fundamental understanding of quantum phenomena and systems, as well as the translation of that fundamental knowledge into technological applications.
2. Deliver proof-of-concept devices, applications, tools, or systems with a demonstrable quantum advantage over their classical counterparts that will form the basis of a revolutionary 21st-century technology.
3. Empower the full spectrum of talent to which NSF has access to build the capacity necessary to achieve goals (1) and (2) and generate the quantum-literate workforce that will implement the results of these breakthroughs.

**FY 2022 Investments by Program Component Area (PCA)**

PCA 1: Foundational Quantum Information Science Advances (QADV) ($62.62 million)
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.

PCA 2: Quantum Computing (QCOMP) ($67.05 million)
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.

PCA 3: Quantum Networks and Communications (QNET) ($45.85 million)
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.

PCA 4: Quantum Sensing and Metrology (QSENS) ($43.07 million)
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.

PCA 5: Future Applications (QTAPP) ($24.90 million)
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.

PCA 6: Risk Mitigation (QTRM) ($11.48 million)
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.

PCA 7: Supporting Technology (QTSUP) ($5.03 million)
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.

**QIS Funding by Program Component Area**

(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|
| Foundational Quantum Information Science Advances | $47.65 | $49.04 | $62.62 |
| Quantum Computing | 51.18 | 56.95 | 67.05 |
| Quantum Networks and Communications | 32.71 | 35.87 | 45.85 |
| Quantum Sensing and Metrology | 37.09 | 40.42 | 43.07 |
| Future Applications | 13.03 | 14.28 | 24.90 |
| Risk Mitigation | 7.09 | 9.39 | 11.48 |
| Supporting Technology | 5.77 | 4.05 | 5.03 |
| **Total** | **$194.52** | **$210.00** | **$260.00** |

## HARNESSING THE DATA REVOLUTION FOR 21ST-CENTURY SCIENCE AND ENGINEERING (HDR)

**HDR Funding**[1]
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|
| **Stewardship Activities (CISE)** | **$30.00** | **$30.00** | **$30.00** |
| **Foundational Activities** | **$183.64** | **$143.86** | **$149.61** |
| BIO | 10.00 | 7.41 | 7.41 |
| CISE | 59.60 | 59.60 | 59.60 |
| EHR | 17.40 | 2.50 | 2.50 |
| ENG | 13.90 | 12.75 | 13.50 |
| GEO | 5.60 | 5.60 | 5.60 |
| MPS | 26.89 | 22.00 | 22.00 |
| SBE | 9.76 | 7.25 | 7.25 |
| TIP[2] | 18.02 | 16.75 | 21.75 |
| IA | 22.47 | 10.00 | 10.00 |
| **Total** | **$213.64** | **$173.86** | **$179.61** |

[1] Funding dissplayed may have overlap with other topics and programs.

[2] FY 2020 and FY 2021 funding for TIP is shown for comparability across fiscal years.

### Overview

HDR enables novel modes of data-driven discovery that will allow new fundamental questions at the frontiers of science and engineering to be asked and answered. It supports fundamental research in data science and engineering; development of a cohesive research data infrastructure needed to power the data revolution; and development of a diverse 21st-century data-skilled workforce. HDR will enable mutually beneficial interactions between data scientists and communities, thus supporting transfer of data science techniques to local communities while providing insights and practical experience to participating data scientists and data science students in real-world settings.

### Goals

The HDR vision is realized through a set of interrelated goals:

1. *The Foundations of Data Science:* Develop the theoretical foundations of data science and its applications through integrated research and training activities.
2. *Algorithms and Systems for Data Science:* Support the development and use of novel algorithms and systems to support data science as well as data-driven science and engineering.
3. *Data-Intensive Science and Engineering:* Stimulate advances in multiple areas of science and engineering through data-intensive research that harnesses diverse data sources and applies new methodologies, technologies, and infrastructure for data generation, collection, modeling, and analysis.
4. *Data Cyberinfrastructure:* Foster the creation of robust, trustworthy, and performant data cyberinfrastructure and services that can support data-driven research and discovery in multiple areas of science and engineering.
5. *Education and Workforce Development:* Develop coordinated activities in data science education, researcher training, and knowledge transfer to prepare a diverse workforce to harness the power of data at the local, state, national, and international levels in the service of science and society.

**FY 2022 Investments**

Stewardship Investments

*Foundations of Data Science ($6.0 million)*
HDR will continue to support research in data science and data-enabled science and engineering primarily through the Transdisciplinary Research In Principles Of Data Science (HDR TRIPODS) program. HDR TRIPODS brings together the electrical engineering, mathematics, statistics, and theoretical computer science communities. Through integrated research and training activities, these communities will collaborate to develop the theoretical foundations of data science. In FY 2019, Phase I HDR TRIPODS awards were made to 15 projects, supporting the development of small, collaborative "data science institutes." In FY 2022, Phase II awards will enable a subset of the most successful of these smaller institutes to expand in scope and impact into larger-sized data science institutes.

*Data-Intensive Research in Science and Engineering ($21.0 million)*
HDR will support Institutes for Data-Intensive Research in Science and Engineering (DIRSE). The DIRSE institutes will complement the HDR TRIPODS institutes described above and will harness diverse data sources and develop new algorithms, methodologies, systems, technologies, and infrastructure for data management and analysis to address critical science and engineering problems. In FY 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 that go beyond traditional disciplinary and organizational boundaries. These projects paved the way for the DIRSE convergence institutes solicitation in FY 2021, which will fund DIRSE institutes in FY 2021 and their continued operation in FY 2022. By creating a portfolio of interrelated DIRSE institutes, NSF aims to accelerate discovery and innovation in multiple areas of data-intensive science and engineering.

*Education and Workforce Development ($3.0 million)*
HDR will continue to support data science education and workforce development through the Data Science Corps (DSC) program. NSF funded 22 DSC awards spanning nine projects in FY 2019. These awards are helping to build the data science workforce by engaging data science students and professionals in real-world data science projects that will help bridge the data-to-knowledge gap in organizations and communities at local, state, national, and international levels. The DSC program continues to provide data science students and professionals with practical experiences, new skills, and teaching opportunities across multiple learning environments; promote data literacy, including the ethical use of data; and provide basic training in data science to the existing workforce across communities throughout the United States. A second round of DSC awards is planned for FY 2021 and these awards will continue in FY 2022. A focal point of the education and workforce development portfolio within HDR is to enable the participation of diverse backgrounds and perspectives in the future workforce.

Foundational Activities

These activities comprise ongoing investments by NSF directorates and offices in programs that laid the initial foundations for the HDR Big Idea. These activities will continue to be supported and aligned with the overall HDR strategic goals. These foundational activities are currently managed by NSF's directorates and offices and will continue to remain within the directorates and offices with respect to their funding and management.

## THE FUTURE OF WORK AT THE HUMAN-TECHNOLOGY FRONTIER (FW-HTF)

**FW-HTF Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|
| **Stewardship Activities (ENG)** | **$30.00** | **$30.00** | **$30.00** |
| **Foundational Activities** | **$137.63** | **$132.30** | **$143.30** |
| CISE | 83.72 | 81.00 | 81.00 |
| EHR | 10.54 | 10.30 | 10.30 |
| ENG | 14.00 | 12.00 | 18.00 |
| SBE | 11.86 | 11.50 | 11.50 |
| TIP[1] | 17.51 | 17.50 | 22.50 |
| **Total** | **$167.63** | **$162.30** | **$173.30** |

[1] FY 2020 and FY 2021 funding for TIP is shown for comparability across fiscal years.

### Overview

The FW-HTF Big Idea supports convergence research to develop new human-technology partnerships leading to increased worker productivity and innovation. This research will prepare the workforce for human-technology partnerships by combining the benefits of new technologies, such as green technologies, AI, and virtual environments, with increased understanding of value-based social, economic, and educational opportunities and impacts.

The landscape of jobs and work is changing with unprecedented speed, driven by the development of new technologies that have moved from the factory floor to an expanding array of knowledge and service occupations. The pace of change has been accelerated by new modes of work during the COVID-19 pandemic. While there are promising benefits to the nation in the creation of new industries through increased productivity, enhanced innovation, and sustained U.S. global leadership, there are also risks for workers as technology may substantially alter, and in some cases, eliminate jobs, and more generally as recovery from the pandemic may not be equitable.

The FW-HTF Big Idea started in FY 2018 and responds to the challenges and opportunities associated with the changing landscape of jobs and work. FW-HTF is supporting new convergent research to understand and advance the human-technology partnership, design new technologies to augment human performance, illuminate the emerging socio-technological landscape, and foster lifelong and pervasive learning with technology. Investments in research and development at the human-technology frontier are enabling technologies that amplify and augment human capabilities to learn, adapt, make decisions, and make sense of complex patterns and situations in the work context. FW-HTF funds interdisciplinary research at the intersection of computer and information science, engineering, the social, behavioral, and economic sciences, and education.

Increasing human capabilities is the result of the incorporation of advances in AI, data science, and closely related technologies for sensing, actuation, coordination, communication, and control with humans in the loop; and depends upon understanding human communication, thinking, and action. These advances will underpin the creation of systems that are adaptive, human-centered, and capable of collaborative interactions with humans. By evaluating the aspects of work that humans do most effectively and the complementary aspects of work that emerging technologies can improve, FW-HTF research will support advances that improve work quality, increase worker productivity, and make work more meaningful. Additionally, these research investments will enable an understanding of how these changes will affect society and what new approaches to education and training will be required for the new jobs created in in emerging industries as well as the adaptation of existing jobs to the new economic landscape. Moreover, NSF investments will explore the ethical and societal implications of emerging technologies, such as AI, and advance the pursuit and adoption of responsible and ethical approaches to using data and furthering data science for work and workers. Likewise, NSF will invest in research on jobs and industries that use environmentally sustainable technologies. These research investments will accelerate progress and enable the Nation's workforce and economy to lead in a future that is increasingly and unavoidably driven by technology and knowledge. The FW-HTF Big Idea will engage research communities to understand how constantly evolving technologies are changing the world of work and the lives of workers, and how people can in turn shape those technologies to human benefit whether it is through the development and creation of new well-paying jobs for the new industries or the training and reskilling of the workforce.

**Goals**

The FW-HTF Big Idea seeks to maximize benefits and minimize risks of the changing technological environment, to foster support of the workforce in increasing productivity and innovation, and to lay the foundation for new knowledge and developments in science and engineering that is informed through ongoing discussions with partners in industry, non-profits, and other government entities, and expressed in the following four strategic goals:

1. *Understand and Build the Human-Technology Partnership*: Research on the future of work will identify how new technologies affect jobs, the workplace, organizations, and society, as well as how these technologies can be designed and built to increase national productivity, job opportunities, and worker satisfaction, while enabling worker creativity.
2. *Design and Develop New Technologies to Augment Human Performance*: By augmenting the physical and mental capabilities of humans, new technology can open new job opportunities. For example, using AI-based, real-time, adaptive physical and cognitive prosthetics can increase job opportunities for those with disabilities and enhance capabilities in all individuals in manufacturing settings.
3. *Illuminate the Emerging Socio-Technological Landscape*: As technology becomes increasingly capable, companies and organizations will be transformed, as will society, the economy, and relevant laws. Research will clarify the benefits and risks of such change and help inform ethical and value-based design of new technology and software in support of a diverse workforce.
4. *Foster Lifelong and Pervasive Learning Through Technology*: Design of training, including novel AI-based approaches, will support both the training and reskilling that the workforce needs to work with new technology and to enable workers to migrate from old jobs to new ones. Adaptive, pervasive training systems will depend on new research in cyberlearning systems, as well as the integration of training into task performance and management.

**FY 2022 Investments**

Stewardship Activities

FY 2022 activities will leverage the investments made through the FY 2018 to FY 2021 FW-HTF solicitations[1] to catalyze interdisciplinary research that understands and builds the human-technology partnership and new job opportunities, designs new technologies to augment human performance and sustain economic competitiveness, illuminates benefits and risk in the emerging socio-technological landscape in ways that benefit quality of life, and fosters lifelong and pervasive learning that drives an innovative and equitable workforce. The FW-HTF strategic goals will be advanced by continued support for standard research grants, workshops, and grants for planning and coordination. In addition, these core

[1] www.nsf.gov/funding/pgm_summ.jsp?pims_id=505620

activities will leverage new transition-to-scale funding opportunities released in FY 2021; these awards will create a new and extended knowledge base for deployment in future workplaces and contexts, entailing more extensive data collection at different levels, either in different sectors or various geographic locations at regional, national, or international levels. A series of FY 2021 stakeholder workshops bringing together leaders from industry, labor, non-profits, and universities will set the foundation for future integrative activities such as collaboration hubs, center-scale institutes, and larger-scale grants in FY 2022 and beyond. During FY 2022, FW-HTF will also develop synergies with other NSF Big Ideas and NSF-wide efforts, such as GCR, HDR, Mid-scale RI, NSF INCLUDES, and NRT.

Foundational Activities

Foundational activities comprise continued investments by participating directorates and offices in existing (ongoing) NSF programs that have laid the foundation for the FW-HTF Big Idea. Also, FW-HTF tracks within the Convergence Accelerator will continue to be aligned with FW-HTF goals. These foundational programs are currently managed by NSF's directorates and offices and will remain within the directorates and offices with respect to their funding and management.

## NAVIGATING THE NEW ARCTIC (NNA)

**NNA Funding**[1]
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|
| **Stewardship Activities (GEO)** | **$27.20** | **$30.00** | **$30.00** |
| **Foundational Activities** | **$4.25** | **$6.20** | **$7.20** |
| BIO | 1.50 | 1.50 | 2.00 |
| EHR | 1.37 | 1.20 | 1.20 |
| ENG | - | 2.00 | 2.00 |
| SBE | 0.24 | 0.50 | 0.50 |
| OISE | 0.30 | 1.00 | 0.50 |
| OPP | 0.84 | - | 1.00 |
| **Total** | **$31.46** | **$36.20** | **$37.20** |

[1] Funding displayed may have overlap with other topics and programs.

### Overview

Arctic temperatures are rising faster than nearly everywhere else on Earth. The rapid and wide-scale changes occurring in response to this warming portend new opportunities and risks to natural systems; social and cultural systems; economic, political, and legal systems; and infrastructure and other engineered systems of the Arctic and across the globe. Gaps in scientific observations and the prevalence of interdependent social, natural, and built systems in the Arctic make it challenging to predict the region's future. Understanding and adapting to a changing Arctic will require creative new directions for Arctic-specific research and education, as well as leveraging of science, engineering, and technology advances from outside the Arctic.

NNA, one of NSF's Big Ideas, embodies the Foundation's forward-looking response to these profound challenges. NNA seeks innovations in Arctic observational networks and fundamental convergence research across engineering and the social, natural, environmental, and computing and information sciences, that address the interactions or connections between natural and built environments and social systems and how these connections inform our understanding of Arctic change and its local and global effects. NNA empowers new research communities; diversifies the next generation of Arctic researchers; integrates the co-production of knowledge with local and Indigenous people and organizations; and engages with interdisciplinary, interagency, and international partners to further pan-Arctic and Arctic-global perspectives.

With respect to observational research, NNA addresses key gaps in the existing array of observation, communication, computation, and data systems. Strong coupling of observation, communication, computation, and data, including the theoretical foundations underlying these, is supported to ensure progress. NNA leverages resources with the Mid-scale RI and HDR Big Ideas as appropriate.

NNA also strongly encourages projects with components that advance STEM education; that deepen public understanding of the changing Arctic to benefit both citizens and policy makers; and that advance workforce-development objectives. NNA builds on NSF's STEM investments and the NSF INCLUDES Big Idea to encourage innovative and appropriately evaluated education and public engagement efforts that leverage exciting NNA science and inspire diverse participation in STEM.

By drawing upon expertise from across the agency, NNA investments accelerate research needed to inform decisions regarding the national security, economic development, and societal well-being of the U.S. as an Arctic nation and enable resilient, sustainable Arctic communities as a result. NSF plans to invest in NNA at least through FY 2023.

**Goals**

1. Improved understanding of Arctic change and its local and global effects that capitalizes on: innovative and optimized observation infrastructure; advances in understanding of fundamental processes; and new approaches to modeling interactions among the natural environment, built environment, and social systems.
2. New and enhanced research communities that are diverse, integrative, and well-positioned to carry out productive research on the interactions or connections between Arctic natural and built environments and social systems and how these connections inform our understanding of Arctic change and its local and global effects.
3. Research outcomes that inform U.S. national security, economic development, and societal well-being and enable resilient, sustainable Arctic communities.
4. Enhanced efforts in formal and informal education that focus on the multi-scale impacts of Arctic change on natural and built environments and social systems and broadly disseminate research outcomes.

In FY 2017, NSF issued a Dear Colleague letter (DCL) on the Growing Convergence Research Big Idea (NSF 17-065)[1] to explore convergence approaches within four of the research-focused NSF Big Ideas, including NNA. This DCL requested proposals for Research Coordination Networks (RCNs), workshops, and activities to enhance Arctic observational systems. In FY 2018, NSF issued a DCL on Stimulating Research Related to NNA (NSF 18-048),[2] requesting research proposals building on the FY 2017 awards, as well as proposals for workshops and RCNs. NSF awarded 25 new projects under these two DCLs and related opportunities with budgets ranging from $50,000 to $1.50 million lasting up to 60 months. In FY 2019, NSF issued a solicitation for NNA (NSF 19-511)[3] and made 13 awards to support research projects, and eight awards to support planning projects that will develop convergence research teams, with budgets ranging from $13,000 to $3.0 million lasting up to 60 months. In FY 2020, NSF issued a solicitation for NNA (NSF 20-514)[4] and made six awards to support research projects and 11 awards to support planning projects; NSF also leveraged NNA funds to support four additional research projects that serve NNA goals but are managed by other programs at NSF. In FY 2021, NSF awarded a multi-year cooperative agreement for the Navigating the New Arctic Community Office to support coordination among NNA projects, build and strengthen relationships between NNA researchers and Arctic residents, and coordinate effective knowledge dissemination, education, and outreach related to NNA and convergence research in the Arctic.

**FY 2022 Investments**

NSF's NNA activities in FY 2022 will focus on enabling advances in priority areas, which will be developed by building on outcomes from FY 2017 to FY 2021 activities. In FY 2021, NSF issued a revised NNA solicitation (NSF 21-524)[5] that focuses on convergent social/built/natural-environment systems science; advances in observation, communication, computation, and data systems; and community-coordination

[1] www.nsf.gov/pubs/2017/nsf17065/nsf17065.jsp
[2] www.nsf.gov/pubs/2018/nsf18048/nsf18048.jsp
[3] www.nsf.gov/pubs/2019/nsf19511/nsf19511.htm
[4] www.nsf.gov/pubs/2020/nsf20514/nsf20514.htm
[5] www.nsf.gov/pubs/2021/nsf21524/nsf21524.htm

activities. This revised solicitation also adds a new opportunity to support larger-scale projects that will provide the foundation for the cultivation of long-term ideas, collaborations, research, synthesis, and investment in future convergence science in and regarding Arctic change. In FY 2022, NSF will continue support for NNA, and expects to issue another solicitation.

NSF will continue to coordinate and leverage NNA-related activities with external stakeholders, including:
- other federal agencies through the Interagency Arctic Research Policy Committee (IARPC) chaired by the NSF Director;
- local residents and Indigenous peoples through state and local governance structures of Alaska; and
- international partners through forums such as the biannual International Arctic Science Ministerial.

The portfolio of FY 2022 NNA activities will support the goals listed above.

## UNDERSTANDING THE RULES OF LIFE: PREDICTING PHENOTYPE (UROL)

**UROL Funding**[1]
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|
| **Stewardship Activities (BIO)** | **$29.95** | **$30.00** | **$30.00** |
| **Foundational Activities** | **$87.47** | **$53.50** | **$83.50** |
| BIO | 20.77 | 20.00 | 40.00 |
| CISE | 9.04 | 6.00 | 6.00 |
| EHR | 10.38 | - | - |
| ENG | 8.40 | 3.00 | 3.00 |
| GEO | 4.00 | 4.00 | 4.00 |
| MPS | 30.11 | 16.00 | 16.00 |
| SBE | 4.77 | 4.50 | 4.50 |
| TIP | - | - | 10.00 |
| **Total** | **$117.42** | **$83.50** | **$113.50** |

[1] Funding displayed may have overlap with other topics and programs

### Overview

The URoL NSF Big Idea aims to create a new paradigm at the convergence of science, engineering, and technology that will elucidate theoretical frameworks, or rules, to enable prediction of the diversity of solutions that biological systems use to support life processes. Advances in understanding life at the fundamental level of the genome will enable re-engineering of cells, organisms, and ecosystems, and innovative biochemicals and biomaterials that sustain a vibrant bioeconomy and strengthen society. URoL also aims to train the next generation of researchers capable of using those rules and theories not only to predict the behavior of living systems, but to design them to benefit humankind.

Associated with URoL, NSF funds convergent research that addresses questions from the molecular to the ecosystem scale, and across biological diversity. These include foundational research on genetic variation and phenotypic emergence; ethical and social implications and societal acceptance of new biotechnologies, such as tools for genetic engineering and synthetic biology; ecological forecasting; and data science and AI to predict phenotype. In FY 2022, NSF will fund new awards in mathematical and physical sciences that utilize theory and novel experimental tools to address fundamental problems in biological systems and build capacity in a convergent research domain; new programs in synthetic biology that enable creation of novel chemicals, materials, and engineered systems; and infrastructure that further enables URoL research.

In FY 2018, NSF released several Dear Colleague Letters to announce URoL opportunities for catalytic activities. In FY 2019, NSF invested a total of $36.0 million in 38 new awards in response to two Foundation-wide URoL solicitations: *URoL: Building a Synthetic Cell: An Ideas Lab Activity*[1] and *URoL: Epigenetics*.[2] In FY 2020, NSF funded 14 awards in response to the revised *URoL: Epigenetics*[3] solicitation, and 26 awards in response to a new NSF-wide solicitation, *URoL: Microbiome Theory and Mechanisms (MTM)*[4]; these totaled $40.0 million, In FY 2021, a second competition is being conducted for a revised *MTM* solicitation, and a new solicitation was issued: *URoL*: *Emergent Networks (URoL:EN)*.

[1] www.nsf.gov/funding/pgm_summ.jsp?pims_id=505600
[2] www.nsf.gov/funding/pgm_summ.jsp?pims_id=505582
[3] www.nsf.gov/pubs/2020/nsf20512/nsf20512.htm
[4] www.nsf.gov/funding/pgm_summ.jsp?pims_id=505694

**Goals**

1. To support a convergence of science, engineering, and technology in discovery of rules governing the emergence of robust, resilient, and adaptable phenotypes at three levels of biological organization, across the tree of life: (1) cells and cell systems; (2) multi-cellular organisms and their co-dependent microbial associations; and (3) complex networks of organisms and species involving social and ecological dynamics. Understanding the rules at these three different scales should enable the prediction of the behavior of living systems and how those systems interact with, respond to, and modify the environment, and will facilitate the engineering of biological systems and enable new forms of bio-manufacturing that are ethically sound, societally acceptable, and beneficial to humankind.
2. To support the discovery of rules governing emergent properties of networks of living systems that impinge on and are influenced by coupled natural, built, and social environments. The often unanticipated outcomes of these interactions rest on, but are not wholly or even partly predicted by, mathematical, chemical, and physical principles and unit-level (molecule/cell/organism/population) biological properties, and prediction is further hampered by accelerating perturbations in environmental circumstances and the associated occurrence of extreme events. A better understanding of the determinants of emergent network properties across various levels of organization will generate actionable information about the impact of specific environmental changes on outcomes for living communities, and vice versa, enabling improved prediction of, preparedness for, and response to natural and man-made environmental challenges, and more effective environmental management.
3. To support networks of researchers, technology developers, and educators engaged in URoL activities and thereby further the development of a robust community, with an impact that is sustained beyond the five-year investment in the URoL Big Idea. The convergent nature of research addressing emergent properties of living systems should stimulate the development of new and improved techniques in molecular, genomic, and cellular examination and manipulation; improved technologies for the capture of biological, behavioral, and social phenotypic data in free-living organisms; advances in data science, AI, and machine learning, as well as computational modeling ; more capable cyberinfrastructure to support robust, data- and computationally-enabled URoL discovery and sharing of research results; and advances in theory coming from relevant fields of science and engineering. URoL also support investments in training and workforce development to produce scientists that have a firm grounding in the life sciences as well as the mathematical, physical, computational, behavioral and/or social sciences and engineering that enable them to work collaboratively across disciplinary boundaries. Finally, URoL provides a rich context in which to expand science-literacy efforts aimed at diverse communities across the nation. Research networks provide a mechanism for sustained support of distributed groups of investigators working to achieve URoL goals.

**FY 2022 Investments**

URoL activities in FY 2022 will build upon the investments made in FYs 2019-2021. The FY 2021 solicitation supporting research on emergence in living systems will continue in FY 2022 (Goals 1 and 2). URoL will explore ways to build upon prior investments through synthesis activities to be developed in FY 2023, supporting networks of researchers, technology developers, and educators in different URoL domains (Goal 3). Foundational investments, aligned with URoL goals, will also provide support for convergent programs initiated in FY 2019 and planned for FY 2022. These activities laid the foundations for the URoL Big Idea; they are currently managed by NSF's directorates and offices and will continue to remain within the directorates and offices with respect to their funding and management.

## WINDOWS ON THE UNIVERSE (WOU)

**Windows on the Universe Funding**[1]
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|
| **Stewardship Activities (MPS)** | **$30.00** | **$30.00** | **$30.00** |
| **Foundational Activities** | **$37.81** | **$34.23** | **$36.85** |
| MPS | 30.71 | 31.00 | 31.00 |
| OPP | 7.10 | 3.23 | 5.85 |
| **Total** | **$67.81** | **$64.23** | **$66.85** |

[1] Funding displayed may have overlap with other topics and programs

### Overview

For millennia, humankind has viewed the universe through the visible part of the electromagnetic spectrum to which human eyes are sensitive. Over the last half century, our view of the universe has been extended to cover the full spectrum of electromagnetic radiation, from radio waves to X-rays and gamma rays. Observatories constructed and operated over the past two decades, have extended this view to include high-energy particles such as neutrinos and cosmic rays. Most recently, with LIGO, NSF has established the ability to view the universe through gravitational waves. Combining these three views of the universe has opened a new era of multi-messenger astrophysics. The three messengers—electromagnetic radiation, high-energy astrophysical particles, and gravitational waves—each provide unique information. Together, they provide a detailed picture of the Universe that allows scientists to study matter, energy, and the cosmos in fundamentally new ways—through several powerful and diverse “windows”. WoU builds these capabilities and accelerates the synergy and interoperability of the three messengers to realize integrated, multi-messenger astrophysical exploration of the Universe.

Prior investments have led to important recent discoveries that demonstrate the power of WoU. The coincident detection of gravitational waves and electromagnetic radiation identified a merging binary neutron star system, confirmed Einstein’s theory of General Relativity, and revealed critical information on the origin of heavy elements. Recent observations of high-energy neutrino emission coincident with gamma-ray flares from the nucleus of an active galaxy have revealed for the first time an astrophysical source of high-energy cosmic rays. These discoveries, along with others, have heralded the era of multi-messenger astrophysics.

WoU is anticipated to be a 10-year effort, building upon prior NSF investments in individual research awards and major research facilities. These include both presently operating observatories, such as IceCube (for the detection of high-energy neutrinos) and LIGO (for the detection of gravitational waves), as well as development efforts for future experiments and facilities, such as the Vera C. Rubin Observatory. The stewardship funding model for WoU was first introduced in the FY 2019 Request, an approach that has dramatically multiplied ongoing NSF investments in foundational activities aimed at building capabilities for each of the three messengers individually. This funding strategy (stewardship funding supplemented with investments in foundational activities) will continue in FY 2022. These investments will also serve to grow the workforce not only for multi-messenger astrophysics but also for engineering, data science, and many other areas.

**Goals**

1. *Enhancing and Accelerating the Theoretical, Computational, and Observational Activities Within the Scientific Community*: Support efforts within the scientific community to build the observational and analysis capabilities in each of the three window areas, integrate the different research communities to develop full interoperability between the three windows, and develop a new workforce that is skilled in this new paradigm.
2. *Building Dedicated Instrumentation and Capabilities*: Construct experiments and instrumentation or develop cyberinfrastructure that will make critical contributions to the multi-messenger research infrastructure by enabling new capabilities in energy range or sky coverage, improved sensitivity, or new experimental or computational capabilities. The Big Idea: Mid-scale Research Infrastructure program, described elsewhere in this chapter, is an essential part of realizing this goal.
3. *Exploiting Current Facilities and Developing the Next Generation of Observatories*: Enhance infrastructure and provide modest upgrades to enable full utilization of the current generation of multi-messenger facilities, and support planning and development for the next generation of observatories to accelerate progress to realize significantly greater capabilities and extend the scientific reach.

**FY 2022 Investments**

WoU continues to be implemented through a dedicated program, "Windows on the Universe: The Era of Multi-Messenger Astrophysics (WoU-MMA)."[1] The WoU-MMA program currently includes the Division of Astronomical Sciences and the Division of Physics within MPS, and the Office of Polar Programs (OPP) within GEO. The WoU-MMA program will address all the WoU goals. Stewardship funding ($30.0 million) resides in the MPS Office of Multidisciplinary Activities but will be allocated to awards from all participating divisions and offices and directorates based on merit and portfolio balance. Participating divisions and offices will supplement this allocation through foundational activities in core research programs to advance particularly compelling scientific opportunities related to WoU. For MPS, this is expected to be primarily through research grants in astronomy, particle astrophysics, and gravitational physics. OPP will supplement the WoU allocation with grants from the Antarctic Astrophysics and Geospace Sciences program. Other NSF divisions may participate when activities originating in their divisions meet the WoU criteria.

[1] www.nsf.gov/funding/pgm_summ.jsp?pims_id=505593

## GROWING CONVERGENCE RESEARCH (GCR)

**GCR Funding**[1]
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|
| | **$15.90** | **$16.00** | **$24.17** |

[1] Funding displayed may have overlap with other topics and programs

### Overview

GCR is a NSF program that empowers the U.S. research community to leverage multiple scientific and engineering (S&E) disciplines and develop novel research strategies to address extremely challenging and complex problems. GCR research challenges are inspired by deep scientific questions or pressing societal needs and require the integration of multi-disciplinary perspectives.

The grand challenges of today—such as developing infrastructure resilient to extreme events and geo-hazards; combining biology, physical sciences, engineering, computer and cognitive science to produce the machines and materials of the future; enhancing sustainability in an era of rapid global change; exploring the universe at all scales; preparing the future scientific workforce for convergence research through innovations in STEM education at all levels; and creating the breakthroughs that will enable emerging industries—will not be solved by one discipline alone. They require convergence: the merging of ideas, approaches, tools, and technologies from widely diverse fields of knowledge to stimulate innovation and discovery. Convergence research is a means of solving complex research problems that have two unifying characteristics: (1) they have the potential to make a significant impact, either on fundamental understanding in S&E or on the Nation's ability to meet pressing societal challenges, or both; and (2) they require the integration of knowledge, tools, and ways of thinking from multiple disciplines.

NSF's GCR responds in part to recommendations from major reports describing the importance of convergence for the research ecosystem. Key reports include National Academies of Science, Engineering, and Medicine reports from 2014 and 2017, Massachusetts Institute of Technology (MIT) reports from 2011 and 2016, and a 2013 report published by Springer. These reports emphasize the importance of convergence approaches to S&E research to address grand challenges. These reports also emphasize the role of federal funding agencies in realizing the benefits of convergence by expanding mechanisms for funding convergence research.

### Goals

The goals of GCR are to:
1. Catalyze convergence approaches to solve compelling scientific and engineering research problems at the intersection of existing disciplines.
2. Identify emerging convergence research challenges.
3. Enhance NSF's review process to more effectively assess the merit of convergence research proposals.

### Approach

GCR will strengthen the global competitiveness of the U.S. S&E enterprise by growing a new generation of convergence researchers skilled at working in teams and able to respond rapidly to new research challenges. To support convergence research, NSF continues to use review processes designed to address the key technical, organizational, and logistical challenges that hinder the evaluation of truly integrative research. GCR's strategic investments in emerging convergence research themes will support the development of new fields of inquiry, discovery of the knowledge necessary for society to develop solutions or technologies to address important societal challenges, and training in convergence research.

GCR uses several mechanisms to accomplish programmatic goals, including:

*Exploratory Grants*
GCR exploratory research grants enable research teams to demonstrate their ability to collaborate effectively, resolve epistemological and ontological differences between disciplines, integrate conceptual models, tools, methodologies, and infrastructure; and show progress on their convergence research projects. Exploratory grants are expected to have budgets of up to $3.60 million and durations of up to five years. Exploratory grants will prepare research teams for larger scale convergence research awards through programs such as Science and Technology Centers, Engineering Research Centers, and NSF Research Traineeships. NSF announced the first exploratory grant opportunity in FY 2018.[1] In February 2019, NSF released a GCR solicitation, NSF 19-551,[2] which described annual funding opportunities starting in FY 2019.

*Emerging Research Challenges*
GCR will take advantage of a number of proven tools to enable the research community to identify and explore important emerging research challenges. Examples include Ideas Labs and Research Coordination Networks, as well as novel incubation approaches that may be suggested by researchers.

*Enhanced Merit Review Process*
An enhanced merit review process is employed for convergence research projects. NSF identified a cadre of experienced convergence researchers using data-mining tools, the knowledge of program staff, and suggestions from learned societies to evaluate GCR research projects. A diverse pool of such researchers participate in a College of Reviewers (CoR). NSF staff draws on members of the CoR as well as other technical experts to review proposals submitted in response to the GCR solicitation.

**FY 2022 Investments**

Exploratory Grants
Investments will focus on two phases: (1) catalyzing convergence of new teams at the intersection of existing disciplines (four to seven new research collaborations, each funded at up to $600,000 per year for the first two years); and (2) continuing support of four to seven teams funded in 2020 who have demonstrated significant progress on their convergence research projects.[3]

Emerging Research Challenges
GCR will invest in research community-led activities to identify and explore 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.

Enhanced Merit Review Process
Additional experts will be recruited to expand the Convergence CoR.

[1] www.nsf.gov/pubs/2018/nsf18058/nsf18058.jsp. This resulted in seven awards in FY 2018 and three in FY 2019.
[2] www.nsf.gov/publications/pub_summ.jsp?WT.z_pims_id=505637&ods_key=nsf19551.
[3] The second phase of projects will be funded up to $800,000 per year and may continue for up to three years pending successful yearly progress.

## INCLUSION ACROSS THE NATION OF COMMUNITIES OF LEARNERS OF UNDERREPRESENTED DISCOVERERS IN ENGINEERING AND SCIENCE (NSF INCLUDES)

**NSF INCLUDES Funding (EHR)**[1]
(Dollars in Millions)

| FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|
| **$20.75** | **$20.00** | **$46.50** |

[1]Funding displayed may have overlap with other topics and programs.

### Overview

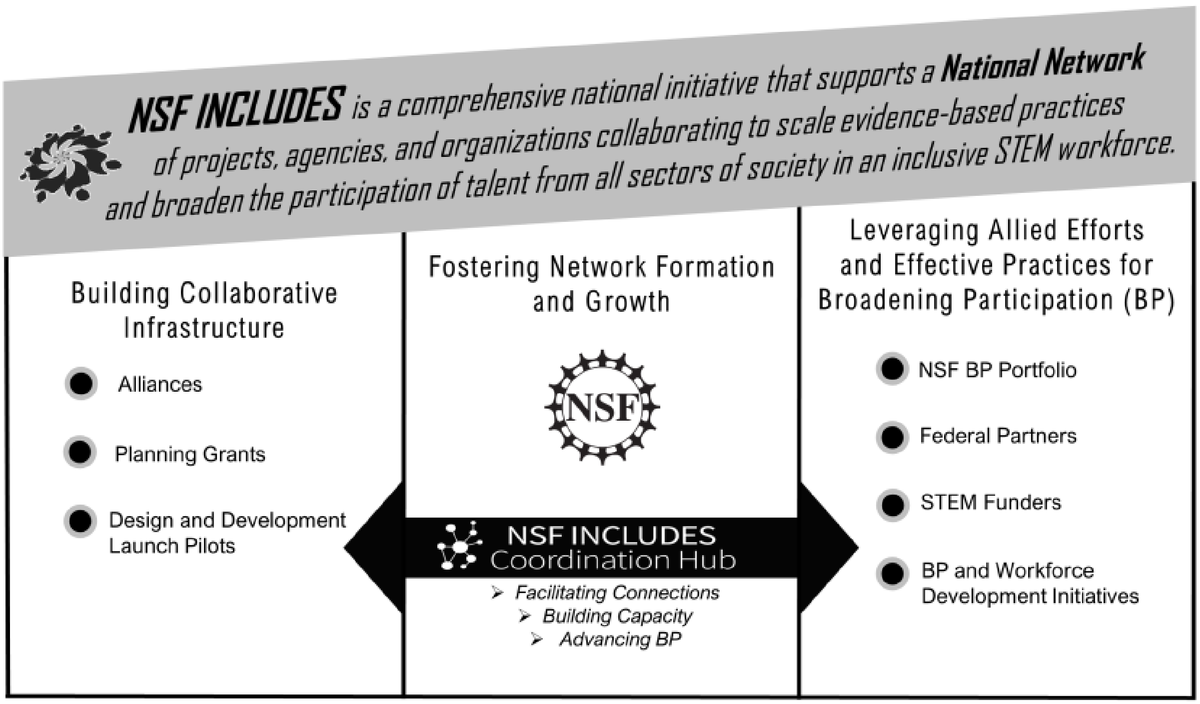
The NSF INCLUDES Big Idea aims to develop a talented, innovative, and capable STEM workforce that reflects the diversity of the Nation. For the United States to remain the world leader in STEM innovation and discovery, it must identify and develop talent from all sectors to become tomorrow's STEM professionals. Providing opportunities and support for members of all communities and sectors across the Nation reflects NSF's commitment to broadening participation and is vital for the Nation's economic welfare, which aligns with the Administration's priority crosscutting action to build and leverage a diverse, highly skilled American workforce.

NSF INCLUDES is NSF's response to the Committee on Equal Opportunities in Science and Engineering's (CEOSE) 2011-2012 Biennial Report to Congress.[1] CEOSE recommended that NSF develop "a bold new initiative focused on broadening participation of underrepresented groups in STEM, similar in concept and scale to NSF's centers." As part of NSF's continuing response to CEOSE's recommendation, NSF is investing in developing and sustaining the NSF INCLUDES National Network, a multifaceted collaboration of agencies, organizations, and individuals working collectively to scale innovations in pursuit of broadening participation in STEM. The NSF INCLUDES National Network comprises NSF INCLUDES Design and Development Launch Pilots,[2] NSF INCLUDES Alliances,[3] NSF INCLUDES Planning Grants, and an NSF INCLUDES Coordination Hub.[4] NSF INCLUDES Alliances serve as testbeds for designing, implementing, studying, and refining change models that are based on collective impact-style approaches.[5] Opportunities to join the NSF INCLUDES National Network have been extended through dear colleague letters and language in multiple agency-wide program solicitations. Other organizations with an interest in broadening participation in STEM are invited to join and support the goals of the NSF INCLUDES National Network via the Coordination Hub and its website.[6] The NSF INCLUDES National Network has expanded through the addition of federal agencies that are part of the NSTC Committee on STEM Education and the Federal Coordination in STEM Subcommittee. The NSF INCLUDES investment continues to provide valuable research and evaluation knowledge that will contribute to NSF's understanding of strategies for addressing the Nation's most challenging STEM diversity and inclusion issues at scale. Significant advancement in the inclusion of groups underrepresented

[1] www.nsf.gov/od/oia/activities/ceose/reports/Full_2011-2012_CEOSE_Report_to_Congress_Final_03-04-2014.pdf
[2] NSF INCLUDES Design and Development Launch Pilots—pilot to address broadening participation planning activities and laying the foundations for potential partners to share common goals and purposes
[3] NSF INCLUDES Alliances: collaborators or partners working to scale best practices in broadening participation
[4] NSF INCLUDES Coordination Hub: collaboration of multiple institutions facilitating activities needed to build and maintain the network
[5] Kania, J., & Kramer, M. (Winter 2011). Collective impact. Stanford Social Innovation Review. https://ssir.org/articles/entry/collective_impact. Kania and Kramer note that collective impact "requires a systematic approach to social impact that focuses on relationships between organizations and the progress toward shared objectives," p. 5.
[6] www.includesnetwork.org/home

in STEM will result in a new generation of STEM talent and leadership to secure our Nation's future economic competitiveness.

The graphic below highlights how the NSF INCLUDES Big Idea will continue to pursue three synergistic approaches to achieve the goal of increasing diversity and inclusion in STEM at a national scale.




**Goals**

NSF INCLUDES investments target the following three strategies:

1. *Support Research on Broadening Participation (BP) in STEM:* Synthesize and build the research base for broadening participation in STEM and foster the spread and adaptation of proven effective practices.
2. *Develop Shared Goals and Objectives:* Support stakeholders as they identify shared goals and objectives, including those from specific STEM disciplines.
3. *Build the NSF INCLUDES National Network:* Support local and regional, discipline-specific, and crosscutting multi-stakeholder partnerships and networks as part of the NSF INCLUDES National Network.

**FY 2022 Investments**

In FY 2022, NSF plans to invest $46.50 million in NSF INCLUDES, with funds stewarded by EHR.

<u>Support Research on Broadening Participation in STEM</u>
NSF INCLUDES will continue to support research on broadening participation in STEM through NSF INCLUDES Alliances and NSF's existing BP portfolio[7]. This research is necessary to document successful practices and build an evidence-based understanding of what works to promote success of all individuals in STEM. NSF INCLUDES also supports the dissemination and adaptation of proven strategies—and the

[7] www.nsf.gov/od/broadeningparticipation/bp_portfolio_dynamic.jsp

study of these activities—for expanding the use of innovative BP practices. NSF INCLUDES pilot projects, planning grants, and supplements serve as connectors to NSF INCLUDES Alliances and the NSF INCLUDES National Network. Twenty-nine successful planning grants awarded in FY 2020 and FY 2021 are expected to yield strong cohorts of Alliance proposals in FY 2022 and the additional funding in FY 2022 will enable NSF to increase the number of meritorious Alliance awards that can be funded. These new alliances will strengthen the program portfolio and expand impact by addressing new disciplines and challenges in broadening participation.

<u>Shared Goals and Objectives</u>

- NSF will provide ongoing funding to the NSF INCLUDES Coordination Hub to oversee the implementation of a system of measurement, communication, and mutually reinforcing activities across the NSF INCLUDES National Network. With additional funding in FY 2022, NSF INCLUDES will expand the scope and diversity of the Hub's activities.
- The NSF INCLUDES developmental evaluation was completed in FY 2020, and the scope of work for a comprehensive formative evaluation is being finalized. Formative evaluation activities will start in FY 2021. The NSF INCLUDES Shared Measures System compiles and communicates information about the progress that initiatives are making with broadening participation in STEM education and careers. The Shared Measures Framework, which is a component of the Shared Measures System is now complete. Refinement of other components of the Shared Measures System, such as the data collection tools and dashboard for display of data is in progress and will continue into FY 2022. A shared measures working group convenes regularly to provide feedback on the shared measures system and proposed common data collection protocols/procedures. Additional funding in FY 2022 will allow for enhancements of the Shared Measure Systems and accelerate its completion.

<u>NSF INCLUDES National Network</u>

- NSF will support connections of existing NSF BP programs and other NSF-funded projects that support the NSF INCLUDES vision through the NSF INCLUDES National Network. The National Network currently has nearly 2,000 members.
- NSF will regularly convene principal investigators of NSF INCLUDES projects (virtually and face-to-face) and its growing network of federal partners to discuss BP challenges, proposed strategies, scaling mechanisms, common metrics, and the feasibility of sustaining projects. Additional funding in FY 2022 will expand the NSF INCLUDES National Network and allow implementation of collaborative activities with federal partners.

## MID-SCALE RESEARCH INFRASTRUCTURE (MID-SCALE RI)

**Mid-scale RI Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|
| Mid-scale RI-1 (R&RA) | $30.37 | $32.67 | $50.00 |
| Mid-scale RI-2 (MREFC) | - | 76.25 | 76.25 |
| **Total** | **$30.37** | **$108.92** | **$126.25** |

### Overview

The Mid-scale RI 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. Mid-scale RI implements agile mechanisms for funding experimental research capabilities costing between $6.0 million and $100.0 million.[1] The 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.

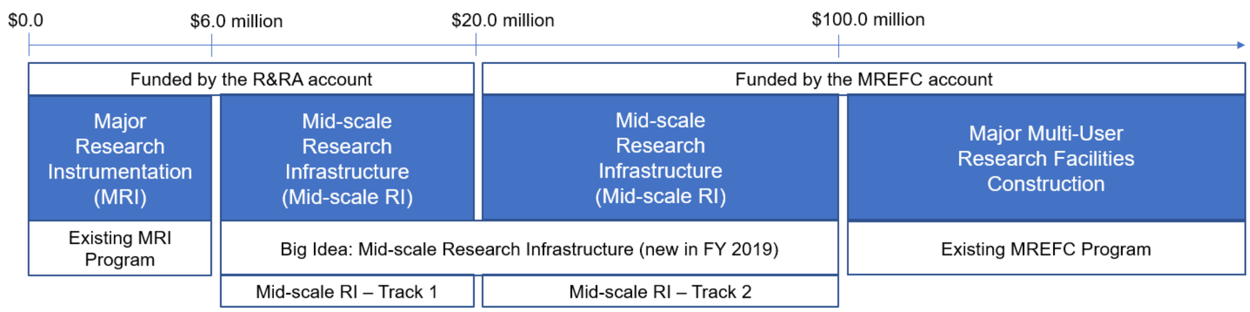
The scientific importance of mid-scale research infrastructure is reflected in the 2017 American Innovation and Competitiveness Act (AICA), which directed NSF to "evaluate the existing and future needs, across all disciplines supported by the Foundation, for mid-scale projects." NSF issued a Request for Information in late 2017 that resulted in nearly 200 ideas for research infrastructure within a project cost range of $20 million to $100 million. Subsequently, FY 2018 appropriations report language directed the NSB to "consider steps to bridge the gap between NSF's Major Research Instrumentation (MRI) program and the agency's MREFC account."[2] Responding to this direction, the NSB report, "Bridging the Gap: Building a Sustained Approach to Mid-scale Research Infrastructure and Cyberinfrastructure at NSF",[3] highlights that:

> "The research community has identified mid-scale research infrastructure as a key enabler of scientific advances on shorter timescales than required for the larger projects funded within the MREFC account. ... Infrastructure investments at the required mid-level can also help maintain the United States' standing among global partners and competitors."

The graphic below shows NSF-wide instrumentation and infrastructure programs. Information presented in this narrative focuses on the Mid-scale RI components, Mid-scale RI - Track 1 (Mid-scale RI-1) and Mid-scale RI - Track 2 (Mid-scale RI-2). Information on the complementary MRI program may be found in the IA narrative, while information on major multi-user research facility construction projects may be found in the MREFC chapter. The Mid-scale RI program supports the implementation of research infrastructure at scales that are above what is possible through the MRI program and below major multi-user research facilities construction. Mid-scale RI-2 awards are funded by the MREFC account and are distinguished from Mid-scale RI-1 awards by their scale, potential risks, and the resulting NSF oversight.

[1] NSF-established thresholds for Mid-scale Track-2 projects have been updated to align with the definitions in AICA and the William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021.
[2] At that time, the MREFC accounts was only used for major facilities. With the introduction of the Mid-Scale RI-2 program, the MREFC account is used for some mid-scale research infrastructure projects and for major facilities.
[3] www.nsf.gov/nsb/publications/2018/NSB-2018-40-Midscale-Research-Infrastructure-Report-to-Congress-Oct2018.pdf

**NSF Portfolio of Central Instrumentation and Infrastructure Implementation Programs**




In FY 2019, NSF received proposals in response to two Mid-scale RI funding opportunities. One included an opportunity to propose Mid-scale RI implementation projects with a total NSF project cost between $6.0 million[4] and $20.0 million, as well as infrastructure design projects with costs between $600,000 and $20.0 million, while a second included an opportunity to implement projects with a total NSF cost between $20.0 million and $70.0 million.

NSF made ten Mid-scale RI-1 awards, including the acquisition of the first 1.2GHz nuclear magnetic resonance system in the U.S.; extremely fast and powerful lasers; a neutron spin echo spectrometer, a part of the Center for High Resolution Neutron Scattering (CHRNS) jointly funded by NSF and the National Institute of Standards and Technology (NIST),to be deployed at NIST; a testbed for experiments for future internet designs; as well as support for the design of a future experiment to study the cosmic microwave background.

NSB authorized the first Mid-scale RI-2 awards at its May 2020 meeting and two additional awards at its February 2021 meeting. The first three awards were made in October 2020. These included a high-magnetic-field beamline at the Cornell High Energy Synchrotron Source, a global array of 500 robotic floats to regularly sample changes in ocean biogeochemistry, and a testing infrastructure for networked control of distributed energy resources. The two additional awards authorized in February 2021 are currently undergoing full cost analyses and final award negotiations, including Independent Cost Estimates and any potential impacts from COVID-19.

**Goals**

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

**FY 2022 Investments**

In FY 2022, 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. Both use a biennial funding opportunity; the second solicitations for Mid-scale RI-1 (NSF-21-505[5]) and Mid-scale RI-2 (NSF-21-537[6]) were issued in FY 2021. Subject to availability of funding in FY 2022, Mid-scale RI-1 will support projects from its FY 2021 competition. NSF anticipates that Mid-scale RI-2 funding will support projects

[4] Design activities to bring Mid-scale or larger projects to readiness for implementation may request a minimum of $600,000.
[5] www.nsf.gov/pubs/2021/nsf21505/nsf21505.htm
[6] www.nsf.gov/pubs/2021/nsf21537/nsf21537.htm

resulting from the first Mid-scale RI-2 competition that concluded in FY 2021 and also may be used to initiate new awards from the second Mid-scale RI-2 competition that began in FY 2021.

## NSF INNOVATION CORPS (I-CORPS™)

**NSF Innovation Corps Funding**[1]
(Dollars in Millions)

| FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|
| **$37.95** | **$40.00** | **$40.00** |

[1] Funding displayed may have overlap with other topics and programs.

### Overview

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 in 2011 by NSF, is to reduce the time and risk associated with translating promising ideas and technologies from the laboratory to the marketplace. The program is designed to support the commercialization of deep technologies, or those revolving around fundamental discoveries in science and engineering. The I-Corps™ program addresses the skill and knowledge gap associated with the transformation of basic research into deep technology ventures. 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.

In 2017, the *American Innovation and Competitiveness Act* (AICA, Public Law 114-329, Sec. 601) formally authorized NSF to carry out, further develop, and expand the I-Corps™ program and other training programs that focus on education in entrepreneurship and commercialization. In the program's initial phase, I-Corps™ Nodes and Sites were funded separately to serve as the backbone of the I-Corps National Innovation Network (NIN). Informed by community feedback and lessons learned over its first eight years, the I-Corps™ program has created a new phase of the NIN anchored by I-Corps™ Hubs.[1] The initial set of Hubs are scheduled to be awarded in FY 2021. In this new model, the Hubs are envisioned as centers of I-Corps™ entrepreneurial training and research activities, anchoring the expanded NIN and coordinating the integration of the existing Nodes and Sites into an active network. The vision for I-Corps™ is that any U.S. college or university will be able to engage with I-Corps™ activities through one of these Hubs, expanding access to the NIN for the broadest and most diverse possible portfolio of teams from all across the country.

In alignment with Administration and Congressional priorities to build, strengthen, and expand strategic multisector partnerships, the NIN supports innovation research and education, and enhances the development of technologies, products, and processes that benefit society. NIN participants are diverse in research areas, resources, tools, programs, capabilities, and geographic locations, and the network as a whole has the flexibility to grow or reconfigure as needs evolve. These components contribute to enhancing and enlarging the NIN's community of mentors, researchers, entrepreneurs, and investors, as well as increasing participation and promoting inclusion of underrepresented populations in the NIN.

The I-Corps™ program supports NSF's strategic vision of "a Nation that is the global leader in research and innovation." Specifically, I-Corps™ contributes directly to strategic objectives in NSF's FY 2018-FY 2022 Strategic Plan, including Objective 1.1, to "advance knowledge through investments in ideas, people, and infrastructure"; Objective 2.1, to "support research and promote partnerships to accelerate

[1] www.nsf.gov/funding/pgm_summ.jsp?pims_id=505760&org=NSF

innovation and to provide new capabilities to meet pressing societal needs"; and Objective 2.2, to "foster the growth of a more capable and diverse research workforce and advance the scientific and innovation skills of the Nation."

**Goals**

The specific goals of the I-Corps™ program are to:
1. Capitalize on NSF's investment in fundamental research and identify, develop, and support promising ideas with commercial potential.
2. Create and implement tools, resources, and training activities that offer academic researchers an opportunity to learn first-hand about technology-based innovation and entrepreneurship.
3. Connect academic researchers with entrepreneurship resources, industrial mentors, startup investors, and peers conducting translational research and commercialization.
4. Provide diverse communities of student innovators with real-world knowledge through curriculum and first-hand participation in transforming scientific and engineering discoveries to meet societal needs.
5. Share and leverage effective innovation practices on a national scale to improve the quality of life for all Americans.

**FY 2022 Investments**

The new phase of the I-Corps™ program has two components:
- NSF expects to fund 250-300 teams in FY 2022, partnering with other federal agencies and programs, states, and regional organizations as well as the potential new Hubs. I-Corps™ Teams are funded at $50,000 per Team with a duration of six months.
- I-Corps™ Hubs will be supported for up to five years, at up to $3.0 million per Hub per year.

NSF will continue to pursue potential scaling through the I-Corps™ Hubs. This strategy calls for new mechanisms to provide I-Corps™ curriculum and experience to a much larger community of technology innovators and entrepreneurs, particularly those without prior connections with NSF and who may not otherwise have access to the I-Corps™ curriculum. The expanded community will include local and regional entrepreneurs, university spinoffs, and awardees of other federal agencies, state governments, and non-profit organizations. By leveraging existing entrepreneurial and innovation capacities in universities and tapping into federal, state, and regional resources, the I-Corps™ NIN holds significant potential to reach a larger number of budding and existing innovators and entrepreneurs.

NSF will continue to build NIN partnerships with stakeholders, including federal agencies, state governments, universities, and non-profit organizations. NSF also has Memoranda of Understanding in place with the U.S. Department of Agriculture, Department of Defense, Advanced Research Projects Agency-Energy, Department of Homeland Security, and National Aeronautics and Space Administration. Each of these agencies supports the participation of its researchers in the NSF-operated I-Corps™ Teams training program.

In addition, in FY 2019, NSF entered into a three-year, $3.50 million cooperative agreement with the National GEM Consortium[2] to promote inclusive and diverse participation in I-Corps™, which is strongly aligned with the Administration's Racial Equity pillar. NSF will continue to broaden participation across the NIN in FY 2022 by engaging minority-serving institutions and principal investigators from groups underrepresented in science and engineering research.

[2] www.gemfellowship.org/

## NATIONAL SCIENCE FOUNDATION CENTERS

NSF supports a variety of centers programs that contribute to the Foundation's mission and vision. Centers exploit opportunities in science, engineering, and technology in which the complexity of the research program or the resources needed to solve the problem require the advantages of scope, scale, duration, equipment, facilities, and students. Centers are a principal means by which NSF fosters interdisciplinary research.

**NSF Centers**
(Dollars in Millions)

| | Program Initiation | Number of Centers in FY 2020 | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|---|---|
| AI Research Institutes | 2020 | 7 | $33.58 | $50.61 | $69.11 | $18.50 | 36.6% |
| Biology Integration Institutes | 2020 | 4 | 21.63 | 25.00 | 35.82 | 10.82 | 43.3% |
| Centers for Analysis & Synthesis | 1995 | 2 | 4.80 | - | 4.00 | 4.00 | N/A |
| Centers for Chemical Innovation | 1998 | 9 | 23.66 | 24.00 | 27.70 | 3.70 | 15.4% |
| Engineering Research Centers[1] | 1985 | 18 | 54.61 | 56.90 | 68.70 | 11.80 | 20.7% |
| Materials Centers | 1994 | 23 | 55.50 | 53.48 | 56.80 | 3.32 | 6.2% |
| Quantum Leap Challenge Insts[1] | 2020 | 3 | 23.10 | 50.00 | 36.00 | -14.00 | -28.0% |
| Regional Innovation Accelerators | 2022 | 0 | - | - | 200.00 | 200.00 | N/A |
| Science & Technology Centers | 1987 | 12 | 41.74 | 57.95 | 60.97 | 3.02 | 5.2% |
| Spectrum Innovation Initiative Ctr | 2021 | 0 | - | 5.00 | 5.00 | 0.00 | - |
| **Total** | | | **$258.62** | **$322.94** | **$564.10** | **$305.48** | **118.1%** |

[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 2022 Request of $69.11 million will support up to 16 National AI Research Institutes—five institutes launched in FY 2020, up to seven anticipated to be awarded in FY 2021, and up to four additional institutes planned in FY 2022. Two additional FY 2020 institutes are wholly funded by the U.S. Department of Agriculture National Institute of Food and Agriculture (USDA NIFA), with one more anticipated to be entirely funded by USDA NIFA in FY 2021. FY 2021 awards are expected to be made in August 2021.

The National AI Research Institutes program, a multisector collaboration among government, industry, and academia, supports multidisciplinary advances on critical 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 critical 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 include 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; AI to Advance Biology; and others. Each institute is funded at up to $4.0 million per year for up to five years, with the possibility of a competitive renewal in the fifth year for another five years.

Biology Integration Institutes – BIO
The FY 2022 Request of $35.82 million is expected to support fourteen Biology Integration Institutes (BII). This will include nine 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-research and training environments that are conducive to an integration of ideas, expertise, 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.

Centers for Analysis and Synthesis - BIO
The FY 2022 Request of $4.0 million for Centers for Analysis and Synthesis is expected to support one new center in environmental science and eco-forecasting. 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 award will be determined after an open competition conducted in FY 2021. The center would 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.

Centers for Chemical Innovation - MPS
The FY 2022 Request level of $27.70 million is to 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.

The CCI program makes awards at two levels: smaller Phase I awards (three-year) for center development, and larger Phase II awards (five-year awards with potential for renewal up to a total of ten years) for full centers. In FY 2022, up to six continuing Phase II CCIs will be funded. In addition, three FY 2019 Phase I CCIs will be eligible to compete for Phase II in FY 2022; up to one new Phase II CCI is anticipated. A Phase I CCI competition will be held in FY 2022, supporting up to three new developmental awards.

These research centers 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. A broad range of chemical research is currently represented in CCIs advancing fundamental understanding in chemical synthesis and catalysis; characterization, theory, computation, and modeling; data science, machine learning, and AI for molecular synthesis; and advanced manufacturing of nanomaterials; along with training for students at all levels. CCIs are also actively engaged in knowledge transfer to industry and the commercialization of their discoveries and new technologies.

The themes of the CCIs are varied and include Administration priorities such as AI, QIS, biotechnology, clean energy technologies, and advanced manufacturing; NSF's Big Ideas: URoL, and HDR; as well as sustainable chemistry. The Center for Aerosol Impacts on the Chemistry of the Environment (CAICE) is studying the fundamental properties of sea spray aerosols and how these reactive particles impact air quality, weather, and cloud formation. The Center for Genetically Encoded Materials, CGEM, is on the cutting edge of synthetic biology, adapting the ribosome to make sequence-defined synthetic polymers. 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 nearly 80 participating academic institutions, 74 non-academic partner institutions, and over 165 Senior Personnel, 140 Postdoctoral Associates, 250 Graduate Students, and 80 Undergraduate Students.

<u>Engineering Research Centers - ENG</u>

The FY 2022 request is $68.70 million to support 15 NSF Engineering Research Centers (ERC). The total includes support for four Gen-4 ERCs, funded as part of the Class of 2022 that will advance convergent engineering research to tackle high-impact challenges that have the potential to benefit U.S. security, prosperity, health, and society. The 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 2011 will receive their final year of NSF funding in FY 2021.

All NSF ERCs enable innovation, combining the energy and intellectual curiosity of university research focused on discovery with real-world engineered systems and technology opportunities through partnerships with industry. Since the program began in 1985, products of ERC innovation include more than 2,500 inventions disclosures, nearly 2,200 patent applications filed, 883 patents awarded, and 1,378 licenses. 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 110 Bachelor's, 100 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 43 percent of those involved in center activities, in comparison to the national average of 24 percent across engineering. Also, the percentage of people from underrepresented groups participating is more than double that of engineering's national average.

The ERC program periodically commissions studies by external evaluators to examine aspects of the program, such as the effectiveness of ERC graduates in industry and the benefits of ERC membership to industry. In FY 2015, NSF funded the National Academies of Sciences, Engineering, and Medicine to study the future of center-based, multidisciplinary engineering research. The study report, delivered May 2, 2017, articulates a vision for the future of NSF-supported center-scale, multidisciplinary engineering research.[1] After careful consideration, in FY 2018 ENG sparked new convergent engineering research collaborations through planning grants, providing 60 awards to build capacity for a new generation of ERCs. In October 2018, ENG released a solicitation (NSF 19-503)[2] for the 4th-generation of ERCs and supported the first four awards in FY 2020, including the Center for Quantum Networks (CQN). The center will lay the foundations for a socially responsible quantum internet that will enable secure communications, provide public access to distributed quantum computers and sensors, and spur new technology industries and a competitive marketplace of quantum service providers and application developers. CQN complements other QIS investments across the Federal government through its unique focus on designing and building the quantum internet's full stack, educating diverse quantum engineers, and transferring knowledge through industry partnerships.

In FY 2021, NSF expects the results of a study on the sustainability of ERCs once NSF funding has ended. A previous 2010 report[3] "Post-Graduation Status of National Science Foundation Engineering Research Centers" (SciTech Communications), augmented by a 2015 update, found that 29 of the 35 centers (83 percent) that graduated after 10 years of NSF support are self-sustaining, with most NSF ERC features in place and strong financial support from other government sources and industry partners.

Materials Centers - MPS

The FY 2022 Request level of $56.80 million is expected to support 19 continuing Materials Research Science and Engineering Centers (MRSEC). A MRSEC competition is not planned for FY 2022 as this long-standing, flagship program completed its triennial competition in FY 2020. Funding in FY 2022 will support three new centers established in FY 2020, eight existing centers that successfully recompeted for funding in FY 2020, as well as eight other existing centers funded in 2017.

MRSECs function as hubs to solve complex grand challenge materials problems requiring broad multidisciplinary expertise within the physical sciences and engineering to understand materials phenomena, exploit materials behavior, and to create and discover new materials. Research in materials science is inherently interdisciplinary and the MRSEC program is a prime example of convergent research encompassing physics, chemistry, mathematics, biology, 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 five major coordinated components: (1) interdisciplinary research groups, (2) education and outreach, (3) industrial outreach/partnerships, (4) the materials research facilities network—providing access to more than 1,250 state-of-the art equipment instrumentation to materials researchers across the Nation—and (5) the seed program, which enables MRSECs to rapidly react/move into new high-risk and potentially transformative areas not yet fully explored. In FY 2019, seeding efforts within each MRSEC were targeting emerging research areas relevant to the Division of Materials Research. These areas include NSF's Big Ideas QL, FW-HTF, URoL, and HDR, as well as recyclable plastics and alternative materials for sustainable development, synthetic materials biology, structural materials under extreme conditions, and the use of machine learning to accelerate materials discovery.

[1] www.nap.edu/catalog/24767/a-new-vision-for-center-based-engineering-research

[2] www.nsf.gov/pubs/2019/nsf19503/nsf19503.htm

[3] http://erc-assoc.org/sites/default/files/topics/Grad_ERC_Report-Final.pdf

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 2022 Request level of $36.0 million will support the third year of the three Quantum Leap Challenge Institutes (QLCI) established in FY 2020 along with the second year of additional institutes that are anticipated to result from the second phase of the QLCI competition being 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 2021competition, in addition to providing an opportunity for increased effort in these three areas, will also allow expansion of the areas to be covered to include quantum simulation. Total award sizes for each institute are $25.0 million over five years.

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 Accelerators – TIP</u>
The FY 2022 Request amount of $200.0 million will support up to 20 Regional Innovation Accelerators (RIAs) starting in FY 2022. The RIAs will simultaneously address major scientific and technological goals while ensuring broad societal benefits and global leadership. They will advance use-inspired, solution-oriented research and innovation in a range of technology areas (e.g., AI, QIS, advanced wireless, advanced manufacturing, semiconductors) as well as in a diverse set of national challenges (e.g., climate change and the bioeconomy). These accelerators will bring together multiple disciplines, institutions, and sectors. They will balance technical and geographic (i.e., local and regional challenges, capabilities, and perspectives) innovation; incentivize partnerships between NSF, academia, industry, nonprofits, state and local governments, and venture capital; and serve as hubs for NSF's broader portfolios of investment in their respective areas of focus. The RIAs are expected to be funded at $10.0 million per year for 10 years.

Science and Technology Centers: Integrative Partnerships – multi-directorate
The FY 2022 Request level of $60.97 million will support at least 12 Science and Technology Centers (STC) and the administrative costs associated with program management and oversight. These include STCs from the FY 2013, FY 2016, and FY 2021 cohorts. In FY 2022, the three FY 2013 cohort centers will be in their final year of funding. In FY 2019, a solicitation for a new STC class was issued to replace the sunsetting 2010 cohort. The program received 188 preliminary proposals with the expectation of making at least five new awards for the FY 2021 cohort. It is anticipated that a solicitation for the Class of 2023 will be released in summer 2021 with awards made in FY 2023. Currently, full STC awards are for five years, with possible renewal for an additional five years, or 10 years total. The award sizes of the existing STCs are approximately $5.0 million per year with ramp down in years nine and ten.

The STC program advances interdisciplinary discovery and innovation in science and engineering through the integration of cutting-edge research, excellence in education, targeted knowledge transfer, and the development of a diverse workforce. The STC portfolio reflects NSF-supported disciplines; examples include: creation of atomic-scale devices and systems based on quantum materials; elucidating the mechanisms and architecture of intelligence in the human brain; studying mechanical forces in molecules, cells, and tissues of plants and animals; and developing atomic scale imaging. STCs 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 in science and engineering, which they achieve through dedicated mentoring and partnerships, most notably with MSIs. 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 policy-makers, 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. NSF anticipates convening a Committee of Visitors to review the program in FY 2022.

Spectrum Innovation Initiative: National Center for Wireless Spectrum Research (SII-Center) – MPS
The FY 2022 Request level of $5.0 million is to fund the continuing operations of a single national center to be awarded in FY 2021. 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 under solicitation NSF 20-557. In FY 2021, NSF expects to continue this process and provide funding for this program under NSF 21-558.

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. The 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. The 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.[4]

**Estimates for Centers Participation in 2020**

| | Number of Participating Institutions[1] | Number of Partners[2] | Total FY 2020 NSF Support ($ in millions) | Total Leveraged Support ($ in millions)[3] | Number of Participants[4] |
|---|---|---|---|---|---|
| AI Research Institutes[5] | 47 | 84 | $33.58 | $8.00 | N/A |
| Biology Integration Institutes[5] | N/A | N/A | 21.63 | N/A | N/A |
| Centers for Analysis & Synthesis | 266 | 136 | 4.80 | 0.45 | 1,002 |
| Centers for Chemical Innovation | 65 | 60 | 23.66 | 5.89 | 632 |
| Engineering Research Centers | 953 | 56 | 54.61 | 91.50 | 4,586 |
| Materials Centers | 268 | 213 | 55.50 | 27.00 | 4,295 |
| Quantum Leap Challenge Insts[5] | 16 | 30 | 23.10 | TBD | 250 |
| Regional Innovation Accelerators[6] | N/A | N/A | N/A | N/A | N/A |
| Science & Technology Centers | 191 | 174 | 41.13 | 55.50 | 2,071 |
| Spectrum Innovation Initiative Ctr[7] | N/A | N/A | N/A | N/A | N/A |

[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 2020. Full estimates for Centers Participation are not available at this time.
[6] New NSF Centers activity in FY 2022.
[7] New NSF Centers activity in FY 2021.

[4] www.fcc.gov/document/fcc-federal-partners-sign-spectrum-innovation-cooperation-agreement

## Centers Supported by NSF in FY 2020

| Center | Institution | State |
|---|---|---|
| **Artificial Intelligence Research Institutes** | | |
| Institute for Trustworthy AI in Weather, Climate, and Coastal Oceanography | 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 Manufacturing | U of Illinois Urbana-Champaign | IL |
| AI Research Institute for Fundamental Interactions | Massachusetts Institute of Techn | MA |
| AI Institute for Next Generation Food Systems | U of California-Davis | CA |
| AI Institute for Future Agricultural Resilience, Management, and Sustainability (AIFARMS) | U of Illinois at Urbana-Champaign | IL |
| **Biology Integration Institutes** | | |
| Behavioral Plasticity Research Institute (BPRI) | Baylor College of Medicine | TX |
| Emergent Ecosystem Responses through Genes-to-Ecosystems 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 |
| **Centers for Analysis and Synthesis** | | |
| National Institute for Mathematical & Biological Synthesis | U of Tennessee | TN |
| Socio-Environmental Synthesis Center | U of Maryland | MD |
| **Centers for Chemical Innovation** (Phase II awards only)[5] | | |
| Center for Chemical Evolution | Georgia Institute of Tech | GA |
| Center for Chemistry at the Space-Time Limit | U of California-Irvine | CA |
| Center for Sustainable Materials Chemistry | Oregon State | OR |
| Center for Sustainable Nanotechnology | U of Wisconsin | WI |
| Center for Sustainable Polymers | U of Minnesota | MN |
| NSF Center for Aerosol Impacts on Chemistry and the Enviro. | U of California-San Diego | CA |
| NSF Center for Selective C-H Functionalization | Emory | GA |
| NSF Center for Genomically Encoded Materials (C-GEM) | U of California-Berkeley | CA |
| NSF Center for Synthetic Organic Electrochemistry (CSOE) | U of Utah | UT |
| **Engineering Research Centers** | | |
| Advanced Self-Powered Systems of Integrated Sensors and Technologies (ASSIST) | North Carolina State | NC |
| Bio-mediated and Bio-inspired Geotechnics (CBBG) | Arizona State | AZ |
| Center for Ultra-wide-area Resilient Electric Energy Transmission Network (CURENT) | U of Tennessee | TN |
| Engineering Research Center for Re-Inventing America's Urban Water Infrastructure (ReNUWIt) | Stanford University | CA |
| 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 Systems (NEWT) | Rice University | TX |
| NSF Engineering Research Center for Cell Manufacturing | Georgia Institute of Tech | GA |

[5] Smaller, developmental Phase I awards do not meet the criteria as formal NSF Centers and so are not captured here.

| | | |
|---|---|---|
| Technologies (CMaT) | | |
| Optimization for Electro-thermal Systems (POETS) | U of Illinois | IL |
| Quantum Energy and Sustainable Solar Technologies (QESST) | Arizona State | AZ |
| Sensorimotor Neural Engineering (CSNE) | U of Washington | WA |
| Translational Applications of Nanoscale Multiferroic Systems (TANMS) | U of California-Los Angeles | CA |
| 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 |
| 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 Urbana-Champaign | IL |
| Laboratory for Research on the Structure of Matter | U of Pennsylvania | PA |
| Materials Research Science and Engineering Center at UCSB | U of California-Santa Barbara | CA |
| Materials Research Science and Engineering Center | U of 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 |
| **Nanoscale Science and Engineering Centers** | | |
| Center for the Environmental Implications of Nanotechnology (CEINT)[6] | Duke | NC |
| Predictive Toxicology Assessment & Safe Implementation of Nanotechnology in the Environment (CEIN)[6] | U of California-Los Angeles | CA |
| **Science and Technology Centers** | | |
| BEACON: An NSF Center for the Study of Evolution in Action | Michigan State | MI |

[6] CEINT and CEIN are operating on no-cost extensions. No funds were obligated for the centers in FY 2020.

| | | |
|---|---|---|
| Biology with X-Ray Free Electron Lasers | SUNY Buffalo | NY |
| Center for Brains, Minds, and Machines: The Science and the Technology of Intelligence | Massachusetts Institute of Tech | MA |
| Center for Bright Beams | Cornell | NY |
| Center for Cellular Construction | U of California-San Francisco | CA |
| Center for Dark Energy Biosphere Investigations | U of Southern California | CA |
| Center for Emergent Behaviors of Integrated Cellular Systems | Massachusetts Institute of Tech | MA |
| Center for Energy Efficient Electronics Science | U of California-Berkeley | CA |
| Center for Engineering MechanoBiology | U of Pennsylvania | PA |
| Center for Integrated Quantum Materials | Harvard | MA |
| Science and Technology Center on Real-Time Functional Imaging | University of Colorado | CO |
| Center for Science of Information | Purdue | IN |

## SECURE AND TRUSTWORTHY COMPUTING (SaTC)

**SaTC Funding**[1]
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|
| CISE | $70.94 | $69.50 | $74.50 |
| EHR | 55.00 | 60.00 | 70.00 |
| ENG | 3.25 | 3.25 | 3.25 |
| MPS | 1.18 | 1.25 | 1.25 |
| SBE | 4.00 | 4.00 | 4.00 |
| **Total** | **$134.37** | **$138.00** | **$153.00** |

[1] Funding displayed may have overlap with other topics and programs.

### 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 a multidisciplinary subject constitutes a promising approach to develop better ways to design, build, and operate cyber systems; to protect existing and future infrastructure; and to motivate and educate individuals about cybersecurity. Achieving these goals not only requires expertise in computer 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*, 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 of and mitigations for current threats. SaTC contributes to the development of foundational countermeasure techniques leveraging sound mathematical and scientific foundations, principled design methodologies, and socio-technical approaches that consider human, social, organizational, economic, and technical factors, as well as design metrics for evaluating success or failure of these approaches. In the space of training and education, SaTC makes recommendations for new instructional materials, degree programs, and educational pathways. Ultimately, through SaTC, NSF funds a broad and deep multidisciplinary research and education portfolio spanning cybersecurity and privacy, whose results underlie methods for securing critical infrastructure. Further, NSF expects to produce an innovation ecosystem that ensures (a) new and existing technologies are secure from both current threats and potential future threats as technologies evolve, and (b) users' information is protected from violations of privacy despite new attack surfaces that 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. *Foundational Research*: Develop the scientific theory, methodologies, and tools necessary for the development of trustworthy and usably secure systems and appropriate privacy safeguards that account for the role of human behavior and decision making.
2. *Accelerating Transition to Practice (TTP)*: Transition 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 solutions and moving them into technical and organizational practice.
3. *Education and Preparation of Cybersecurity Researchers and Professionals*: Increase the number of qualified American students who pursue degrees in cybersecurity and privacy and enhance the capacity of institutions of higher education to produce professionals in these fields to meet the needs of our increasingly digital society. This goal includes NSF's investment in the CyberCorps®: Scholarship for Service (SFS) program.

## FY 2022 Investments

Foundational Research

- NSF will issue a revised SaTC solicitation in FY 2022 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 healthcare information technology infrastructure as well as 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 2022, NSF will continue to explore the role of cybersecurity and privacy research in future pandemics through a virtual organization established in FY 2020 that engages researchers, industry, government, and other stakeholders. This organization will hold a series of workshops to encourage research collaborations with the aim of generating a community-driven research roadmap that identifies key research challenges and directions.
- NSF will invest in research to analyze the flow of information and to mitigate the impacts of false or misleading information in online and other computer-mediated systems. Topics will include detecting, mitigating, and countering threats to accurate information, and understanding the interactions of people with information 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 multi-disciplinary research collaborations 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.

<u>Accelerating TTP</u>

- NSF will continue its focus on transitioning to practice research results that are ready for experimental deployment, early adoption, commercial innovation, and/or implementation in cyberinfrastructure through support of TTP-designated projects. NSF will also continue to support research infrastructure in security and privacy in conjunction with the CISE Community Research Infrastructure program.

<u>Education and Preparation of Cybersecurity Researchers and Professionals</u>

- In support of the 2019 *Federal Cybersecurity Research and Development Strategic Plan*, NSF will continue its focus on cybersecurity education in FY 2022, with the aims of (i) building and sustaining an unrivaled cybersecurity workforce; (ii) promoting the development and maintenance of inclusive learning settings to improve diversity in cybersecurity; and (iii) raising cybersecurity awareness across the general population.
- CyberCorps®: SFS will address a critical shortage of cybersecurity educators and researchers by preparing up to 80 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 other priority areas such as quantum information science and engineering as well as next-generation wireless networks.
- CyberCorps®: SFS will accelerate investments in K-12 education with the aim of growing interest in cybersecurity careers; promoting foundational cybersecurity principles and safe online behavior; improving teaching methods to help K-12 teachers integrate cybersecurity into formal and informal learning settings; and promoting teacher recruitment in the field of cybersecurity.
- NSF will address cybersecurity education and workforce development challenges emerging as a result of the COVID-19 pandemic, including the security, reliability, and privacy of a teleworking and online learning society; cloud services, digitization, and contact-free processes; cyber awareness against opportunistic cybercrime; innovation in incident handling; cyber-enterprise risk management; and societal resilience to misinformation and related activities.

## NSF SELECTED CROSS-CUTTING PROGRAMS

Many investments at NSF draw on interdisciplinary teams from across the Foundation. Other parts of this chapter, NSF-Wide Investments, provide narratives for NSF-wide priority investments. Additional cross-cutting programs at NSF are selected for presentation in the narrative below. Full funding data for these programs are provided in the Summary Tables chapter.

### ADVANCE

In FY 2022, $20.50 million in funding is requested for the ADVANCE program to encourage institutions of higher education and the broader science, technology, engineering, and mathematics (STEM) community, including professional societies and other STEM-related not-for-profit organizations, to address various aspects of STEM academic culture and institutional structure to enhance gender equity for faculty and academic administrators. As such, ADVANCE is an integral part of the NSF's multifaceted strategy to broaden participation in the STEM workforce and supports the critical role of the Foundation in advancing the status of women in academic science and engineering. Further, ADVANCE contributes important research on successfully supporting women in STEM. EHR stewards funding for ADVANCE in FY 2022 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 2022 Request provides $365.02 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% of these student researchers are hired by the member companies.

The FY 2022 Request provides $23.50 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 2022 Request provides $33.54 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 2022 will be used to sustain site-specific research activities examining ecological and evolutionary dynamics in natural populations, communities, and ecosystems, some of which have been studied for over 30 years and conducting syntheses of long-term data using contemporary modeling methods. Funding for LTER is provided by BIO, GEO, and SBE.

The National Ecological Observatory Network (NEON) infrastructure is co-located at eight LTER sites. NEON is a continental-scale infrastructure facility providing standardized physical and data resources to researchers and educators. LTER is a network of long-term research projects aimed at understanding ecological processes in a wide range of ecosystems. Ongoing research at LTER sites may take advantage of data generated using NEON infrastructure. In addition, the co-location of NEON infrastructure at 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 2022, $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.

**Research Experiences for Undergraduates (REU)**

In FY 2022, $84.54 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 Disabilities Education (RDE)**

The FY 2022 Request for NSF's RDE program totals $6.50 million. The RDE activity helps increase participation in STEM for postsecondary students with disabilities. RDE proposals are accepted in all fields of science and engineering supported by NSF, particularly research on learning and education. Planned funding for RDE is provided through EHR's Division on Research on Learning in Formal and Informal Settings, with additional funding provided by OIA, SBE, and EHR's Divisions of Human Resource Development and Undergraduate Education for meritorious projects relevant their communities.

**Research in Undergraduate Institutions (RUI)**

The FY 2022 Request for NSF's RUI program totals $32.99 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.

## SPECTRUM INNOVATION INITIATIVE (SII)

**SII Funding**
(Dollars in Millions)

| FY 2020 Actual | FY 2021 Estimate | FY 2022 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 more efficiently and robustly use this limited natural resource 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 frequency 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 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.
2. Establish and sustain an interdisciplinary National Center for Wireless Spectrum Research (SII-Center), which will catalyze partnerships between government, industry, and academia, and bring teams of scientists, engineers, computer scientists, and social scientists together to innovate. The ultimate goal of the SII-Center is to develop new solutions that enable more efficient use of the electromagnetic spectrum.

[1] www.fcc.gov/document/fcc-federal-partners-sign-spectrum-innovation-cooperation-agreement

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 2022 Investments**

Investments in FY 2022 include the following:

<u>National Radio Dynamic Zones ($9.0 million)</u>
This investment includes funding of initial key milestones toward enhancements in active electromagnetic spectrum management efforts at NSF's major research facilities and platforms as well as computing infrastructure and hardware research and development to support the National Radio Dynamic Zones.

<u>National Center for Wireless Spectrum Research ($5.0 million)</u>
This investment will sustain activities of the first interdisciplinary SII-Center awarded in FY 2021 that will bring together a diverse group of researchers that serve as a hub to develop, innovate, and sustain new solutions that enable more efficient use of the electromagnetic spectrum.

<u>Integration Activities ($2.0 million)</u>
This investment will continue to integrate ongoing and increasing NSF activities, including SWIFT research 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, 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.

## IMPROVING UNDERGRADUATE STEM EDUCATION (IUSE)

**IUSE Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|
| BIO | $2.18 | $5.00 | $4.00 |
| CISE | 3.00 | 3.00 | 3.00 |
| EHR | 89.99 | 90.00 | 90.00 |
| ENG | 7.14 | 5.00 | 5.15 |
| GEO | 6.86 | 8.00 | 6.00 |
| OPP | 0.37 | 0.50 | 0.45 |
| **Total** | **$109.54** | **$111.50** | **$108.60** |

### 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, enabling it to respond rapidly to support Administration priorities. In addition to supporting projects that have specific relevance to any NSF-supported discipline, it also supports projects that span all STEM disciplines. Examples of such cross-cutting efforts include incorporating active learning, increasing access to undergraduate research experiences, and developing cyberlearning courses and instructional materials. This flexibility enables IUSE to respond rapidly to emerging areas and priorities. For example, in FY 2020, 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 science education in service to science and society, contributing to a strong national data science infrastructure and workforce.

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

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[1] National Science Board (2018). Our Nation's Future Competitiveness Relies on Building a STEM-Capable U. S. Workforce. www.nsf.gov/nsb/sei/companion-brief/NSB-2018-7.pdf

[2] Hulten, C. (2017). The Importance of Education and Skill Development for Economic Growth in the Information Era. In Education, Skills, and Technical Change: Implications for Future US GDP Growth. University of Chicago Press. Retrieved from: www.nber.org/chapters/c13937

[3] National Academies of Sciences, Engineering, and Medicine. (2016). Science literacy: Concepts, contexts, and consequences. National Academies Press. Retrieved from: www.nap.edu/catalog/23595/science-literacy-concepts-contexts-and-consequences

remains current with advances in STEM and STEM education. Assessment of the IUSE portfolio will inform decisions about continuing the program beyond FY 2022. However, 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 2022 Investments**

As part of its mission to advance STEM, NSF plans to invest $108.60 million in IUSE in FY 2022. The IUSE initiative's anchor investment is made by IUSE/EHR, a program solicitation within EHR's Division of Undergraduate Education. IUSE/EHR 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/EHR 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/EHR:

- EHR - *IUSE: Hispanic Serving Institutions (HSI) Program*: Supports improvements in retention and graduation rates at HSIs that have not received high levels of NSF support; approximately 40 awards.
- BIO - *IUSE: Research Coordination Networks/Undergraduate Biology Education (RCN-UBE)*: Supports collaborative networks to improve undergraduate biology education; approximately 13 awards.
- ENG - *IUSE/Professional Formation of Engineers: Revolutionizing Engineering Departments (IUSE/PFE:RED)*: Supports organizational change strategies to transform undergraduate engineering education; approximately five awards.
- CISE - *IUSE: Computing in Undergraduate Education (IUSE:CUE)*: Supports teams of institutions of higher education to re-envision the role of computer science 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 seven awards.
- GEO - *IUSE: Pathways into the Earth, Ocean, Polar, and Atmospheric & Geospace Sciences (IUSE:GEOPATHS)*: Supports strategies to increase the number and diversity of undergraduate students pursuing geoscience degrees; approximately 20 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. STEM workforce with graduate-level preparation in 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. Computationally intensive and data-enabled science in areas such as AI and QIS is dramatically changing the knowledge and experience required of researchers and other STEM professionals across all fields. Thus, the preparation of graduate students in STEM must continue to evolve to provide 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 to support discoverers, thus building the diverse and talented next generation of STEM research leaders and professionals in leading-edge scientific areas, across sectors and through inclusive processes. NSF makes a significant investment in the education of graduate students via research assistantships supported 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.

### FY 2022 Investments

NSF's two major agency-wide programs in graduate education are the NSF Research Traineeship (NRT) program and the Graduate Research Fellowship Program (GRFP). EHR's 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.

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[1] National Science Foundation (2016). NSF Strategic Framework for Investments in Graduate Education. National Science Foundation, Alexandria, VA. Retrieved from: www.nsf.gov/pubs/2016/nsf16074/nsf16074.pdf.

[2] National Academy of Sciences, Engineering, and Medicine. 2018. Graduate STEM Education in the 21st Century. Washington,

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 2022, NRT will focus particularly on traineeships that prepare students to lead in emerging industries, such as AI, QIS, Biotechnology, and Advanced Manufacturing.

NRT addresses interdisciplinary graduate education through two approaches: traineeships and fundamental research into graduate education. Traineeships emphasize a comprehensive training model that is innovative, evidence-based, and aligned with changing workforce and research needs, which effectively prepares 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 programs 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 15-18 traineeships and invest up to $4.0 million in fundamental research on graduate education.

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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 acd.od.nih.gov/documents/reports/bmw_report.pdf

**NRT Funding**
(Dollars in Millions)

| FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|
| **$49.63** | **$58.00** | **$58.00** |

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 2022, GRFP will be funded entirely within EHR at a total of $318.52 million. This funding will support a total of 2,500 new fellows with a cost of education allowance of $12,000 and a stipend of $34,000. The GRFP program will continue to welcome proposals from all S&E fields and also align awards with NSF and Administration research priorities, including AI, QIS, and other emerging industries.

**GRFP Funding by Account**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|
| Education and Human Resources | $284.51 | $284.52 | $318.52 |
| Research and Related Activities[2] | *[142.26]* | *[142.26]* | - |
| **Total** | **$284.51** | **$284.52** | **$318.52** |
| Number of New Fellows | 2,007 | 2,000 | 2,500 |
| Projected Fellows on Tenure[1] | 5,664 | 5,820 | 6,170 |

[1] Fellowship tenure status is the period of time during which fellows actively use the fellowship award to pursue an advanced degree in a STEM or STEM education field.

[2] In FY 2022, funding will be consolidated in Education and Human Resources. Prior year funding is restated for comparability across fiscal years.

CyberCorps®: Scholarship for Service

The SFS program addresses cybersecurity education and workforce development by providing funding to institutions to support development of cybersecurity educational programs 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 to improve cybersecurity education, 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 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|
| **$54.99** | **$60.00** | **$70.00** |

Additional Programs and Activities Supporting STEM Graduate Education and Workforce Development

*Louis Stokes Alliances for Minority Participation-Bridge to the Doctorate (LSAMP-BD)*
The LSAMP program assists universities and colleges in diversifying the STEM workforce by increasing the number of STEM baccalaureate and graduate degrees awarded to 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 underrepresented groups. 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 2022, LSAMP expects to direct about $10.60 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 about 300 Masters or PhD students in FY 2022. 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 2022, 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 critical 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**

<table>
<tr><th>Track</th><th>Outcome</th><th>Eligible Individuals</th><th>Support</th><th>Length of Commitment to Teach in High-need Schools</th></tr>
<tr><td>Scholarships and Stipends</td><td rowspan="2">Highly effective K-12 STEM teachers in high need schools/districts</td><td rowspan="2">STEM professionals</td><td>One-year scholarship to become certified/licensed teacher</td><td>2 years</td></tr>
<tr><td>Teaching Fellowship</td><td>One-year Scholarship to complete a master’s degree in education and salary supplement* during teaching commitment</td><td>4 years</td></tr>
<tr><td>Master Teaching Fellowships</td><td>Highly effective K-12 teacher leaders in STEM education in high need schools/districts</td><td>K-12 STEM teachers without a master’s degree</td><td>One-year Scholarship to complete a master’s degree and salary supplement during teaching commitment</td><td>5 years**</td></tr>
</table>

**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 2022.

**Additional Programs Supporting STEM Graduate Education and Funding Workforce Development**

(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|
| LSAMP-BD | $5.38 | - | $10.60 |
| S-STEM | 13.90 | 10.00 | 10.00 |
| Noyce Teaching and Master Teaching Fellows (10A) | 27.75 | 20.00 | 20.00 |
| **Total** | **$47.03** | **$30.00** | **$40.60** |

**RESEARCH AND RELATED ACTIVITIES (R&RA)** **$8,139,710,000**
**+$1,259,230,000 / 18.3%**

The FY 2022 Budget Request for the Research and Related Activities account is $8,139.71 million. Funding within the R&RA Appropriation invests in early-stage research as well as development of a future-focused science and engineering workforce that can support the private sector and accelerate progress in basic science and engineering research.

NSF is the only federal agency dedicated to funding basic research across all areas of non-biomedical science and engineering. In FY 2022, NSF will continue its longstanding commitment to investing in learning and discovery that will promote the innovations that will be the foundation for the Nation's future prosperity.

This Budget Request establishes a new Directorate for Technology, Innovation, and Partnerships (TIP) to advance research and innovation leading to breakthrough technologies and solutions to national and societal challenges. This directorate will constitute a crosscutting platform that leverages, energizes, and rapidly brings to market and to society the innovations that result from all of NSF's investments. Further, TIP will open up new possibilities for research and education by catalyzing strategic partnerships linking academia, industry, government, philanthropy, investors, and civil society to cultivate 21st-century local, regional, and national innovation ecosystems. See the crosswalk on the next page for more information.

**R&RA Funding**[1]
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| Biological Sciences | $809.31 | $818.14 | $948.51 | $130.37 | 15.9% |
| Computer & Information Science & Engineering | 996.40 | 1,005.49 | 1,116.06 | 110.57 | 11.0% |
| Engineering | 754.31 | 761.85 | 916.79 | 154.94 | 20.3% |
| Geosciences | 993.72 | 1,004.18 | 1,194.92 | 190.74 | 19.0% |
| Mathematical & Physical Sciences | 1,530.12 | 1,580.48 | 1,690.74 | 110.26 | 7.0% |
| Social, Behavioral & Economic Sciences | 280.35 | 282.06 | 319.66 | 37.60 | 13.3% |
| Technology, Innovation, & Partnerships | 352.31 | 364.87 | 864.87 | 500.00 | 137.0% |
| Office of International Science & Engineering | 51.04 | 51.32 | 75.32 | 24.00 | 46.8% |
| Office of Polar Programs | 480.59 | 483.35 | 506.29 | 22.94 | 4.7% |
| Integrative Activities[2] | 352.97 | 527.14 | 504.90 | -22.24 | -4.2% |
| U.S. Arctic Research Commission | 1.60 | 1.60 | 1.65 | 0.05 | 3.1% |
| **Total** | **$6,602.70** | **$6,880.48** | **$8,139.71** | **$1,259.23** | **18.3%** |

[1] To account for the creation of TIP in FY 2022, funding in FY 2020 and FY 2021 is restated for comparability across fiscal years. Impacted programs include Convergence Accelerator, NSF Innovation Corps, Partnerships for Innovation, and SBIR/STTR (including operations).

[2] The Graduate Research Fellowship Program will be consolidated into the Directorate for Education and Human Resources in FY 2022. Funding in FY 2020 and FY 2021 is removed from IA for comparability across fiscal years. See the EHR chapter for more information.

**Restatement of Programs to the Directorate for Technology, Innovation, and Partnerships (TIP)**
(Dollars in Millions)

| NSF Directorates/Office & Divisions | FY 2020 Actual | Programs Moved | Restated FY 2020 Actual | FY 2021 Estimate | Programs Moved | Restated FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Restated Estimate: Amount | Change over FY 2021 Restated Estimate: Percent |
|---|---|---|---|---|---|---|---|---|---|
| *Biological Sciences* | | | | | | | | | |
| Molecular & Cellular Biosciences (MCB) | 153.54 | - | 153.54 | 155.64 | - | 155.64 | 170.74 | 15.10 | 9.7% |
| Integrative Organismal Systems (IOS) | 204.05 | - | 204.05 | 206.98 | - | 206.98 | 227.07 | 20.09 | 9.7% |
| Environmental Biology (DEB) | 171.31 | - | 171.31 | 178.86 | - | 178.86 | 196.22 | 17.36 | 9.7% |
| Biological Infrastructure (DBI) | 181.85 | - | 181.85 | 167.08 | - | 167.08 | 204.89 | 37.81 | 22.6% |
| Emerging Frontiers (EF) | 99.71 | -1.15 | 98.56 | 110.79 | -1.21 | 109.58 | 149.59 | 40.01 | 36.5% |
| *NSF Innovation Corps (I-Corps™)* | *1.15* | *-1.15* | - | *1.21* | *-1.21* | - | | | |
| **Total, BIO** | **$810.46** | **-$1.15** | **$809.31** | **$819.35** | **-$1.21** | **$818.14** | **$948.51** | **$130.37** | **15.9%** |
| *Computer & Information Science & Engineering* | | | | | | | | | |
| Office of Advanced Cyberinfrastructure (OAC) | 228.65 | - | 228.65 | 230.54 | - | 230.54 | 252.19 | 21.65 | 9.4% |
| Computing & Communication Foundations (CCF) | 199.34 | - | 199.34 | 201.00 | - | 201.00 | 218.50 | 17.50 | 8.7% |
| Computer & Network Systems (CNS) | 236.14 | - | 236.14 | 238.12 | - | 238.12 | 259.87 | 21.75 | 9.1% |
| Information & Intelligent Systems (IIS) | 216.02 | - | 216.02 | 217.87 | - | 217.87 | 238.59 | 20.72 | 9.5% |
| Information Technology Research (ITR) | 132.13 | -15.89 | 116.24 | 134.69 | -16.73 | 117.96 | 146.91 | 28.95 | 24.5% |
| *NSF Innovation Corps (I-Corps™)* | *15.89* | *-15.89* | - | *16.73* | *-16.73* | - | | | |
| **Total, CISE** | **$1,012.29** | **-$15.89** | **$996.40** | **$1,022.22** | **-$16.73** | **$1,005.49** | **$1,116.06** | **$110.57** | **11.0%** |
| *Engineering* | | | | | | | | | |
| Chemical, Bioengineering, Enviro. & Transport Systems (CBET) | 197.92 | - | 197.92 | 199.96 | - | 199.96 | 241.05 | 41.09 | 20.5% |
| Civil, Mechanical, & Manufacturing Innovation (CMMI) | 238.58 | - | 238.58 | 241.13 | - | 241.13 | 290.50 | 49.37 | 20.5% |
| Electrical, Communications, & Cyber Systems (ECCS) | 122.86 | - | 122.86 | 124.05 | - | 124.05 | 149.52 | 25.47 | 20.5% |
| Emerging Frontiers & Multidisciplinary Activities (EFMA) | 70.88 | - | 70.88 | 71.69 | - | 71.69 | 86.42 | 14.73 | 20.5% |
| Engineering Education & Centers (EEC) | 104.42 | 19.64 | 124.06 | 105.57 | 19.45 | 125.02 | 149.30 | 24.28 | 19.4% |
| *Disciplinary/Interdisciplinary Research - shifted from IIP* | | *7.48* | *7.48* | | *6.17* | *6.17* | | | |
| *Industry/University Coop. Research Ctrs. (I/UCRC) - shifted from IIP* | | *12.04* | *12.04* | | *12.88* | *12.88* | | | |
| *Improving Undergraduate STEM Education (IUSE) -- shifted from IIP* | | *0.13* | *0.13* | | *0.25* | *0.25* | | | |
| *REU Supplements - shifted from IIP* | - | - | - | - | *0.15* | *0.15* | | | |
| Industrial Innovation & Partnerships (IIP) | 291.46 | -291.46 | - | 292.98 | -292.98 | - | - | - | N/A |
| *Disciplinary/Interdisciplinary Research - shifted to EEC* | *7.48* | *-7.48* | - | *6.17* | *-6.17* | - | | | |
| *Industry/University Coop. Research Ctrs. (I/UCRC) - shifted to EEC* | *12.04* | *-12.04* | - | *12.88* | *-12.88* | - | | | |
| *Improving Undergraduate STEM Education (IUSE) - shifted to EEC* | *0.13* | *-0.13* | - | *0.25* | *-0.25* | - | | | |
| *REU Supplements - shifted to EEC* | - | - | - | *0.15* | *-0.15* | - | | | |
| *SBIR/STTR Operations - shifted to TIP* | *4.93* | *-4.93* | - | *5.00* | *-5.00* | - | | | |
| *Small Business Innovation Research (SBIR) - shifted to TIP* | *196.04* | *-196.04* | - | *199.06* | *-199.06* | - | | | |
| *Small Business Technology Transfer (STTR) - shifted to TIP* | *31.10* | *-31.10* | - | *28.00* | *-28.00* | - | | | |
| *NSF Innovation Corps (I-Corps™) - shifted to TIP* | *17.68* | *-17.68* | - | *18.66* | *-18.66* | - | | | |
| *Partnerships for Innovation (PFI) - shifted to TIP* | *22.07* | *-22.07* | - | *22.81* | *-22.81* | - | | | |
| **Total, ENG** | **$1,026.13** | **-$271.82** | **$754.31** | **$1,035.38** | **-$273.53** | **$761.85** | **$916.79** | **$154.94** | **20.3%** |
| *Geosciences* | | | | | | | | | |
| Atmospheric & Geospace Sciences (AGS) | 280.08 | - | 280.08 | 283.47 | - | 283.47 | 341.71 | 58.24 | 20.5% |
| Earth Sciences (EAR) | 199.21 | - | 199.21 | 201.36 | - | 201.36 | 240.04 | 38.68 | 19.2% |
| Ocean Sciences (OCE) | 401.36 | - | 401.36 | 403.05 | - | 403.05 | 476.14 | 73.09 | 18.1% |
| Integrative & Collaborative Education & Research (ICER) | 113.76 | -0.69 | 113.07 | 117.03 | -0.73 | 116.30 | 137.03 | 20.73 | 17.8% |
| *NSF Innovation Corps (I-Corps™)* | *0.69* | *-0.69* | - | *0.73* | *-0.73* | - | | | |
| **Total, GEO** | **$994.41** | **-$0.69** | **$993.72** | **$1,004.91** | **-$0.73** | **$1,004.18** | **$1,194.92** | **$190.74** | **19.0%** |
| *Mathematical & Physical Sciences* | | | | | | | | | |
| Astronomical Sciences (AST) | 279.10 | - | 279.10 | 277.05 | - | 277.05 | 294.05 | 17.00 | 6.1% |
| Chemistry (CHE) | 260.37 | - | 260.37 | 259.71 | - | 259.71 | 284.14 | 24.43 | 9.4% |
| Materials Research (DMR) | 330.15 | - | 330.15 | 329.78 | - | 329.78 | 349.92 | 20.14 | 6.1% |
| Mathematical Sciences (DMS) | 244.09 | - | 244.09 | 243.54 | - | 243.54 | 259.47 | 15.93 | 6.5% |
| Physics (PHY) | 304.39 | | 304.39 | 303.90 | - | 303.90 | 316.59 | 12.69 | 4.2% |
| Office of Multidisciplinary Activities (OMA) | 113.97 | -1.96 | 112.01 | 168.56 | -2.06 | 166.50 | 186.57 | 20.07 | 12.1% |
| *NSF Innovation Corps (I-Corps™)* | *1.96* | *-1.96* | - | *2.06* | *-2.06* | - | | | |
| **Total, MPS** | **$1,532.08** | **-$1.96** | **$1,530.12** | **$1,582.54** | **-$2.06** | **$1,580.48** | **$1,690.74** | **$110.26** | **7.0%** |
| *Social, Behavioral & Economic Sciences* | | | | | | | | | |
| Division of Behavioral & Cognitive Sciences (BCS) | 98.64 | - | 98.64 | 99.41 | - | 99.41 | 113.16 | 13.75 | 13.8% |
| Division of Social & Economic Sciences (SES) | 99.87 | - | 99.87 | 102.83 | - | 102.83 | 117.08 | 14.25 | 13.9% |
| National Center for Science & Engineering Statistics (NCSES) | 55.20 | - | 55.20 | 55.48 | - | 55.48 | 61.48 | 6.00 | 10.8% |
| SBE Office of Multidisciplinary Activities (SMA) | 27.22 | -0.58 | 26.64 | 24.95 | -0.61 | 24.34 | 27.94 | 3.60 | 14.8% |
| *NSF Innovation Corps (I-Corps™)* | *0.58* | *-0.58* | - | *0.61* | *-0.61* | - | | | |
| **Total, SBE** | **$280.93** | **-$0.58** | **$280.35** | **$282.67** | **-$0.61** | **$282.06** | **$319.66** | **$37.60** | **13.3%** |
| *Integrative Activities* | | | | | | | | | |
| IA Program Funding | 555.45 | -$60.23 | 495.23 | 597.14 | -70.00 | 527.14 | 504.90 | -22.24 | -4.2% |
| *Convergence Accelerator (CA)* | *60.23* | *-60.23* | - | *70.00* | *-70.00* | - | | | |
| **Total, IA** | **$555.45** | **-$60.23** | **$495.23** | **$597.14** | **-$70.00** | **$527.14** | **$504.90** | **-$22.24** | **-$0.04** |
| *Technology Innovation Partnerships* | | | | | | | | | |
| Innovation Ecosystems (IE) | - | $98.18 | $98.18 | - | $110.00 | $110.00 | 335.00 | 225.00 | 204.5% |
| *Convergence Accelerator (CA)* | | *60.23* | *60.23* | | *70.00* | *70.00* | *70.00* | - | - |
| *NSF Innovation Corps (I-Corps™)* | | *37.95* | *37.95* | | *40.00* | *40.00* | *40.00* | - | - |
| Partnerships Office (PO) | - | - | - | - | - | - | 50.00 | 50.00 | N/A |
| Technology Frontiers (TF) | - | - | - | - | - | - | 150.00 | 150.00 | N/A |
| Translational Impact (TI) | - | 254.13 | 254.13 | - | 254.87 | 254.87 | 329.87 | 75.00 | 29.4% |
| *Partnerships for Innovation (PFI)* | | *22.07* | *22.07* | | *22.81* | *22.81* | *30.00* | *7.19* | *31.5%* |
| *SBIR/STTR Operations* | | *4.93* | *4.93* | | *5.00* | *5.00* | *5.00* | - | - |
| *Small Business Innovation Research (SBIR)* | | *196.04* | *196.04* | | *199.06* | *199.06* | *236.39* | *37.33* | *18.8%* |
| *Small Business Technology Transfer (STTR)* | | *31.10* | *31.10* | | *28.00* | *28.00* | *33.25* | *5.25* | *18.8%* |
| **Total, TIP** | **-** | **$352.31** | **$352.31** | **-** | **$364.87** | **$364.87** | **$864.87** | **$500.00** | **137.0%** |

See the individual directorate and office narratives in this chapter for more detail.

## Appropriations Language

For necessary expenses in carrying out the National Science Foundation Act of 1950 (42 U.S.C. 1861 et seq.), and Public Law 86-209 (42 U.S.C. 1880 et seq.); services as authorized by section 3109 of title 5, United States Code; maintenance and operation of aircraft and purchase of flight services for research support; acquisition of aircraft; and authorized travel; $~~6,909,769,000~~8,139,710,000, to remain available until September 30, ~~2022~~2023, of which not to exceed $544,000,000 shall remain available until expended for polar research and operations support, and for reimbursement to other Federal agencies for operational and science support and logistical and other related activities for the United States Antarctic program: *Provided*, That receipts for scientific support services and materials furnished by the National Research Centers and other National Science Foundation supported research facilities may be credited to this appropriation.

**Research and Related Activities**
**FY 2022 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 2020 Appropriation | $6,812.20 | $16.21 | -$10.27 | $19.22 | -$22.40 | $6,814.96 |
| FY 2021 Estimated | 6,909.77 | 10.27 | | | -$29.29 | 6,890.75 |
| FY 2022 Request | 8,139.71 | | | | | 8,139.71 |
| $ Change from FY 2021 Estimated | | | | | | $1,248.96 |
| % Change from FY 2021 Estimated | | | | | | 18.1% |

Totals exclude reimbursable amounts.

## Explanation of Carryover

<u>Research and Related Activities (R&RA)</u>
Within the R&RA account, $10.27 million (including $3.27 million in no-year recoveries) was carried over into FY 2021.

Integrative Activities Research Investment Communications

- Amount: $1.93 million
- Purpose: Funding will be used on four procurement actions in process that will be completed in time for award this fiscal year.
- Obligation: FY 2021 Quarter 2

Integrative Activities for Convergence Accelerator–Future of Work at the Human Technology Frontier (CA-FW-HTF)

- Amount: $2.30 million
- Purpose: Grantee failed the Division of Institution and Award Support (DIAS) pre-award administrative/financial review. Cost Analysis and Pre-award Branch (CAP) delayed any re-evaluations until FY 2021; thus, funding is delayed until FY 2021.
- Obligation: FY 2021 Quarter 2 and Anticipated FY 2021 Quarter 3

Integrative Activities for Convergence Accelerator Research

- Amount: $553,198
- Purpose: Funds will be used to pay for curriculum development and delivery for both the 2019 Cohort Phase II and the 2020 Cohort Phase I.
- Obligation: FY 2021 Quarter 2 and Anticipated FY 2021 Quarter 3

Integrative Activities for Program Planning and Policy Development

- Amount: $441,580
- Purpose: These funds will be used to support IA's stewardship of merit review process.
- Obligation: FY 2021 Quarter 2 and Anticipated FY 2021 Quarter 3

National Coordination Office for Networking and Information Technology Research and Development

- Amount: $67,409
- Purpose: Funding to continue government procurements and operational expenses (i.e., credit card purchases, government travel, mailroom operations, etc.).
- Obligation: Anticipated FY 2021 Quarter 4

National Nanotechnology Coordination Office

- Amount: $2,982
- Purpose: Funding for the National Nanotechnology Coordination Office (NNCO) for NNCO operational expenses.
- Obligation: Anticipated FY 2021 Quarter 4

The remaining $1.71 million within R&RA consists of funds from throughout the Foundation for projects not funded in FY 2020.

**DIRECTORATE FOR BIOLOGICAL SCIENCES (BIO)** **$948,510,000**
**+$130,370,000 / 15.9%**

**BIO Funding**
(Dollars in Millions)

| | FY 2020 Actual[1] | FY 2020 CARES Act Actual | FY 2021 Estimate[1] | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|---|
| Molecular and Cellular Biosciences (MCB) | $153.54 | - | $155.64 | $170.74 | $15.10 | 9.7% |
| Integrative Organismal Systems (IOS) | 204.05 | - | 206.98 | 227.07 | 20.09 | 9.7% |
| Environmental Biology (DEB) | 171.31 | - | 178.86 | 196.22 | 17.36 | 9.7% |
| Biological Infrastructure (DBI) | 181.85 | | 167.08 | 204.89 | 37.81 | 22.6% |
| Emerging Frontiers (EF) | 98.56 | 19.00 | 109.58 | 149.59 | 40.01 | 36.5% |
| **Total** | **$809.31** | **$19.00** | **$818.14** | **$948.51** | **$130.37** | **15.9%** |

[1] FY 2020 and FY 2021 funding is adjusted for comparabilty to reflect the movement of I-Corps™ to TIP in FY 2022. See the R&RA Overview for more details.

## About BIO

BIO supports fundamental research and infrastructure that promotes a unified understanding of life in all forms, from the biological molecules that are the machinery of living cells to the populations of organisms and species that underpin the functioning of the Nation's ecosystems. In the past decade, biology has been transformed by new tools to describe and manipulate genomes, new means of sensing processes at multiple biological scales simultaneously, and new computational and artificial intelligence (AI) approaches in bioinformatics and modeling to unveil the regulation of complex living systems. BIO seeks to capitalize on these advances to vastly improve our ability to understand life's deepest mysteries, and to enable new capabilities to modify organisms and ecosystems for societal benefit and economic prosperity. The key to innovations that will drive the Nation's bioeconomy is through discovery and harnessing of 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, in cellular, organismal, and developmental biology, and in bioinformatics spur further development of capabilities in synthetic biology and enhance biotechnology beyond the current state-of-the-art. The accelerating power of this advanced biotechnology promises to sustain U.S. economic growth and innovation across multiple sectors including agriculture, biomanufacturing, pharmaceuticals, and other bioproducts. BIO investments in biotechnology also aid development of a circular bioeconomy that reduces carbon emissions and creates new sources of clean energy. BIO investments in ecology, evolution, and biodiversity, including support for the National Ecological Observatory Network (NEON), promote the development of dynamic, eco-forecasting models to predict climate change impacts at local, national, and global scales. BIO investments in life's innovations will similarly 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 statistics, 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.

As the lead directorate, BIO is the steward of funds designated for NSF-wide investments for Big Idea: Understanding the Rules of Life (URoL). URoL is a convergence research funding opportunity addressing scientific and societal needs pertinent to advancing biotechnology and promoting the bioeconomy. URoL is focused on elucidating the rules that govern the emergence of complex organismal traits and behaviors, such as robustness and adaptability, using highly interdisciplinary approaches that engage all the major disciplines represented across NSF's directorates and offices. URoL frames the essential challenges and opportunities associated with genotype to phenotype (structure to function) relationships. Through stewardship of URoL, BIO enables research that leads to a predictive understanding of biological systems at all scales. This knowledge is what drives advances in understanding the human body and improving health, enabling sustainable and efficient food production, harnessing biological systems to mitigate the impacts of climate change, and to enable bio-based manufacturing and new forms of energy production. For more information about the Big Ideas, please see the narratives in the NSF-Wide Investments chapter.

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. Unlike URoL, 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.

There will be great emphasis placed on racial equity, as BIO continues to invest in activities to broaden participation, including INCLUDES and HBCU-EiR as well as new opportunities for mid-career scientists and researchers from groups underrepresented in STEM and with strong track records of prior accomplishment to pursue new transformative avenues of research. BIO will continue to utilize its Postdoctoral Research Fellowships in Biology program to support a diversity of young researchers, with a focus on broadening participation. BIO will increase investments in Research Experiences for Teachers (RET) to provide new opportunities to engage teachers and their classrooms in STEM, and support early engagement, creating inclusive learning environments. BIO is investing in new efforts to encourage professional societies to develop collaborative networks focused on advancing diversity, equity, and inclusion through an activity called LEAPS: Leading cultural change through Professional Societies.

BIO promotes other opportunities for convergence research and training through active participation and foundational investments in several Big Ideas beyond URoL. BIO participates in the NNA Big Idea through investments in environmental research and observational infrastructure in the Arctic, through the Long-Term Ecological Research program (LTER) and NEON. BIO participates in Quantum Information Science (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 provides 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 establish a new Center for Open Environmental Data Synthesis to advance modeling and forecasting capability for climate change impacts.

BIO provides 66 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 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| Advanced Manufacturing | $8.48 | $7.16 | $17.16 | $10.00 | 139.7% |
| Artificial Intelligence | 13.78 | 20.00 | 20.00 | - | - |
| Biotechnology | 110.00 | 110.00 | 130.00 | 20.00 | 18.2% |
| Climate: Clean Energy Technnology | 18.00 | 45.00 | 59.28 | 14.28 | 31.7% |
| Climate: USGCRP | 90.00 | 145.00 | 212.15 | 67.15 | 46.3% |
| Improving Undergraduate STEM Education | 2.18 | 5.00 | 4.00 | -1.00 | -20.0% |
| Quantum Information Science | 3.28 | 3.28 | 3.28 | - | - |
| NSF's Big Ideas | | | | | |
| *URoL Stewardship* | *29.95* | *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.

- 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: 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, and 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.
- 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 NSF-Wide Investments chapter.
- Quantum Information Science (QIS): BIO will continue to support QIS through investments in fundamental research in biophysics that seek to understand quantum phenomena within living systems and can inform applications in quantum information science.
- URoL: BIO will provide stewardship support for NSF URoL Big Idea, 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 increase 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.

- COVID-19: In response to the pandemic, BIO has reviewed and expanded existing programs in infectious disease research to better align with Administration priorities and national needs. BIO will enhance support for research to advance a predictive understanding of mechanisms mediating antagonistic or beneficial interactions among viruses, bacteria, plants, and animals. BIO will also increase investments in the Ecology and Evolution of Infectious Diseases (EEID) program, supporting research on the ecological, evolutionary, and social drivers that influence infectious diseases' transmission dynamics. BIO will launch a new funding opportunity, Predictive Intelligence for Pandemic Prevention (PIPP), which aims to forecast the emergence of infectious disease and prevent future pandemics. This new effort is being co-led by BIO and CISE but emphasizes interdisciplinary research that includes ENG and SBE.

**BIO Funding for Centers Programs and Major Facilities**

**BIO Funding for Centers Programs**

(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| Biology Integration Institutes | $21.63 | $25.00 | $35.82 | $10.82 | 43.3% |
| Centers for Analysis & Synthesis | 4.80 | - | 4.00 | 4.00 | N/A |
| STC: Bio/computation Evolution in Action CONsortium (BEACON) | 1.30 | - | - | - | N/A |
| STC: Biology with X-ray Lasers (BioXFEL) | 5.00 | 4.15 | 3.32 | -0.83 | -20.0% |
| STC: Center for Cellular Construction (CCC) | 5.00 | 5.00 | 5.00 | - | - |
| **Total** | **$37.73** | **$34.15** | **$48.14** | **$13.99** | **41.0%** |

For detailed information on individual centers programs, please see the NSF-Wide Investments chapter.

**BIO Funding for Major Facilities**

(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| National Ecological Observatory Network (NEON) (DBI) | $65.00 | $65.00 | $70.00 | $5.00 | 7.7% |
| **Total** | **$65.00** | **$65.00** | **$70.00** | **$5.00** | **7.7%** |

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

## Funding Profile

**BIO Funding Profile**

| | FY 2020 Actual Estimate | FY 2021 Estimate | FY 2022 Estimate |
|---|---|---|---|
| **Statistics for Competitive Awards:** | | | |
| Number of Proposals | 3,785 | 3,200 | 3,300 |
| Number of New Awards | 1,371 | 1,100 | 1,200 |
| Regular Appropriation | 1,255 | 1,100 | 1,200 |
| CARES Act | 116 | | |
| Funding Rate | 36% | 34% | 36% |
| **Statistics for Research Grants:** | | | |
| Number of Research Grant Proposals | 3,063 | 2,600 | 2,700 |
| Number of Research Grants | 1,116 | 900 | 1,000 |
| Regular Appropriation | 1,001 | 900 | 1,000 |
| CARES Act | 115 | | |
| Funding Rate | 36% | 35% | 37% |
| Median Annualized Award Size | $200,000 | $210,000 | $220,000 |
| Average Annualized Award Size | $242,781 | $260,000 | $270,000 |
| Average Award Duration, in years | 3.0 | 3.2 | 3.4 |

BIO supports investment in core research and education as well as research infrastructure. In FY 2022, BIO will invest $48.14 million in research centers, accounting for 5.08 percent of the BIO budget, funding fourteen BIIs, a new Center 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 2022 Request.

## Program Monitoring and Evaluation

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

## People Involved in BIO Activities

**Number of People Involved in BIO Activities**

| | FY 2020 Actual Estimate | FY 2020 CARES Act Actual Estimate | FY 2021 Estimate | FY 2022 Estimate |
|---|---|---|---|---|
| Senior Researchers | 4,232 | 170 | 4,300 | 5,000 |
| Other Professionals | 1,341 | 46 | 1,400 | 1,600 |
| Postdoctoral Associates | 1,422 | 44 | 1,500 | 1,600 |
| Graduate Students | 2,765 | 79 | 2,800 | 3,000 |
| Undergraduate Students[1] | 4,578 | 30 | 5,000 | 5,800 |
| **Total Number of People** | **14,338** | **369** | **15,000** | **17,000** |

[1] The FY 2020 Actual for Undergraduates is adjusted downward from prior agency reported levels to correct an award reporting error.

**DIVISION OF MOLECULAR AND CELLULAR BIOSCIENCES (MCB)** **$170,740,000**
**+$15,100,000 / 9.7%**

**MCB Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| **Total** | **$153.54** | **$155.64** | **$170.74** | **$15.10** | **9.7%** |
| **Research** | **149.90** | **153.64** | **167.54** | **13.90** | **9.0%** |
| CAREER | 21.81 | 37.36 | 37.36 | - | - |
| **Education** | **1.64** | **1.00** | **2.20** | **1.20** | **120.0%** |
| **Infrastructure** | **2.00** | **1.00** | **1.00** | - | - |
| Midscale Research Infrastructure Programs | 1.00 | - | - | - | N/A |
| Center for High Energy X-ray Sciences (CHEXS) | 1.00 | 1.00 | 1.00 | - | - |

## 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 how it guides expression of cellular characteristics; (b) how material and energy are taken up, transformed, and flow through biological systems, and (c) how biological molecules assemble into complex structures and compartments with varied functions. MCB supported research uses tools of molecular biophysics, systems biology, and synthetic biology to probe these 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 the molecular and cellular scales. This basic research at the interface of biological, mathematical, physical, and computer sciences and engineering provides the basis for a quantitative, predictive, theory driven understanding of molecular and cellular functions of biological systems across the tree of life. MCB supported research continues to leverage the latest advances across science and engineering, including single molecule imaging, artificial intelligence, and synthetic biology, and advances a clear mechanistic understanding of biological processes such as deoxyribonucleic acid (DNA) maintenance and repair, clustered regularly interspaced short palindromic repeats (CRISPR), and CRISPR-associated (Cas) genome editing. Advances in basic research enable the development of design rules for engineering molecules and cells, which contributes directly to biological innovations that advance emerging industries, and advance the U.S. bioeconomy, medicine, agriculture, environmental sustainability, and biomanufacturing. MCB research has the potential to address challenges by providing biotechnology solutions to mitigate the impact of climate change; by expanding the molecular level understanding of virus replication; and by supporting the development platform technologies using the tools of synthetic biology necessary to rapidly detect (and treat) future threats from infectious organisms.

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 INTEGRATIVE ORGANISMAL SYSTEMS (IOS)** **$227,070,000**
**+$20,090,000 / 9.7%**

**IOS Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| **Total** | **$204.05** | **$206.98** | **$227.07** | **$20.09** | **9.7%** |
| **Research** | **195.36** | **198.18** | **216.67** | **18.49** | **9.3%** |
| CAREER | 26.37 | 25.24 | 25.24 | - | - |
| **Education** | **5.14** | **4.80** | **6.40** | **1.60** | **33.3%** |
| **Infrastructure** | **3.55** | **4.00** | **4.00** | **-** | **-** |
| Research Resources | 3.55 | 4.00 | 4.00 | - | - |

**About IOS**

IOS supports fundamental research and training that focuses on the functional, phenotypic characteristics of diverse organisms. IOS prioritizes research aimed at integrating knowledge that links biological molecules and complex populations, with the goal of understanding the processes that build and maintain organisms. Specifically, IOS funded research focuses on mechanistic analyses of how biological systems interact and function – spanning the nervous system, organism growth and development, behavior, and genetic, genomic, biochemical, biophysical, and physiological processes – and how these are integrated and result in stability of organisms living in dynamic environments. Such analysis is fundamental to understanding the principles that produce the vast diversity of life on Earth and the mechanisms that allow for biological adaptation to change.

IOS encourages interdisciplinary science and the development of new approaches through the Enabling Discovery through GEnomics (EDGE) program which partners with NIH. IOS will continue to leverage its activities across the spectrum of NSF basic science in conjunction with agricultural research supported by the U.S. Department of Agriculture's National Institutes of Food and Agriculture. Funding research on plant biotic interactions and tools for high-throughput analysis of agriculturally important plants, are examples of this partnership. Previous investments in computational biology in neuroscience and support for the NSF-Simons Research Centers for Mathematics of Complex Biological Systems are maintained as priorities.

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

In general, about 72 percent of the IOS portfolio is available for new research grants, and 28 percent is available for continuing grants.

**DIVISION OF ENVIRONMENTAL BIOLOGY (DEB)** **$196,220,000**
**+$17,360,000 / 9.7%**

**DEB Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| **Total** | **$171.31** | **$178.86** | **$196.22** | **$17.36** | **9.7%** |
| **Research** | **165.85** | **176.16** | **192.52** | **16.36** | **9.3%** |
| CAREER | 11.82 | 30.55 | 30.55 | - | - |
| **Education** | **5.46** | **2.70** | **3.70** | **1.00** | **37.0%** |

## About DEB

DEB supports fundamental research on Earth's biodiversity and the ecological and evolutionary processes that explain the origin and maintenance of genetic variation in nature, including its history and patterns of speciation and extinction. DEB supported research also advances understanding of the functional importance of our natural biodiversity heritage to ecological and ecosystem processes occurring over short- and long-temporal and spatial scales. The discoveries from this research can inform strategies to develop, use, and sustain biological resources, including natural, agricultural, and other managed ecosystems, and to forecast changes in species populations and ecosystems 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 of invasive species, and their impacts on wild, managed, and agricultural systems. Eco-forecasting models developed from biodiversity and ecological research are also used to predict environmental drivers of conflict, enhance our ability to strategically prepare for environmental threats, and field defense and mitigation capabilities that are resilient and adaptive.

In general, 76 percent of the DEB portfolio is available for new research grants, and 24 percent is available for continuing grants.

**DIVISION OF BIOLOGICAL INFRASTRUCTURE (DBI)** **$204,890,000**
**+$37,810,000 / 22.6%**

**DBI Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| **Total** | **$181.85** | **$167.08** | **$204.89** | **$37.81** | **22.6%** |
| **Research** | **44.20** | **33.91** | **56.29** | **22.38** | **66.0%** |
| CAREER | 7.08 | 6.58 | 6.58 | - | - |
| Centers Funding (total) | 37.73 | 34.15 | 44.14 | 9.99 | 29.3% |
| Biology Integration Institutes | 21.63 | 25.00 | 35.82 | 10.82 | 43.3% |
| Centers for Analysis & Synthesis | 4.80 | - | - | - | N/A |
| STC: Bio/computation Evolution in Action CONsortium (BEACON) | 1.30 | - | - | - | N/A |
| STC: Biology with X-ray Lasers (BioXFEL) | 5.00 | 4.15 | 3.32 | -0.83 | -20.0% |
| STC: Center for Cellular Construction (CCC) | 5.00 | 5.00 | 5.00 | - | - |
| **Education** | **22.03** | **19.95** | **24.60** | **4.65** | **23.3%** |
| **Infrastructure** | **115.62** | **113.22** | **124.00** | **10.78** | **9.5%** |
| NEON | 65.00 | 65.00 | 70.00 | 5.00 | 7.7% |
| NNCI | 0.35 | 0.35 | 0.35 | - | - |
| Research Resources | 50.27 | 47.87 | 53.65 | 5.78 | 12.1% |

**About DBI**

DBI empowers biological discovery by supporting the development and enhancement of biological research resources, human capital, and facilities. DBI supports the development of, or improvements to, research infrastructure, including cyberinfrastructure; 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. In addition, DBI offers a multi-track postdoctoral research fellowships program with special emphasis on interdisciplinary research training, and on broadening participation in the biological sciences. 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 capacity of the biological sciences research community through funding cyberinfrastructure and other tools necessary to address the NSF URoL Big Idea.

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

**DIVISION OF EMERGING FRONTIERS (EF)** **$149,590,000**
**+$40,010,000 / 36.5%**

**EF Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| **Total** | **$98.56** | **$109.58** | **$149.59** | **$40.01** | **36.5%** |
| **Research** | **87.52** | **109.58** | **149.59** | **40.01** | **36.5%** |
| Centers Funding (total) | - | - | 4.00 | 4.00 | N/A |
| Centers for Analysis & Synthesis | - | - | 4.00 | 4.00 | N/A |
| **Education** | **3.11** | **-** | **-** | **-** | **N/A** |
| **Infrastructure** | **7.93** | **-** | **-** | **-** | **N/A** |
| Research Resources | 7.93 | - | - | - | N/A |

**About EF**

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

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

In general, 70 percent of the EF portfolio is available for new research grants, and 30 percent is available for continuing grants.

## DIRECTORATE FOR COMPUTER AND INFORMATION SCIENCE AND ENGINEERING (CISE) $1,116,0600,000 +$110,577,000 / 11.0%

**CISE Funding**
(Dollars in Millions)

| | FY 2020 Actual[1] | FY 2020 CARES Act Actual | FY 2021 Estimate[1] | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|---|
| Office of Advanced Cyberinfrastructure (OAC) | $228.65 | $0.90 | $230.54 | $252.19 | $21.65 | 9.4% |
| Computing and Communication Foundations (CCF) | 199.34 | 1.40 | 201.00 | 218.50 | 17.50 | 8.7% |
| Computer and Network Systems (CNS) | 236.14 | 6.20 | 238.12 | 259.87 | 21.75 | 9.1% |
| Information and Intelligent Systems (IIS) | 216.02 | 6.00 | 217.87 | 238.59 | 20.72 | 9.5% |
| Information Technology Research (ITR) | 116.24 | 0.50 | 117.96 | 146.91 | 28.95 | 24.5% |
| **Total** | **$996.40** | **$15.00** | **$1,005.49** | **$1,116.06** | **$110.57** | **11.0%** |

[1] Funding for FY 2020 and FY 2021 is adjusted for comparability to reflect the movement of I-Corps™ to TIP in FY 2022. See the R&RA Overview for more details.

### About CISE

Advances in information technology (IT) over the past two 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 permeate 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 racial equity in science and engineering, 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, long-term research and research infrastructure projects within and across the many subfields of computing, as well as advanced research CI for all areas of science and engineering; contributes to the education and training of computing 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 racial 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 and Technology Research (ITR), and through the Office of Advanced Cyberinfrastructure (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, the private sector, and international funders.

In FY 2022, CISE will continue to play a leadership role in advancing the Nation's priorities, through seminal investments in artificial intelligence (AI), advanced computing systems and services including

[1] www.nap.edu/catalog/25961/information-technology-innovation-resurgence-confluence-and-continuing-impact

high-performance computing (HPC), quantum information science (QIS), advanced communications technologies, advanced manufacturing, biotechnology, cybersecurity, and disaster response and resilience. CISE's investments in these areas are critically important for national security, economic competitiveness, 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.

CISE's FY 2022 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 funds in its ITR division to support convergent activities that transcend the traditional disciplinary boundaries of individual NSF units. CISE's FY 2022 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 Future Advanced Computing Ecosystem (FACE).[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. Key foci will include sustainable and interoperable software that will exploit emerging highly multicore, heterogeneous, and energy-efficient architectures; data maintenance and curation; next-generation security capabilities; and workforce training and re-skilling. These investments will enable shared resources and improved capabilities across a range of disciplines, a diverse set of users within a large number of academic institutions, and a wide range of science and engineering advances.

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

As 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 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. Finally, CISE's investments in Computer Science for All (CSforAll) and CISE Graduate Fellowships (CSGrad4US) will emphasize training of U.S.-based students with diverse backgrounds.

Finally, CISE will build, strengthen, and expand strategic, multisector partnerships, including those with

[2] www.nitrd.gov/pubs/Future-Advanced-Computing-Ecosystem-Strategic-Plan-Nov-2020.pdf

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 the Partnerships Office within the TIP directorate.

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

**Major Investments**

**CISE Major Investments**
(Dollars in Millions)

| Area of Investment[1,2] | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| Advanced Manufacturing | $42.37 | $42.22 | $42.22 | - | - |
| Advanced Wireless Research | 88.76 | 88.76 | 93.26 | 4.50 | 5.1% |
| Artificial Intelligence | 329.80 | 329.80 | 349.80 | 20.00 | 6.1% |
| Climate: Clean Energy Technology | 18.50 | 23.50 | 31.12 | 7.62 | 32.4% |
| Microelectornics and Semiconductors | 18.46 | 18.46 | 23.46 | 5.00 | 27.1% |
| Quantum Information Science | 17.59 | 19.28 | 24.28 | 5.00 | 25.9% |
| Secure & Trustworthy Cyberspace | 70.94 | 69.50 | 74.50 | 5.00 | 7.2% |
| NSF's Big Ideas | | | | | |
| *HDR Stewardship* | *30.00* | *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.

- 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 other federal agencies and the private sector, CISE will support the Resilient and Intelligent Next-Generation Systems program, laying the groundwork for next-generation wireless connections that will enable faster service, networks more resilient to natural disasters and service interruptions, and broader access for people across the U.S. CISE investments in city-scale research testing platforms through the Platforms for Advanced Wireless Research program will also speed up the lab-to-market translation of innovative research outcomes in academic and government labs to successful commercial products and services.
- AI: CISE, together with other NSF directorates/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; 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 critical gap in America's AI research and education portfolio by accelerating AI innovations, training AI researchers and innovators, and transitioning outcomes across a range of sectors. CISE investments in AI align with the *National Artificial Intelligence Research and Development Strategic Plan: 2019 Update*.[3] CISE AI investments will also emphasize AI research, education and workforce development, and infrastructure activities at minority-serving institutions (MSIs). Specifically, CISE will broaden participation by intentionally focusing on the development of AI research capacity at MSIs, the involvement of populations long underrepresented in AI in research activities, and the formation of partnerships spanning multiple MSIs and other institution types.

- Climate: Clean Energy Technology: CISE will support research and education projects on all sustainability topics in which advances in computing and information 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. Information technologies, computational solutions, and investments in cyberinfrastructure are essential to understanding the complex interactions and tradeoffs tied to immediate and emerging sustainability challenges in many critical areas, including climate change, natural resource depletion, loss of biodiversity, extreme events, sustainable energy and infrastructure, and human well-being on a resource-constrained planet. 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.
- 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 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. A particular focus of CISE's investments in QIS will be to continue growing capacity within academic computer and information science departments, including cross-disciplinary and multi-department collaborations, to support advances in quantum computing and/or communication over the long term.
- SaTC: CISE will continue to lead SaTC in partnership with EHR, ENG, MPS, and SBE, investing in current and emerging areas of importance for security and privacy. These areas include the application of AI to security, security and resilience of AI systems, security implications of quantum computation and communication, and critical infrastructure security. CISE will also invest in research to analyze the flow of information and mitigate the impacts of misinformation in online and other computer-mediated systems. Topics will include detecting, countering, and mitigating threats to information systems; and understanding the interactions of humans with information systems. This includes analyzing factors that increase trust in communications and understanding the motivations of actors creating and transmitting information and misinformation. CISE SaTC investments will also nurture the next generation of American cybersecurity and privacy researchers and practitioners.
- HDR Stewardship: CISE, as the steward for HDR, will support fundamental research in data science and engineering; development of a cohesive, federated approach to the research data infrastructure; and

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

development of a 21st-century data-capable workforce.

## CISE Funding for Centers Programs

**CISE Funding for Centers Programs**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| Artificial Intelligence Research Institutes | $9.71 | $25.50 | $30.50 | $5.00 | 19.6% |
| STC: Center for the Science of Information (CCF) | 1.30 | - | - | - | N/A |
| STC: Center for Brains, Minds and Machines: The Science and the Technology of Intelligence (CCF, IIS, ITR) | 5.00 | 4.15 | 3.32 | -0.83 | -20.0% |
| **Total** | **$16.01** | **$29.65** | **$33.82** | **$4.17** | **14.1%** |

For detailed information on individual centers programs, please see the NSF-Wide Investments chapter.

## Funding Profile

**CISE Funding Profile**

| | FY 2020 Actual Estimate | FY 2021 Estimate | FY 2022 Estimate |
|---|---|---|---|
| **Statistics for Competitive Awards:** | | | |
| Number of Proposals | 7,925 | 8,250 | 9,000 |
| Number of New Awards | 1,965 | 2,010 | 2,450 |
| Regular Appropriation | 1,838 | 2,010 | 2,450 |
| CARES Act | 127 | | |
| Funding Rate | 25% | 24% | 27% |
| **Statistics for Research Grants:** | | | |
| Number of Research Grant Proposals | 7,587 | 7,950 | 8,150 |
| Number of Research Grants | 1,767 | 1,800 | 2,200 |
| Regular Appropriation | 1,640 | 1,800 | 2,200 |
| CARES Act | 127 | | |
| Funding Rate | 23% | 23% | 27% |
| Median Annualized Award Size | $165,793 | $166,000 | $200,000 |
| Average Annualized Award Size | $203,545 | $204,000 | $250,000 |
| Average Award Duration, in years | 2.8 | 2.8 | 3.0 |

In FY 2022, the number of research grant proposals is expected to increase as compared to the FY 2021 Estimate, and correspondingly the number of research grant awards is anticipated to increase to 2,250. The funding rate for research grants is expected to be 28 percent in FY 2022, an increase over the FY 2021 estimate. Average annualized award size and average award duration are expected to increase slightly between the FY 2021 Estimate and FY 2022 Estimate.

## Program Monitoring and Evaluation

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

## People Involved in CISE Activities

**Number of People Involved in CISE Activities**

| | FY 2020 Actual Estimate | FY 2020 CARES Act Actual Estimate | FY 2021 Estimate | FY 2022 Estimate |
|---|---|---|---|---|
| Senior Researchers | 7,982 | 223 | 8,100 | 9,000 |
| Other Professionals | 1,059 | 23 | 1,100 | 1,200 |
| Postdoctoral Associates | 559 | 19 | 600 | 700 |
| Graduate Students | 6,578 | 140 | 6,600 | 7,300 |
| Undergraduate Students | 3,192 | 30 | 3,200 | 3,500 |
| **Total Number of People** | **19,370** | **435** | **19,600** | **21,700** |

## OFFICE OF ADVANCED CYBERINFRASTRUCTURE (OAC) **$252,190,000** **+21,650,000 / 9.4%**

**OAC Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| **Total** | **$228.65** | **$230.54** | **$252.19** | **$21.65** | **9.4%** |
| **Research** | **70.87** | **86.22** | **96.99** | **10.77** | **12.5%** |
| CAREER | 2.60 | 1.25 | 1.40 | 0.15 | 12.0% |
| Centers Funding (total) | - | 4.00 | 4.00 | - | - |
| Artificial Intelligence Research Institutes | - | 4.00 | 4.00 | - | - |
| **Education** | **7.50** | **10.07** | **10.95** | **0.88** | **8.7%** |
| **Infrastructure** | **150.28** | **134.25** | **144.25** | **10.00** | **7.4%** |
| Networking and Computational Resources | 150.28 | 134.25 | 144.25 | 10.00 | 7.4% |

### About OAC

OAC supports the conceptualization, design, and implementation of the advanced research cyberinfrastructure (CI) ecosystem that is critical to advances in all areas of science and engineering research and education in the 21st century, including 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 provide NSF's leadership of the Future Advanced Computing Ecosystem (FACE) strategic plan. This activity supports 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.

In general, about 48 percent of the OAC portfolio is available to support new grants. The remaining 52 percent supports grants made in prior years.

## DIVISION OF COMPUTING AND COMMUNICATION FOUNDATIONS (CCF) — $218,500,000 / +$17,500,000 / 8.7%

**CCF Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| **Total** | **$199.34** | **$201.00** | **$218.50** | **$17.50** | **8.7%** |
| **Research** | **187.28** | **186.41** | **203.10** | **16.69** | **9.0%** |
| CAREER | 24.44 | 16.50 | 18.30 | 1.80 | 10.9% |
| Centers Funding (total) | 6.05 | 4.99 | 5.00 | 0.01 | 0.2% |
| Artificial Intelligence Research Institutes | 1.75 | 2.50 | 3.00 | 0.50 | 20.0% |
| STC: Center for the Science of Information (CCF) | 1.30 | - | - | - | N/A |
| STC: Center for Brains, Minds and Machines: The Science and the Technology of Intelligence (CCF, IIS, ITR) | 3.00 | 2.49 | 2.00 | -0.49 | -19.7% |
| **Education** | **10.46** | **12.99** | **13.80** | **0.81** | **6.2%** |
| **Infrastructure** | **1.60** | **1.60** | **1.60** | **-** | **-** |
| National Nanotechnology Coordinated Infrastructure (NNCI) | 0.60 | 0.60 | 0.60 | - | - |
| Research Resources | 1.00 | 1.00 | 1.00 | - | - |

### About CCF

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

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

**DIVISION OF COMPUTER AND NETWORK SYSTEMS (CNS)** **$259,870,000**
**+$21,750,000 / 9.1%**

**CNS Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| **Total** | **$236.14** | **$238.12** | **$259.87** | **$21.75** | **9.1%** |
| **Research** | **191.27** | **199.38** | **221.27** | **21.89** | **11.0%** |
| CAREER | 15.62 | 11.50 | 12.75 | 1.25 | 10.9% |
| Centers Funding (total) | - | 3.00 | 3.50 | 0.50 | 16.7% |
| Artificial Intelligence Research Institutes | - | 3.00 | 3.50 | 0.50 | 16.7% |
| **Education** | **16.25** | **14.99** | **15.60** | **0.61** | **4.1%** |
| **Infrastructure** | **28.62** | **23.75** | **23.00** | **-0.75** | **-3.2%** |
| Research Resources | 28.62 | 23.75 | 23.00 | -0.75 | -3.2% |

**About CNS**

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

In general, about 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) — $238,590,000 +$20,720,000 / 9.5%

**IIS Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| **Total** | **$216.02** | **$217.87** | **$238.59** | **$20.72** | **9.5%** |
| **Research** | **201.83** | **202.28** | **222.39** | **20.11** | **9.9%** |
| CAREER | 30.12 | 21.00 | 23.30 | 2.30 | 11.0% |
| Centers Funding (total) | 4.96 | 8.83 | 10.66 | 1.83 | 20.7% |
| Artificial Intelligence Research Institutes | 3.96 | 8.00 | 10.00 | 2.00 | 25.0% |
| STC: Center for Brains, Minds and Machines: | 1.00 | 0.83 | 0.66 | -0.17 | -20.5% |
| **Education** | **12.19** | **13.59** | **14.20** | **0.61** | **4.5%** |
| **Infrastructure** | **2.00** | **2.00** | **2.00** | **-** | **-** |
| Research Resources | 2.00 | 2.00 | 2.00 | - | - |

### 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 71 percent of the IIS portfolio is available to support new grants. The remaining 29 percent supports grants made in prior years.

**DIVISION OF INFORMATION TECHNOLOGY RESEARCH (ITR)** **$146,910,000**
**+$28,950,000 / 24.5%**

**ITR Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| **Total** | **$116.24** | **$117.96** | **$146.91** | **$28.95** | **24.5%** |
| **Research** | **92.98** | **95.31** | **132.12** | **36.81** | **38.6%** |
| CAREER | 0.01 | - | - | - | N/A |
| Centers Funding (total) | 5.00 | 8.83 | 10.66 | 1.83 | 20.7% |
| Artificial Intelligence Research Institutes | 4.00 | 8.00 | 10.00 | 2.00 | 25.0% |
| STC: Center for Brains, Minds and Machines: The Science and the Technology of Intelligence | 1.00 | 0.83 | 0.66 | -0.17 | -20.5% |
| **Education** | **6.40** | **8.65** | **3.55** | **-5.10** | **-59.0%** |
| **Infrastructure** | **16.87** | **14.00** | **11.24** | **-2.76** | **-19.7%** |
| Research Resources | 16.87 | 14.00 | 11.24 | -2.76 | -19.7% |

## 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 urgent high-priority areas that cut across traditional disciplinary boundaries and promise to accelerate discovery at the frontiers of the field. This includes support for foundational research on AI, QIS, particularly quantum computation and communication, and advanced wireless; innovative partnerships and collaborations between academia and industry; as well as the development of world-class research infrastructure. ITR investments, often in partnership with all CISE divisions as well as NSF directorates, agencies, and industry, further understanding of the climate, address racial equity, and 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. These activities will enable pursuit of fundamental research in data science and engineering; the development of a cohesive, federated, national-scale approach to research data infrastructure; and the development of a 21st-century data-capable workforce. While budget management and reporting for this investment will be the responsibility of CISE, the convergent activities will be overseen and managed collaboratively by the multi-directorate/office HDR leadership team.

In general, about 35 percent of the ITR portfolio is available to support new grants. The remaining 65 percent supports grants made in prior years.

## APPENDIX A – ADVANCED COMPUTING SYSTEMS AND SERVICES PORTFOLIO

**Advanced Computing Systems and Services Funding**
(Dollar in Millions)

| | FY 2020 Actual Estimate | FY 2021 Estimate | FY 2022 Estimate |
|---|---|---|---|
| Leadership Class Computing | $4.00 | $12.50 | $14.50 |
| Advanced/Innovative Computing Systems and Services | 55.60 | 61.25 | 42.00 |
| Coordination and Support Services | 23.84 | 10.00 | 37.50 |
| **Total** | **$83.44** | **$83.75** | **$94.00** |

### Advanced Computing Systems and Services Overview

For nearly four decades, NSF has been a recognized leader in enabling the innovative use and broad availability of a cohesive, powerful, and advanced computing ecosystem to accelerate fundamental science and engineering (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 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 2017, OAC launched an effort to refresh the vision, strategy, and investment approaches for CI, including advanced computing, to support the evolving needs of the S&E community,[8] and also funded a study seeking to identify and catalog best practices for collaborations between academic

[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] sc20.supercomputing.org/proceedings/bof/bof_pages/bof143.html
[8] www.nsf.gov/cise/oac/ci2030/

or federally-funded HPC centers and industry.[9] This refresh effort was informed, in part, by responses to an RFI on *Future Needs for Advanced Cyberinfrastructure to Support Science and Engineering Research (NSF CI 2030)*.[10] In 2019, NSF funded a conference focused on the *National Cyberinfrastructure Coordination Service Conference*, which examined the configuration of services intrinsic to a national CI.[11] 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."[12] Although focused primarily on data and software CI, the responses to this RFI[13] 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[14] 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.[15] As detailed in the blueprint, NSF will enhance its current investments in three broad and complementary advanced computing areas that enable it to meet these 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 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 2022, 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.

[9] www.ncsa.illinois.edu/assets/pdf/industry/Industry_Report_2017.pdf
[10] www.nsf.gov/cise/oac/ci2030/rfi_responses.jsp
[11] www.rti.org/publication/national-cyberinfrastructure-coordination-service-conference
[12] www.nsf.gov/pubs/2020/nsf20015/nsf20015.jsp
[13] www.nsf.gov/cise/oac/datacirfi/rfi_responses.jsp
[14] www.rcac.purdue.edu/ciworkforce2020/
[15] 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.

The previous NSF leadership-class computing system, Blue Waters, which is deployed at the National Center for Supercomputing Applications at the University of Illinois at Urbana-Champaign (UIUC), was originally anticipated to complete its operational cycle in December 2019. However, the National Geospatial-Intelligence Agency provided funding to NSF to maintain the system into FY 2021 to support automated, large-scale generation of digital elevation models. As a result, Blue Waters will now complete its operational service in December 2021.

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 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[16] 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 Major Facilities Guide.[17] LCCF planning will continue in FY 2022, with construction start for 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[18] describing a new innovative pilot mechanism for the Nation's researchers to request

[16] www.nsf.gov/pubs/2017/nsf17558/nsf17558.htm

[17] www.nsf.gov/pubs/2019/nsf19068/nsf19068.pdf

[18] www.nsf.gov/pubs/2020/nsf20018/nsf20018.jsp

access to Frontera to enable scientific and engineering research that would not otherwise be possible without access to a leadership-class computing resource. This effort resulted in 48 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; detailed material modeling in support of the Materials Genome Initiative to facilitate the computational design of future novel materials; atomic-level simulation of the influenza virus to understand influenza infection processes and transmissibility; 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 critical 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[19] which provides a year-long opportunity for talented graduate students to compute on Frontera and collaborate with experts at TACC; this program awarded five fellowships in FY 2020.

Management and Oversight

The Frontera and Blue Waters projects are overseen by OAC's program directors and BFA's Division of Grants and Agreements staff, who receive strategic advice from the AD Council. Advice from the NSF Office of General Counsel is also sought, as necessary. Planning for the 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**

Description

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

Deployed systems currently serve as a cohesive set of allocable resources within the eXtreme Digital (XD) integrated services infrastructure, which is described in the following section. Awards are generally made as two parts: an acquisition and deployment award, which may be the result of a competitive or a renewal proposal; and a separate award for O&M following deployment. When an award is made, the awardee

[19] frontera-portal.tacc.utexas.edu/fellowship/

institution issues subawards to vendors and/or other organizations for acquisitions and services, as necessary. Expenditures are contingent on successful completion of deployment milestones.

Current Status

Three advanced computing systems (Comet, Bridges, and Jetstream) commenced operations in FY 2015 and FY 2016, and their periods of operation were extended in FY 2018, as noted below, allowing for increased return on investment and ensuring continuity of operations for the research community. Stampede 2, the largest of the currently active HPC resources within this portfolio, commenced operation in FY 2017.

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

Bridges came online in FY 2016 at the Pittsburgh Supercomputing Center (PSC) on the campus of Carnegie Mellon University (CMU). Bridges provides an innovative HPC and data analytics system integrating advanced memory technologies to empower new communities. It brings desktop convenience to HPC, potentially enabling new communities to access advanced computing resources. Bridges was augmented with GPU nodes in FY 2018 and may remain operational through November 2021. Operation of the successor system, Bridges-2 (described below), begins in FY 2021 and as a result Bridges may be decommissioned earlier than the planned November 2021 date.

Jetstream also came online in FY 2016 at Indiana University. Jetstream is a cloud-based platform that incorporates the elements of commercial cloud computing resources with important scientific applications. Jetstream's system operation was augmented in FY 2017 to provide additional focused staff expertise to accelerate effective researcher utilizations of the programmable CI/virtual machine-enabled architecture. Initially planned to conclude operations in November 2020, NSF awarded a supplement in FY 2020 to enable this system to continue operations through November 2021. This supplement will also maintain continuity of operations through the COVID-19 pandemic, enabling seamless transition to a successor resource (Jetstream 2) described below.

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 as a successor resource to the highly successful Stampede system. Like its predecessor system, 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 November 2022 with a possible one-year extension to enable seamless transition to a newer generation of systems as described below.

As noted above, Comet, Bridges, and Jetstream are all scheduled to ramp down operations in FY 2021. During this period, Stampede 2 and Frontera will continue full operations, ensuring continued support for the S&E research community. 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[20] in FY 2019, with the first cohort of three awards running from FY 2019

[20] nsf.gov/funding/pgm_summ.jsp?pims_id=503148

to FY 2024,[21] followed by a second cohort of five awards running from FY 2020 to FY 2025.[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 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 UIUC; and two Category II awards were made to SDSC and PSC. Given interruptions to supply chains resulting from the COVID-19 pandemic, scheduled deployments of the FY 2019 cohort were slightly delayed, but the systems are coming online in FY 2021. When fully deployed, the suite of Category I systems will include the following:

- *Expanse*: Located at SDSC and intended to be the successor system to Comet, 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 and intended to be the successor to the current Bridges system, this system is expected to be operational from FY 2021 through FY 2024. Bridges 2 will integrate 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. Bridges-2 currently supports "early users" and transition to production operations, following a successful acceptance review, is anticipated by June 20, 2021.
- *Anvil*: Located at Purdue University, a new service provider within the NSF ecosystem of advanced computing systems, Anvil is expected to 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.
- *Jetstream 2*: Located at Indiana University and intended to be the successor to the current Jetstream system, Jetstream 2 is expected to be operational from FY 2022 through FY 2025. Jetstream 2 will be 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.

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 will incorporate processors originally developed to lead Japanese national efforts[23] towards future computing to advance U.S.-based S&E research and education. Given its success to date, this system transitioned to production operations in January 2021.

[21] www.nsf.gov/pubs/2019/nsf19534/nsf19534.htm
[22] www.nsf.gov/pubs/2019/nsf19587/nsf19587.htm
[23] www.r-ccs.riken.jp/en/fugaku/project

- *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 highly-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.

The ACSS solicitation was reissued for FY 2021 with a focus on Category II Systems. NSF expects to make up to two additional awards. In FY 2022, NSF expects to make up to three awards in Category I to offset the effects of retiring Stampede 2 as previously discussed.

<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 of the periodic NSF external reviews, conducted by an external panel of experts, is to revisit and reassess the risk situation and make recommendations as deemed necessary. In the case of projects that involve an acquisition, project risks are generally substantially reduced subsequent to deployment. Thus, the pacing of the acquisitions and deployments for such projects provides balance in the overall risk portfolio for the program.

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

**Coordination and Support Services**

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 and expertise to diverse, dynamic, and distributed resources is a cornerstone of the American advanced computing ecosystem; enabling the connection between individual campuses and national resources is an essential aspect.

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

XD shared services consist of several interrelated parts: allocation of resources to computational and data research projects; advanced user assistance; training, education, and outreach; architecture and operation of an integrated digital services infrastructure; metrics services; and overall coordination. These elements are designed and implemented in a way that is clearly tied to the requirements of the 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.

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).

The 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.

The 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. In FY 2020, the XMS project was extended to June 2021.

Based on its engagements with the community about the structure and composition of future coordination efforts, NSF issued the *Advanced Cyberinfrastructure Coordination Ecosystem: Services & Support (ACCESS)* and *ACCESS - Coordination Office (ACCESS-ACO)* solicitations[24-25] in early FY 2021 and expects to make a suite of coordination services awards in FY 2022. The continuation of the XSEDE and XMS awards is intended to provide a smooth transition to the new structure with minimal disruption to the community.

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,

[24] www.nsf.gov/pubs/2021/nsf21555/nsf21555.htm
[25] www.nsf.gov/pubs/2021/nsf21556/nsf21556.htm?org=NSF

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.

XSEDE has annual external reviews at NSF. The first external review of the renewed XSEDE project took place in June 2017; subsequent external milestone reviews have taken place in January and June of every year, with the most recent review having occurred in June 2020. On the basis of these successful reviews, funds were authorized for continued operations.

NSF has outlined its plans for national CI coordination services moving forward in a blueprint document released in FY 2020,[26] and subsequently issued the *ACCESS* and *ACCESS-ACO* solicitations in FY 2021.

S&E Research and Education Activities Enabled by Coordination and Support Services

Coordination and support services, as exemplified by XD, 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 extreme-scale digital resources beyond those typically available on most campuses, together with the interfaces, consulting, advanced user support, and training necessary to facilitate their use.

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

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

The XMS project develops analysis tools and collects operational data from XSEDE services and the advanced computing/innovative systems and services. The immediate users of these methods and tools are the providers of NSF-supported advanced computing systems and services. However, both tools and data are publicly available and used by other projects such as Frontera, many academic research computing centers, federal agencies, and industry.

Management and Oversight

OAC's program directors oversee the XD projects. XSEDE has an external advisory board, a user board, and a service provider forum to ensure that all stakeholders can provide project input. OAC oversight of the XSEDE project includes participation in weekly teleconferences with senior XSEDE personnel and in quarterly project-wide staff meetings. Formal reporting consists of quarterly and annual reports, which are reviewed by the program directors. Each XD award is managed under a cooperative agreement that includes requirements for a specific management structure, milestones, reporting of spending levels over time, and a review schedule. Each awardee is responsible for the satisfactory completion of milestones prior to NSF authorization of spending. In addition, each project is required to have a detailed management plan in place.

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

While XD is operational in nature, the virtual organizations of the XSEDE project and the services of all XD projects are innovative and thus bear inherent risks. The projects maintain risk registers that are reviewed periodically by external panels and by the cognizant program directors. Annual reviews for XSEDE and mid-project reviews for XMS are conducted by external panels of expert reviewers and managed by OAC program directors.

## DIRECTORATE FOR ENGINEERING (ENG) $916,790,000

**+ $154,940,000 / 20.3%**

**ENG Funding**[1]

(Dollars in Millions)

| | FY 2020 Actual | FY 2020 CARES Act Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|---|
| Chemical, Bioengineering, Environmental and Transport Systems (CBET) | $197.92 | $7.70 | $199.96 | $241.05 | $41.09 | 20.5% |
| Civil, Mechanical, and Manufacturing Innovation (CMMI) | 238.58 | 3.75 | 241.13 | 290.50 | 49.37 | 20.5% |
| Electrical, Communications, and Cyber Systems (ECCS) | 122.86 | 1.50 | 124.05 | 149.52 | 25.47 | 20.5% |
| Engineering Education and Centers (EEC) | 124.06 | 1.30 | 125.02 | 149.30 | 24.28 | 19.4% |
| Emerging Frontiers and Multidisciplinary Activities (EFMA) | 70.88 | 0.75 | 71.69 | 86.42 | 14.73 | 20.5% |
| **Total** | **$754.31** | **$15.00** | **$761.85** | **$916.79** | **$154.94** | **20.3%** |

[1] The Division of Industrial Innovation and Partnerships (IIP) will be 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. See the R&RA Overview for more details.

### About ENG

In FY 2022, 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 commercial 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, IUCRC, GOALI). Working together with the new TIP directorate, ENG will spur the engineering research community to follow existing well-established pathways towards technology translation, including I-Corps, PFI, and 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 2022 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 2022 investments will build future prosperity through essential contributions to research on advanced manufacturing and supply chains, new materials and semiconductor technologies, and clean energy. 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 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.

There will also be great emphasis placed on supporting 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.

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.

While fundamental engineering research fuels U.S. technological innovation and competitiveness, ENG support for workforce development and innovation speeds and strengthens the translation of discoveries. The directorate will invest in research on education, broadening participation, 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, investment in CAREER, and opportunities for mid-size, interdisciplinary team research. ENG investments in academic partnerships with industry will help bring new ideas from lab to market and fortify the Nation's innovation ecosystem.

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

ENG provides 39 percent of the federal funding for basic research at academic institutions in the engineering disciplines.

## Major Investments

**ENG Major Investments**

(Dollars in Millions)

| Area of Investment[1,2] | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| Advanced Manufacturing | $127.99 | $117.37 | $174.37 | $57.00 | 48.6% |
| Advanced Wireless Research | 24.36 | 23.45 | 25.80 | 2.35 | 10.0% |
| Artificial Intelligence | 91.47 | 87.15 | 95.80 | 8.65 | 9.9% |
| Biotechnology | 92.76 | 90.94 | 101.50 | 10.56 | 11.6% |
| Climate: Clean Energy Technnology | 113.54 | 123.03 | 178.57 | 55.54 | 45.1% |
| Improving Undergraduate STEM Education | 7.14 | 5.00 | 5.15 | 0.15 | 3.0% |
| Microelectronics & Semiconductors | 30.43 | 34.77 | 40.00 | 5.23 | 15.0% |
| Quantum Information Science | 23.83 | 27.89 | 32.89 | 5.00 | 17.9% |
| Secure & Trustworthy Cyberspace | 3.25 | 3.25 | 3.25 | - | - |
| NSF's Big Ideas | | | | | |
| *FW-HTF Stewardship* | *30.00* | *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.

- 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 2022 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, 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 and capacity for revolutionary microelectronics design, architecture, and fabrication, as well as high-performance computing. New discoveries will enable the nation to overcome crucial scientific barriers for emerging technologies such as artificial intelligence, quantum technologies, and interconnected autonomous systems, and they will strengthen U.S. scientific leadership, economic prosperity, and national security.
- QIS: ENG, together with other NSF directorates and offices, will increase support for quantum information science and engineering research. ENG's QIS investments strongly align with the *National Quantum Initiative Act* (P.L. 115-368) to consolidate and expand U.S. global leadership in fundamental quantum research. QIS research will deliver proof-of-concept devices, applications, tools, or systems with a demonstrable quantum advantage over their classical counterparts. Research in QIS examines uniquely quantum phenomena that can be harnessed to advance information processing, transmission, measurement, and fundamental understanding in ways that classical approaches can only do much less efficiently, or not at all. Current and future QIS applications differ from prior applications of quantum mechanics, such as the laser, transistor, and magnetic resonance imaging, by using distinct quantum phenomena—superposition and entanglement—that do not have classical counterparts. QIS research activities will also address education and workforce development needs, with specific investments in Minority Serving Institutions (MSIs), broadening research collaborations, promoting innovative team-building activities, and stimulating cross-disciplinary curriculum development and training to provide a quantum-smart workforce.

- SaTC: ENG support for SaTC will focus on the engineering aspects of the NITRD Strategic Plan for the Federal Cybersecurity Research and Development Program.[1] NITRD's research thrusts cover a set of interrelated priorities for U.S. government agencies that conduct or sponsor research and development in cybersecurity.
- FW-HTF: ENG will continue to steward the FW-HTF Big Idea. While financial stewardship for this Emerging Frontiers and Multidisciplinary Activities (EFMA) investment will be the responsibility of ENG, the convergence activities will be overseen and managed collaboratively by the multi-directorate/office FW-HTF leadership team. ENG will work closely with OIA's Convergence Accelerator (CA) for the area of FW-HTF, building on collaborative design of the CA model that draws on ENG experience in technology translation and partnerships.

**ENG Funding for Centers Programs**

**ENG Funding for Centers Programs**

(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| Engineering Research Centers (EEC) | $54.61 | $56.90 | $68.70 | $11.80 | 20.7% |
| National Artificial Intelligence Research Institutes (Multiple) | 5.00 | 9.05 | 9.25 | 0.20 | 2.2% |
| STC: Emergent Behaviors for Integrated Cellular Systems (CBET)[1] | 1.30 | - | - | - | N/A |
| STC: Engineering Mechano-Biology (CMMI) | 4.95 | 5.00 | 5.00 | - | - |
| STC: Energy Efficient Electronics Sytems (ECCS)[1] | 1.30 | - | - | - | N/A |
| **Total** | **$67.16** | **$70.95** | **$82.95** | **$12.00** | **16.9%** |

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

For detailed information on individual centers programs, please see the NSF-Wide Investments chapter.

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

## Funding Profile

**ENG Funding Profile**

| | FY 2020 Actual Estimate | FY 2021 Estimate | FY 2022 Estimate |
|---|---|---|---|
| **Statistics for Competitive Awards:** | | | |
| Number of Proposals | 6,358 | 6,400 | 7,400 |
| Number of New Awards | 1,633 | 1,520 | 1,750 |
| Regular Appropriation | 1,516 | 1,520 | 1,750 |
| CARES Act | 117 | | |
| Funding Rate | 26% | 24% | 24% |
| **Statistics for Research Grants:** | | | |
| Number of Research Grant Proposals | 5,852 | 5,900 | 6,800 |
| Number of Research Grants | 1,460 | 1,360 | 1,560 |
| Regular Appropriation | 1,343 | 1,360 | 1,560 |
| CARES Act | 117 | | |
| Funding Rate | 25% | 23% | 23% |
| Median Annualized Award Size | $134,479 | $134,500 | $135,000 |
| Average Annualized Award Size | $164,737 | $165,000 | $166,000 |
| Average Award Duration, in years | 3.1 | 3.1 | 3.1 |

ENG investments support fundamental engineering research, engineering education, and innovation, as well as research infrastructure such as facilities. In FY 2022, funding for centers accounts for approximately nine percent of ENG's Request.

## Program Monitoring and Evaluation

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

## People Involved in ENG Activities

**Number of People Involved in ENG Activities**

| | FY 2020 Actual Estimate | FY 2020 CARES Act Actual Estimate | FY 2021 Estimate | FY 2022 Estimate |
|---|---|---|---|---|
| Senior Researchers | 7,066 | 183 | 7,100 | 8,200 |
| Other Professionals | 662 | 22 | 670 | 800 |
| Postdoctoral Associates | 411 | 28 | 420 | 450 |
| Graduate Students | 7,044 | 136 | 7,100 | 8,200 |
| Undergraduate Students | 3,899 | 26 | 4,000 | 4,600 |
| **Total Number of People** | **19,082** | **395** | **19,290** | **22,250** |

## DIVISION OF CHEMICAL, BIOENGINEERING, ENVIRONMENTAL, AND TRANSPORT SYSTEMS (CBET) $241,050,000 +$41,090,000 / 20.5%

**CBET Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| **Total** | **$197.92** | **$199.96** | **$241.05** | **$41.09** | **20.5%** |
| **Research** | **193.45** | **194.87** | **235.76** | **40.89** | **21.0%** |
| CAREER | 46.74 | 38.00 | 45.60 | 7.60 | 20.0% |
| Centers Funding (total) | 2.30 | 1.30 | 1.30 | - | - |
| Artificial Intelligence Research Institutes | 1.00 | 1.30 | 1.30 | - | - |
| STC: Emergent Behaviors for Integrated Cellular Systems | 1.30 | - | - | - | N/A |
| **Education** | **0.79** | **1.40** | **1.60** | **0.20** | **14.3%** |
| **Infrastructure** | **3.68** | **3.69** | **3.69** | **-** | **-** |
| National Nanotechnology Coordinated Infrastructure (NNCI) | 3.68 | 3.69 | 3.69 | - | - |

### About CBET

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

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

CBET also contributes to the directorate's annual operations support of NSF facilities such as NNCI.

In general, 84 percent of the CBET portfolio is available to support new research grants. The remaining 16 percent supports research grants made in prior years.

## DIVISION OF CIVIL, MECHANICAL, AND MANUFACTURING INNOVATION (CMMI) — $290,500,000 +$49,370,000 / 20.5%

**CMMI Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| **Total** | **$238.58** | **$241.13** | **$290.50** | **$49.37** | **20.5%** |
| **Research** | **219.95** | **224.58** | **273.30** | **48.72** | **21.7%** |
| CAREER | 46.22 | 28.00 | 33.60 | 5.60 | 20.0% |
| Centers Funding (total) | 6.75 | 8.75 | 8.75 | - | - |
| Artificial Intelligence Research Institutes | 1.80 | 3.75 | 3.75 | - | - |
| STC: Engineering Mechano-Biology | 4.95 | 5.00 | 5.00 | - | - |
| **Education** | **2.90** | **2.10** | **2.50** | **0.40** | **19.0%** |
| **Infrastructure** | **15.74** | **14.45** | **14.70** | **0.25** | **1.7%** |
| Natural Hazards Engineering Research Infrastructure (NHERI) | 13.04 | 11.75 | 12.00 | 0.25 | 2.1% |
| Center for High Energy X-ray Science (CHEXS) | 0.80 | 0.80 | 0.80 | - | - |
| National Nanotechnology Coordinated Infrastructure (NNCI) | 1.90 | 1.90 | 1.90 | - | - |

### About CMMI

CMMI funds fundamental research that advances civil, mechanical, industrial, systems, manufacturing, and materials engineering. In addition, the division has a focus on the reduction of risks and damage resulting from earthquakes, wind, and other hazards. CMMI encourages discoveries enabled by cross-cutting technologies such as adaptive systems, artificial intelligence, 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 manufacturing technology that does not exist today (such as future manufacturing); enable the design and analysis of complex engineered systems; enhance the sustainability and resilience of U.S. infrastructure (for example, buildings, transportation, and communication networks); help protect the Nation from extreme natural and human-induced events; and apply engineering principles to improve the Nation's service and manufacturing enterprise systems, such as healthcare.

CMMI also provides funding and management of NHERI and contributes to the directorate's annual operations support of the NNCI and CHEX/S facilities.

In general, 80 percent of the CMMI portfolio is comprised of new research grants and 20 percent supports continuing grants.

## DIVISION OF ELECTRICAL, COMMUNICATIONS, AND CYBER SYSTEMS (ECCS) — $149,520,000 +$25,470,000 / 20.5%

**ECCS Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| **Total** | **$122.86** | **$124.05** | **$149.52** | **$25.47** | **20.5%** |
| **Research** | **116.27** | **117.91** | **143.21** | **25.30** | **21.5%** |
| CAREER | 21.77 | 15.50 | 18.60 | 3.10 | 20.0% |
| Centers Funding (total) | 2.75 | 2.70 | 2.70 | - | - |
| Artificial Intelligence Research Institutes | 1.45 | 2.70 | 2.70 | - | - |
| STC: Energy Efficient Electronics Systems | 1.30 | - | - | - | N/A |
| **Education** | **1.15** | **0.80** | **0.97** | **0.17** | **21.3%** |
| **Infrastructure** | **5.44** | **5.34** | **5.34** | **-** | **-** |
| Center for High Energy X-ray Science (CHEXS) | 0.10 | 0.10 | 0.10 | - | - |
| National Nanotechnology Coordinated Infrastructure (NNCI) | 5.34 | 5.24 | 5.24 | - | - |

### About ECCS

ECCS supports enabling and transformative research at the nano, micro, and macro scales that fuels progress in engineering system applications with high societal impacts. The division's programs encompass novel electronic, photonic, quantum, and magnetic devices (such as low-power 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), energy and power, healthcare, transportation, robotics, advanced manufacturing, and other systems-related areas.

The division also provides funding, in partnership with other NSF directorates, and management of the National Nanotechnology Coordinated Infrastructure (NNCI) and contributes to the directorate's annual operations support of the CHEX/S facility.

In general, 84 percent of the ECCS portfolio is comprised of new research grants and 16 percent supports continuing grants.

**DIVISION OF ENGINEERING EDUCATION AND CENTERS (EEC)** **$149,300,000**
**+$24,280,000 / 19.4%**

**EEC Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| **Total** | **$124.06** | **$125.02** | **$149.30** | **$24.28** | **19.4%** |
| **Research** | **107.89** | **109.02** | **130.10** | **21.08** | **19.3%** |
| CAREER | 0.83 | - | - | - | N/A |
| Centers Funding (total) | 55.36 | 58.20 | 70.20 | 12.00 | 20.6% |
| Artificial Intelligence Research Institutes | 0.75 | 1.30 | 1.50 | 0.20 | 15.4% |
| Engineering Research Centers (EEC) | 54.61 | 56.90 | 68.70 | 11.80 | 20.7% |
| **Education** | **16.17** | **16.00** | **19.20** | **3.20** | **20.0%** |

## 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 Industry–University Cooperative Research Centers (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 2022 funding level supports 15 centers. The total includes funding to support four 4th-generation (Gen-4) 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.

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.

Engineering Workforce Development includes programs such as Research Experiences for Undergraduates (REU) and Research Experiences for Teachers (RET), as well as support for Grant Opportunities for Academic Liaison with Industry (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.

Broadening Participation in Engineering supports research and activities that enhance opportunities for underrepresented groups by addressing structural inequalities and biases within educational and workforce systems. This cluster also includes EEC's engagement with the NSF INCLUDES Big Idea, which integrates the agency's investments to build on and scale up what works in broadening participation programs.

In general, 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) $86,420,000 +$14,730,000 / 20.5%

**EFMA Funding**

(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| **Total** | **$70.88** | **$71.69** | **$86.42** | **$14.73** | **20.5%** |
| **Research** | **70.72** | **71.49** | **86.20** | **14.71** | **20.6%** |
| CAREER | 0.04 | - | - | - | N/A |
| **Education** | **0.06** | **0.10** | **0.12** | **0.02** | **20.0%** |
| **Infrastructure** | **0.10** | **0.10** | **0.10** | **-** | **-** |
| Center for High Energy X-ray Science (CHEXS) | 0.10 | 0.10 | 0.10 | - | - |

### 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. EFRI is intended to have the necessary flexibility to target long-term challenges, while retaining the ability and agility to adapt as new challenges demand.

In FY 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 office also supports special activities such as the Engineering Research Visioning Alliance, which convenes the engineering community to identify important engineering research challenges and opportunities. EFMA also contributes to the directorate's annual operations support of NSF facilities such as CHEX/S.

Funding for the FW-HTF Big Idea ($30.0 million) 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, 92 percent of the EFMA portfolio is comprised of new research grants, and about 8 percent supports continuing increments for grants made in previous years.

## DIRECTORATE FOR GEOSCIENCES (GEO) $1,194,920,000
**+$190,740,000 / 19.0%**

**GEO Funding**[1]
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| Atmospheric and Geospace Sciences (AGS) | $280.08 | $283.47 | $341.71 | $58.24 | 20.5% |
| Earth Sciences (EAR) | 199.21 | 201.36 | 240.04 | 38.68 | 19.2% |
| Integrative & Collaborative Education & Research (ICER) | 113.07 | 116.30 | 137.03 | 20.73 | 17.8% |
| Ocean Sciences (OCE) | 401.36 | 403.05 | 476.14 | 73.09 | 18.1% |
| **Total** | **$993.72** | **$1,004.18** | **$1,194.92** | **$190.74** | **19.0%** |

[1] Funding for FY 2020 and FY 2021 is adjusted for comparability to reflect the movement of I-Corps™ to TIP in FY 2022. See the R&RA Overview for more details.

### 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 the Office of Polar Programs, GEO investigates diverse Earth processes including the planet's water cycle, interactions across the land-ocean interface, the behavior of ice sheets, and geologic processes responsible for hydrocarbon energy sources and strategic minerals. 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 the U.S. Global Change Research Program (USGCRP) is a particular emphasis in FY 2022. Investments are framed around five major themes: Ocean's Role in Climate Change and Climate Solutions, Terrestrial-Climate Interactions and Water Sustainability, Cryosphere and Climate Change, Forcings and Feedbacks, and Earth System Predictability and Resilience. Crossing climate change themes, a new activity on climate change and social justice will utilize 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 narratives in the NSF-Wide Investments chapter.

GEO strongly supports the concept of racial equity and seeks to encourage the removal of barriers to participation in the geosciences. In FY 2022, a new activity on climate change and racial equity will use the integrating theme of climate change as the foundation for building diverse and inclusive research ecosystems that also focus on institutional transformation towards inclusivity.

GEO provides 57 percent of the federal funding for basic research at academic institutions in the environmental sciences.

## Major Investments

**GEO Major Investments**

(Dollars in Millions)

| Area of Investment[1,2] | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| Artificial Intelligence | $5.00 | $5.00 | $5.00 | - | - |
| Biotechnology | 8.00 | 10.00 | 10.00 | - | - |
| Climate: USGCRP | 294.17 | 329.23 | 481.70 | 152.47 | 46.3% |
| Coastlines and People (CoPe) | 4.41 | 15.00 | 23.00 | 8.00 | 53.3% |
| Improving Undergraduate STEM Education (IUSE) | 6.86 | 8.00 | 6.00 | -2.00 | -25.0% |
| NSF's Big Ideas | | | | | |
| *NNA Stewardship* | *27.20* | *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.

- Artificial Intelligence: GEO, in partnership with CISE and other NSF directorates and offices, other 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/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. In FY 2022, investment is 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.
- CoPe: CoPe was a new program 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. Investment in FY 2022 increases in response to the tremendous number of strong proposals received in 2021.
- IUSE: Funding for the NSF-wide IUSE activity continues to support development of the next generation of geoscientists. In FY 2021, there was a special emphasis in IUSE related to COVID response and recovery, which has been discontinued for FY 2022.
- I-Corps™: In FY 2022, support for I-Corps has been consolidated in the TIP Directorate.
- NNA: GEO provides stewardship of the NNA Big Idea. NNA fosters innovations in Arctic observational networks and fundamental convergence research across the social, natural, environmental, and computing and information sciences and engineering that address the intersection of natural, social, and built systems. Improved Earth system prediction is a major NNA objective.

**GEO Funding for Centers Programs and Major Facilities**

**GEO Funding for Centers Programs**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| Artificial Intelligence Research Institutes | $5.00 | $5.00 | $5.00 | - | - |
| STC: Center for Dark Energy Biosphere Investigations | 1.30 | - | - | - | N/A |
| **Total** | **$6.30** | **$5.00** | **$5.00** | **-** | **-** |

GEO will continue support for the AI Research Institute: Artificial Intelligence for Environmental Sciences (AI2ES) in FY 2022. For detailed information on individual centers programs, please see the NSF-Wide Investments chapter.

**GEO Funding for Major Facilities**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| Academic Research Fleet (ARF) | $105.38 | $107.38 | $117.88 | $10.50 | 9.8% |
| Arecibo Observatory (AO) | 2.76 | 12.38 | 8.00 | -4.38 | -35.4% |
| Geodetic Facility for the Advancement of GEoscience (GAGE) | 12.37 | 12.75 | 12.75 | - | - |
| International Ocean Discovery Program (IODP) | 48.00 | 48.00 | 48.00 | - | - |
| National Center for Atmospheric Research (NCAR) | 99.70 | 104.00 | 104.00 | - | - |
| Ocean Observatories Initiative (OOI) | 43.97 | 44.00 | 48.50 | $4.50 | 10.2% |
| Seismological Facility for the Advancement of GEoscience (SAGE) | 20.66 | 21.00 | 21.00 | - | - |
| **Total** | **$332.85** | **$349.51** | **$360.13** | **$10.62** | **3.0%** |

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

## Funding Profile

**GEO Funding Profile**

| | FY 2020 Actual Estimate | FY 2021 Estimate | FY 2022 Estimate |
|---|---|---|---|
| **Statistics for Competitive Awards:** | | | |
| Number of Proposals | 3,309 | 3,700 | 4,200 |
| Number of New Awards | 1,359 | 1,200 | 1,500 |
| Regular Appropriation | 1,359 | 1,200 | 1,500 |
| CARES Act | - | | |
| Funding Rate | 41% | 32% | 36% |
| **Statistics for Research Grants:** | | | |
| Number of Research Grant Proposals | 2,968 | 3,300 | 3,800 |
| Number of Research Grants | 1,152 | 1,000 | 1,300 |
| Regular Appropriation | 1,152 | 1,000 | 1,300 |
| CARES Act | - | | |
| Funding Rate | 39% | 30% | 34% |
| Median Annualized Award Size | $162,217 | $152,000 | $175,000 |
| Average Annualized Award Size | $214,870 | $220,000 | $225,000 |
| Average Award Duration, in years | 2.9 | 3.0 | 3.0 |

In FY 2022, the number of research grant proposals is expected to increase by about 850 compared to the FY 2020 Actual, and GEO expects to award about 150 more research grants as grant competitions related to climate change are anticipated. Average annual award size and duration are expected to rise slightly between FY 2020 and FY 2022.

## Program Monitoring and Evaluation

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

## People Involved in GEO Activities

**Number of People Involved in GEO Activities**

| | FY 2020 Actual Estimate | FY 2021 Estimate | FY 2022 Estimate |
|---|---|---|---|
| Senior Researchers | 5,304 | 5,300 | 6,300 |
| Other Professionals | 2,850 | 2,900 | 3,300 |
| Postdoctoral Associates | 631 | 600 | 800 |
| Graduate Students | 2,543 | 2,600 | 3,000 |
| Undergraduate Students | 3,057 | 3,100 | 3,600 |
| **Total Number of People** | **14,385** | **14,500** | **17,000** |

**DIVISION OF ATMOSPHERIC AND GEOSPACE SCIENCES (AGS)** **$341,710,000**
**+$58,240,000 / 20.5%**

**AGS Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| **Total** | **$280.08** | **$283.47** | **$341.71** | **$58.24** | **20.5%** |
| **Research** | **141.90** | **135.45** | **184.97** | **49.52** | **36.6%** |
| CAREER | 8.90 | 5.00 | 10.00 | 5.00 | 100.0% |
| **Education** | **5.18** | **3.14** | **3.77** | **0.63** | **20.1%** |
| **Infrastructure** | **133.00** | **144.88** | **152.97** | **8.09** | **5.6%** |
| AO | 2.76 | 12.38 | 8.00 | -4.38 | -35.4% |
| NCAR | 99.70 | 104.00 | 104.00 | - | - |
| Research Resources | 30.54 | 28.50 | 40.97 | 12.47 | 43.8% |

## 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 NOAA and NASA, research is conducted using world-class facilities provided by NCAR and other groups across the US. 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.

About 35 percent of the AGS portfolio is available for new research grants. The remaining 65 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)** **240,040,000**
**+38,680,000 / 19.2%**

**EAR Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| **Total** | **$199.21** | **$201.36** | **$240.04** | **$38.68** | **19.2%** |
| **Research** | **133.84** | **134.27** | **168.51** | **34.24** | **25.5%** |
| CAREER | 9.99 | 7.50 | 9.00 | 1.50 | 20.0% |
| **Education** | **7.17** | **6.71** | **7.95** | **1.24** | **18.5%** |
| **Infrastructure** | **58.21** | **60.38** | **63.58** | **3.20** | **5.3%** |
| GAGE | 12.37 | 12.75 | 12.75 | - | - |
| NNCI | 0.40 | 0.30 | 0.30 | - | - |
| SAGE | 20.66 | 21.00 | 21.00 | - | - |
| Research Resources | 24.77 | 26.33 | 29.53 | 3.20 | 12.2% |

## About EAR

EAR supports fundamental research into the structure and composition of the Earth and the processes that govern it. Research spans from the Earth's surface to its center, and includes the evolution and history of the Earth, and the life it has sustained over 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 programs support state-of-the-art science using observational, experimental, theoretical, and computational approaches in scientific domains spanning geobiology and low temperature geochemistry, geomorphology and land-use dynamics, geophysics, hydrology, petrology and geochemistry, sedimentary geology and paleobiology, and tectonics. 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. EAR also supports community-based, shared-use facilities, and the acquisition and development of instrumentation by individual 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 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. 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 53 percent of the EAR portfolio is available for new research grants. The remaining 47 percent supports research grants made in prior years and the research infrastructure needed by this community.

**DIVISION OF INTEGRATIVE AND COLLABORATIVE EDUCATION & RESEARCH (ICER)** — **$137,030,000**
**+$20,730,000 / 17.8%**

**ICER Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| **Total** | **$113.07** | **$116.30** | **$137.03** | **$20.73** | **17.8%** |
| **Research** | **105.00** | **116.30** | **137.03** | **20.73** | **17.8%** |
| CAREER | 0.15 | - | - | - | N/A |
| Centers Funding (total) | 5.00 | 5.00 | 5.00 | - | - |
| Artificial Intelligence Research Institutes | 5.00 | 5.00 | 5.00 | - | - |
| **Education** | **4.70** | **-** | **-** | **-** | **N/A** |
| **Infrastructure** | **3.36** | **-** | **-** | **-** | **N/A** |
| ARF | 3.36 | - | - | - | N/A |

## About ICER

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

Numerous ICER activities directly support the USGCRP. The NNA Big Idea focuses on the impacts of Arctic change and the NSF-wide Coastlines and People program, which is primarily supported in ICER, examines the impacts of climate on coastal regions in order to improve human and community resilience to climate change. In addition, ICER supports international collaborative activities which focus on climate change.

In general, about 57 percent of the ICER portfolio is available for new research grants with the remaining 43 percent supporting grants made in prior years.

**DIVISION OF OCEAN SCIENCES (OCE)** **$476,140,000**
**+$73,090,000 / 18.1%**

**OCE Funding**

(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| **Total** | **$401.36** | **$403.05** | **$476.14** | **$73.09** | **18.1%** |
| **Research** | **183.23** | **184.54** | **238.63** | **54.09** | **29.3%** |
| CAREER | 5.06 | 2.00 | 2.50 | 0.50 | 25.0% |
| Centers Funding (total) | 1.30 | - | - | - | N/A |
| STC: Center for Dark Energy Biosphere Investigations | 1.30 | - | - | - | N/A |
| **Education** | **5.24** | **9.13** | **11.13** | **2.00** | **21.9%** |
| **Infrastructure** | **212.89** | **209.38** | **226.38** | **17.00** | **8.1%** |
| ARF | 102.02 | 107.38 | 117.88 | 10.50 | 9.8% |
| IODP | 48.00 | 48.00 | 48.00 | - | - |
| OOI | 43.97 | 44.00 | 48.50 | 4.50 | 10.2% |
| Research Resources | 18.90 | 10.00 | 12.00 | 2.00 | 20.0% |

**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). 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.

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 30 percent of the OCE portfolio is available for new research grants, with the remaining 70 percent supporting grants made in prior years and the research infrastructure needed by this community.

## DIRECTORATE FOR MATHEMATICAL AND PHYSICAL SCIENCES (MPS) 1,690,740,000 +$110,26,000 / 7.0%

**MPS Funding**
(Dollars in Millions)

| | FY 2020 Actual[1] | FY 2020 CARES Act Actual | FY 2021 Estimate[1] | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|---|
| Astronomical Sciences (AST) | $279.10 | - | $277.05 | $294.05 | $17.00 | 6.1% |
| Chemistry (CHE) | 260.37 | - | 259.71 | 284.14 | 24.43 | 9.4% |
| Materials Research (DMR) | 330.15 | - | 329.78 | 349.92 | 20.14 | 6.1% |
| Mathematical Sciences (DMS) | 244.09 | - | 243.54 | 259.47 | 15.93 | 6.5% |
| Physics (PHY) | 304.39 | - | 303.90 | 316.59 | 12.69 | 4.2% |
| Office of Multidisciplinary Activities (OMA) | 112.01 | 6.00 | 166.50 | 186.57 | 20.07 | 12.1% |
| **Total** | **$1,530.12** | **$6.00** | **$1,580.48** | **$1,690.74** | **$110.26** | **7.0%** |

[1] Funding for FY 2020 and FY 2021 is adjusted for comparability to reflect the movement of I-Corps™ to TIP in FY 2022. See the R&RA Overview for more details.

## About MPS

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

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

Research tools and infrastructure are key priorities that MPS will continue funding. Mid-scale research infrastructure in astronomical sciences, chemistry, materials research, and physics continue to be critical to the advancement of these disciplines. Large scale research infrastructure is also critical and provides opportunities for partnerships with international groups, other federal agencies, and private foundations, as is evidenced by facilities such as the Atacama Large Millimeter/submillimeter Array (ALMA), the Gemini Observatory, the Large Hadron Collider (LHC), and National High Magnetic Field Laboratory. Upgrades to the Large Hadron Collider (LHC), designed to prepare the NSF-funded LHC detectors for High Luminosity operations of the particle accelerator, began construction activities in April 2020, and 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 Daniel K. Inouye Solar Telescope (DKIST) is approaching its anticipated completion near the end of 2021, atop Haleakalā on Maui, Hawai'i, and is poised to become the world's most powerful solar observatory. DKIST achieved a key milestone in FY 2020, first light on the sun, producing spectacular images of the solar surface at the highest resolution ever made. Since its detection of gravitation waves for the very first time in 2015, the Laser Interferometer Gravitational-Wave Observatory (LIGO) has been reporting event alerts on a regular basis, including a neutron star-neutron star merge and a collision of heavy and light black holes.

MPS' FY 2022 Request builds on past efforts and aligns with NSF's priorities articulated for FY 2022. There are exciting new opportunities emerging, research efforts that are maturing, and established programs and activities that continue to meet important goals and support science that will transform the Nation's future. MPS investments are influenced by the following key priorities: (a) sustaining core research programs, (b) supporting the highest priority 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 quantum information science (QIS), advanced manufacturing (AM), Biotechnology, the spectrum innovation initiative (SII), and artificial intelligence (AI), and (f) increasing support for clean energy and climate research.

There will also be great emphasis placed on supporting racial equity efforts. MPS will enhance funding of a variety of programs geared to broaden the participation of groups underrepresented in STEM research and MPS fields, including the MPS-Ascend Postdoctoral Research Fellowship, Partnerships for Research and Education in Materials (PREM), Partnerships in Astronomy and Astrophysics (PAARE), and the Alliances for Graduate Education and the Professoriate – Graduate Research Supplements (AGEP-GRS).

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

MPS provides 47 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 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| Advanced Manufacturing | $160.62 | $123.03 | $123.13 | $0.10 | 0.1% |
| Advanced Wireless Research | 17.00 | 17.00 | 17.00 | - | - |
| Artificial Intelligence | 71.67 | 62.48 | 71.76 | 9.28 | 14.9% |
| Biotechnology | 73.48 | 51.20 | 52.20 | 1.00 | 2.0% |
| Climate: Clean Energy Technology | 92.62 | 90.00 | 118.56 | 28.56 | 31.7% |
| Climate: USGCRP | - | 10.00 | 14.63 | 4.63 | 46.3% |
| Microelectronics and Semiconductors | 35.07 | 15.20 | 25.20 | 10.00 | 65.8% |
| Quantum Information Science | 125.46 | 136.13 | 146.13 | 10.00 | 7.3% |
| Secure & Trustworthy Cyberspace | 1.18 | 1.25 | 1.25 | - | - |
| NSF's Big Ideas | | | | | |
| *QL Stewardship* [3] | *30.00* | - | - | - | *N/A* |
| *WoU Stewardship* | *30.00* | *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] Starting in FY 2021, all Quantum Leap stewardship activties are managed with the broader Quantum Information Science (QIS) portfolio. See the NSF-Wide Investments chapter for detail on QIS.

- Advanced Manufacturing: MPS will invest in activities that develop new methods, processes, analyses, tools, or equipment for new or existing manufacturing products, supply chain components, or materials. These will yield advantages such as reduced time to market, new performance attributes, improved small-batch production, cost, and energy savings, and reduced environmental impact.
- Advanced Wireless—Spectrum Innovation Initiative: 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 support three cross-cutting initiatives: (1) a novel mechanism for piloting, testing, and rolling out the most innovative approaches to dynamic spectrum sharing in specialized geographic regions, "National Radio Dynamic Zones"; (2) a national center for wireless spectrum Research (SII-Center); and (3) education and workforce development specifically related to spectrum research.
- AI: Together with other NSF directorates/offices, MPS will increase support for AI research, with a focus on supporting basic research in machine learning and deep learning and development of tools and technical driven by 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 of clean energy systems and sources as well as energy sources that are renewable or otherwise alternative to traditional fossil fuels.
- Microelectronics and Semiconductors: MPS will support research that addresses fundamental science questions on the concepts, materials, devices, circuits, and platforms necessary to sustain progress in semiconductor-microelectronic technologies, with a focus on materials. This research is critical to

future advances and security in information technology, communications, sensing, smart electric grid, transportation, health, advanced manufacturing, and other areas.

- QIS: As the steward for QIS, MPS will work together with other NSF directorates and offices to increase support for quantum information science research and development. These investments align with the National Quantum Initiative[1] to coordinate and expand the United States' world-leading position in fundamental quantum research. QIS investments will deliver proof-of-concept devices, applications, tools, or systems with a demonstrable quantum advantage over their classical counterparts. Research in QIS examines uniquely quantum phenomena that can be harnessed to advance information processing transmission, measurement, and fundamental understanding in ways that classical approaches can only do much less efficiently, or not at all. Current and future QIS applications differ from prior applications of quantum mechanics, such as lasers, transistors, and magnetic resonance imaging, by using distinct quantum phenomena—superposition and entanglement—that do not have classical counterparts. MPS will continue the investment in QIS workforce development and in targeted activities designed to grow the participation of investigators and students from institutions currently under-represented in QIS.
- 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 (MMA). Through WoU investments, NSF will also grow the workforce not only for multi-messenger astrophysics but also for engineering, data science, and many other areas in our modern society. For more information about the Big Ideas, see the narratives in the NSF-Wide Investments chapter.

## MPS Funding for Centers Programs and Major Facilities

**MPS Funding for Centers Programs**

(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| Artificial Intelligence Research Institutes | $11.20 | $2.70 | $6.00 | $3.30 | 122.2% |
| Centers for Chemical Innovation (CHE) | 23.66 | 24.00 | 27.70 | 3.70 | 15.4% |
| Materials Centers (DMR) | 55.50 | 53.48 | 56.80 | 3.32 | 6.2% |
| Quantum Leap Challenge Institutes (OMA)[1] | 23.10 | 50.00 | 36.00 | -14.00 | -28.0% |
| STC: Center for Integrated Materials (DMR) | 5.00 | 4.15 | 3.73 | -0.42 | -10.1% |
| STC: STC on Real-Time Functional Imaging (DMR) | 5.01 | 5.00 | 5.00 | - | - |
| STC: Center for Bright Beams (PHY) | 4.66 | 5.00 | 5.00 | - | - |
| Spectrum Innovation Initiative Center (OMA) | 4.62 | 5.00 | 5.00 | - | - |
| **Total** | **$132.75** | **$149.33** | **$145.23** | **-$4.10** | **-2.7%** |

[1] Since FY 2020, Quantum Leap Challenge Institutes (QLCI) funding has been a vital part of NSF's overall $50 million investment in multidisciplinary centers for quantum research and education.

For detailed information on individual centers programs, please see the NSF-Wide Investments chapter.

**MPS Funding for Major Facilities**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| Arecibo Observatory[1] | $3.75 | $32.68 | $18.00 | -$14.68 | -44.9% |
| Green Bank Observatory (GBO)[2] | 9.42 | 8.90 | 9.12 | 0.22 | 2.5% |
| IceCube Neutrino Observatory (IceCube) | 3.50 | 3.50 | 3.65 | 0.15 | 4.3% |
| Large Hadron Collider (LHC) | 20.00 | 20.00 | 20.50 | 0.50 | 2.5% |
| Laser Interferometer Gravitational-Wave Observatory (LIGO) | 45.00 | 45.00 | 45.00 | - | - |
| National High Magnetic Field Laboratory (NHMFL)[3] | 34.59 | 25.98 | 38.91 | 12.93 | 49.8% |
| National Radio Astronomy Observatory (NRAO) | 89.25 | 88.13 | 91.16 | 3.03 | 3.4% |
| *NRAO O&M[4]* | *41.98* | *39.45* | *40.53* | *1.08* | *2.7%* |
| *Atacama Large Millimeter Array (ALMA) O&M* | *47.27* | *48.68* | *50.63* | *1.95* | *4.0%* |
| National Solar Observatory (NSO) | 21.79 | 22.09 | 25.46 | 3.37 | 15.3% |
| *NSO O&M* | *4.78* | *4.55* | *5.88* | *1.33* | *29.2%* |
| *Daniel K. Inouye Solar Telescope (DKIST) O&M[5]* | *17.01* | *17.54* | *19.58* | *2.04* | *11.6%* |
| National Superconducting Cyclotron Laboratory (NSCL)[6] | 22.00 | 15.50 | - | -15.50 | -100.0% |
| NSF's National Optical-Infrared Astronomy Research Laboratory (NOIRLab) | 57.86 | 57.93 | 54.44 | -3.49 | -6.0% |
| *NOIRLab O&M (Mid-Scale Observatories & Community Science and Data Center)[7]* | *35.54* | *29.95* | *26.26* | *-3.69* | *-12.3%* |
| *Gemini Observatory O&M* | *22.31* | *22.98* | *22.98* | - | - |
| *Vera C. Rubin Observatory O&M* | *0.01* | *5.00* | *5.20* | *0.20* | *4.0%* |
| **Total** | **$307.16** | **$319.71** | **$306.24** | **-$13.47** | **-4.2%** |

[1] Includes $28.88 million in FY 2021 and $15.0 million in FY 2022 in supplemental funding for cleanup of the Arecibo site.

[2] FY 2020 Actual includes $1.75 million from a technical deobligation/reobligation action from a previous award.

[3] FY 2020 Actual includes $12.0 million to fund part of FY 2021 operations costs, and excludes $14.20 million obligated in FY 2019 for FY 2020 operations.

[4] FY 2020 Actual includes one-time funding of $3.50 million for a special project associated with NSF's Spectrum Innovation Initiative.

[5] FY 2021 Estimate excludes funding of $2.0 million for cultural mitigation activities as agreed to during the compliance process.

[6] FY 2021 is the final year of NSF stewardship of NSCL, after which NSCL will transition into the Department of Energy's Facility for Rare Isotope Beams. Since FY 2019, $4.50 million has been provided on an annual basis for continuity of operations into the subsequent fiscal year; O&M funding is reduced by this amount in FY 2021.

[7] Includes $2.0 million in FY 2020 for transition activities associated with the creation of NOIRLab, as well as special projects funding of $13.63 million in FY 2020, $9.44 million in FY 2021, and $5.13 million in FY 2022.

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

**Funding Profile**

**MPS Funding Profile**

| | FY 2020 Actual Estimate | FY 2021 Estimate | FY 2022 Estimate |
|---|---|---|---|
| **Statistics for Competitive Awards:** | | | |
| Number of Proposals | 8,617 | 8,900 | 9,500 |
| Number of New Awards | 2,557 | 2,600 | 3,000 |
| Regular Appropriation | 2,519 | 2,600 | 3,000 |
| CARES Act | 38 | | |
| Funding Rate | 30% | 29% | 32% |
| **Statistics for Research Grants:** | | | |
| Number of Research Grant Proposals | 7,560 | 7,800 | 8,350 |
| Number of Research Grants | 2,131 | 2,200 | 2,400 |
| Regular Appropriation | 2,093 | 2,200 | 2,400 |
| CARES Act | 38 | | |
| Funding Rate | 28% | 28% | 29% |
| Median Annualized Award Size | $130,637 | $131,000 | $135,000 |
| Average Annualized Award Size | $166,130 | $167,000 | $169,000 |
| Average Award Duration, in years | 3.1 | 3.1 | 3.1 |

In FY 2022, the number of research grant proposals is expected to remain level with FY 2021 Estimates. MPS expects to award approximately 1,800 research grants to support research and infrastructure activities in both core and crosscutting areas. Average annual award size and duration as well as funding rate are not expected to materially fluctuate from FY 2021 to FY 2022. In FY 2022, MPS maintains its commitment to Science and Technology Centers, Materials Centers, Centers for Chemical Innovation, and SII Center and will invest $103.23 million, accounting for roughly six percent of the total MPS budget. Operations and maintenance funding for MPS-supported major multi-user facilities comprises approximately 23 percent of MPS's FY 2022 Request.

**Program Monitoring and Evaluation**

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

**People Involved in MPS Activities**

**Number of People Involved in MPS Activities**

| | FY 2020 Actual Estimate | FY 2020 CARES Act Actual Estimate | FY 2021 Estimate | FY 2022 Estimate |
|---|---|---|---|---|
| Senior Researchers | 9,233 | 61 | 9,500 | 10,200 |
| Other Professionals | 2,303 | 8 | 2,400 | 2,500 |
| Postdoctoral Associates | 2,009 | 21 | 2,000 | 2,200 |
| Graduate Students | 9,291 | 35 | 9,600 | 10,300 |
| Undergraduate Students | 6,328 | 9 | 6,500 | 7,000 |
| **Total Number of People** | **29,164** | **134** | **30,000** | **32,200** |

## DIVISION OF ASTRONOMICAL SCIENCES (AST) $294,050,000 +$17,000,000 / 6.1%

**AST Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| **Total** | **$279.10** | **$277.05** | **$294.05** | **$17.00** | **6.1%** |
| **Research** | **64.99** | **52.92** | **72.47** | **19.55** | **36.9%** |
| CAREER | 4.74 | 4.81 | 4.81 | - | - |
| **Education** | **4.27** | **4.60** | **5.10** | **0.50** | **10.9%** |
| **Infrastructure** | **209.85** | **219.53** | **216.48** | **-3.05** | **-1.4%** |
| Arecibo Observatory[1] | 3.75 | 12.68 | 8.00 | -4.68 | -36.9% |
| AST Portfolio Review Implementation | 0.05 | - | - | - | N/A |
| Green Bank Observatory[2] | 9.42 | 8.90 | 9.12 | 0.22 | 2.5% |
| Midscale Research Infrastructure | 23.30 | 20.80 | 19.50 | -1.30 | -6.3% |
| National Radio Astronomy Observatory (NRAO) | 85.75 | 88.13 | 91.16 | 3.03 | 3.4% |
| *NRAO O&M* | *38.48* | *39.45* | *40.53* | *1.08* | *2.7%* |
| *Atacama Large Millimeter Arrary (ALMA)* | *47.27* | *48.68* | *50.63* | *1.95* | *4.0%* |
| National Solar Observatory (NSO) | 21.79 | 22.09 | 25.46 | 3.37 | 15.3% |
| *NSO O&M* | *4.78* | *4.55* | *5.88* | *1.33* | *29.2%* |
| *Daniel K. Inouye Solar Telescope (DKIST) O&M*[3] | *17.01* | *17.54* | *19.58* | *2.04* | *11.6%* |
| NSF's National Optical-Infrared Astronomy Research Lab (NOIRLab) | 57.86 | 57.93 | 54.44 | -3.49 | -6.0% |
| *NOIRLab O&M (Mid-Scale Observatories & Community Science and Data Center)*[4] | *35.54* | *29.95* | *26.26* | *-3.69* | *-12.3%* |
| *Gemini Observatory O&M* | *22.31* | *22.98* | *22.98* | - | - |
| *Vera C. Rubin Observatory O&M* | *0.01* | *5.00* | *5.20* | *0.20* | *4.0%* |
| Research Resources | 7.92 | 7.00 | 8.80 | 1.80 | 25.7% |

[1] Includes $28.88 million in FY 2021 and $15.0 million in FY 2022 in supplemental funding for cleanup of the Arecibo site.

[2] FY 2020 Actual includes $1.75 million from a technical deobligation/reobligation action from a previous award.

[3] FY 2021 Estimate excludes funding of $2.0 million for cultural mitigation activities as agreed to during the compliance process.

[4] Includes $2.0 million in FY 2020 for transition activities associated with the creation of NOIRLab, as well as special projects funding of $13.63 million in FY 2020, $9.44 million in FY 2021, and $5.13 million in FY 2022.

### About AST

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

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

In general, about 28 percent of the AST portfolio is available for new research grants. About 75 percent of

AST's budget supports the instrumentation and facilities needed for progress at the frontiers of observational astronomy, while 25 percent supports the research of individual investigators. Through the MREFC appropriation, AST also oversees the construction of the Vera C. Rubin Observatory. For detailed information on AST's individual facilities, see the Facilities chapter. For detailed information on the construction of the Vera C. Rubin Observatory, see the MREFC chapter.

## DIVISION OF CHEMISTRY (CHE)

**$284,140,000**
**+$24,430,000 / 9.4%**

**CHE Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| **Total** | **$260.37** | **$259.71** | **$284.14** | **$24.43** | **9.4%** |
| **Research** | **190.79** | **196.73** | **217.61** | **20.88** | **10.6%** |
| CAREER | 28.93 | 26.00 | 26.00 | - | - |
| Centers Funding (total) | 23.66 | 24.00 | 27.70 | 3.70 | 15.4% |
| Centers for Chemical Innovation (CHE) | 23.66 | 24.00 | 27.70 | 3.70 | 15.4% |
| **Education** | **4.88** | **4.55** | **4.55** | **-** | **-** |
| **Infrastructure** | **12.11** | **8.43** | **8.28** | **-0.15** | **-1.8%** |
| Midscale Research Infrastructure | 3.00 | 0.60 | 0.60 | - | - |
| NHMFL | 1.73 | 1.88 | 1.73 | -0.15 | -8.0% |
| National Nanotechnology Coordinated Infrastructure (NNCI) | 0.30 | 0.30 | 0.30 | - | - |
| Research Resources | 7.08 | 5.65 | 5.65 | - | - |

### About CHE

CHE supports discovery research and workforce development in chemistry that have the potential to be transformative to major commercial sectors of the U.S. economy: energy, pharmaceuticals, medical applications, plastics, electronics, food, agriculture, and transportation. CHE investments also support highly competitive and rapidly evolving fields that include advanced manufacturing, quantum information sciences, data mining and artificial intelligence, sensor and instrument development, biotechnology, 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 learnings, invention, and innovation, but also have significant ramifications for training and employment of the workforce of the future.

In general, about 71 percent of the CHE portfolio is available to support new research grants. The remaining 29 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**
**+$20,140,000 / 6.1%**

**DMR Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| **Total** | **$330.15** | **$329.78** | **$349.92** | **$20.14** | **6.1%** |
| **Research** | **150.04** | **181.52** | **189.54** | **8.02** | **4.4%** |
| CAREER | 30.56 | 25.00 | 25.00 | - | - |
| Centers Funding (total) | 65.51 | 62.63 | 65.53 | 2.90 | 4.6% |
| Materials Centers (DMR) | 55.50 | 53.48 | 56.80 | 3.32 | 6.2% |
| STC: Center for Integrated Materials (DMR) | 5.00 | 4.15 | 3.73 | -0.42 | -10.1% |
| STC: STC on Real-Time Functional Imaging (DMR) | 5.01 | 5.00 | 5.00 | - | - |
| **Education** | **7.02** | **2.50** | **2.50** | **-** | **-** |
| **Infrastructure** | **77.02** | **58.13** | **67.35** | **9.22** | **15.9%** |
| Center for High Energy X-ray Science (CHEXS) | 10.00 | 9.00 | 8.00 | -1.00 | -11.1% |
| Midscale Research Infrastructure | 25.53 | 18.00 | 15.14 | -2.86 | -15.9% |
| National High-Magnetic Field Laboratory (NHMFL) | 32.86 | 24.10 | 37.18 | 13.08 | 54.3% |
| National Nanotechnology Coordinated Infrastructure (NNCI) | 2.58 | 2.58 | 2.58 | - | - |
| Other MPS Facilities | 3.00 | 3.00 | 3.00 | - | - |
| Research Resources | 3.05 | 1.45 | 1.45 | - | - |

## 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 abundant and pervasive, serving as critical building blocks in technology and innovation. This research impacts life and society, as it shapes our understanding of the world and enables significant advances in electronics, communications, transportation, and health-related fields. The development and deployment of advanced materials are major drivers of U.S. economic growth.

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

In general, about 35 percent of the DMR portfolio is available to support new research grants. The remaining 65 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**
**+$15,930,000 / 6.5%**

**DMS Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| **Total** | **$244.09** | **$243.54** | **$259.47** | **$15.93** | **6.5%** |
| **Research** | **214.24** | **217.65** | **230.32** | **12.67** | **5.8%** |
| CAREER | 16.35 | 12.24 | 15.00 | 2.76 | 22.5% |
| **Education** | **13.50** | **13.65** | **14.15** | **0.50** | **3.7%** |

## 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 67 percent of the DMS portfolio is available to support new research grants each year. The remaining 33 percent supports research grants made in prior years.

## DIVISION OF PHYSICS (PHY)

**$316,590,000**
**+$12,690,000 / 4.2%**

**PHY Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| **Total** | **$304.39** | **$303.90** | **$316.59** | **$12.69** | **4.2%** |
| **Research** | **175.08** | **187.32** | **203.22** | **15.90** | **8.5%** |
| CAREER | 10.24 | 7.30 | 7.30 | - | - |
| Centers Funding (total) | 7.45 | 7.70 | 11.00 | 3.30 | 42.9% |
| Artificial Intelligence Research Institutes | 2.79 | 2.70 | 6.00 | 3.30 | 122.2% |
| STC: Center for Bright Beams (PHY) | 4.66 | 5.00 | 5.00 | - | - |
| **Education** | **5.76** | **4.92** | **4.92** | **-** | **-** |
| **Infrastructure** | **105.86** | **96.66** | **90.15** | **-6.51** | **-6.7%** |
| IceCube | 3.50 | 3.50 | 3.65 | 0.15 | 4.3% |
| LHC | 20.00 | 20.00 | 20.50 | 0.50 | 2.5% |
| LIGO | 45.00 | 45.00 | 45.00 | - | - |
| Midscale Research Infrastructure | 15.36 | 12.66 | 18.50 | 5.84 | 46.1% |
| NSCL | 22.00 | 15.50 | 2.50 | -13.00 | -83.9% |
| Research Resources | - | 1.00 | 2.50 | 1.50 | 150.0% |

### 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 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 22 percent of the PHY portfolio is available for new research grants. The remaining 78 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 (about 25% percent). Through the MREFC appropriation, PHY also oversees the construction of HL-LHC. For detailed information on PHY's individual facilities, see the Facilities chapter. For detailed information on the construction of HL-LHC, see the MREFC chapter.

**OFFICE OF MULTIDISCIPLINARY ACTIVITIES (OMA)** **$186,570,000**
**+$20,070,000 / 12.1%**

**OMA Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| **Total** | **$112.01** | **$166.50** | **$186.57** | **$20.07** | **12.1%** |
| **Research** | **-** | **-** | **-** | **-** | **N/A** |
| CAREER | | | | - | N/A |
| Centers Funding (total) | 27.72 | 55.00 | 41.00 | -14.00 | -25.5% |
| Quantum Leap Challenge Institutes[1] | 23.10 | 50.00 | 36.00 | -14.00 | -28.0% |
| Spectrum Innovation Initiative Center | 4.62 | 5.00 | 5.00 | - | - |
| **Education** | **-** | **10.00** | **10.00** | **-** | **-** |
| **Infrastructure** | **4.65** | **20.00** | **10.00** | **-10.00** | **-50.0%** |

[1] FY 2021 and FY 2022 include other QIS-related center and institutes, that combined with QLCIs, total $50M.

## About OMA

In partnership with MPS division 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: Quantum Information Science, Windows on the Universe, Artificial Intelligence, Spectrum Innovation Initiative, 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. OMA is the steward for the Spectrum Innovation Initiative that promotes transformative use and management of the electromagnetic spectrum, resulting in profound benefits for science and engineering, industry, and other national interests. OMA will foster broadening participation through the new Mathematical and Physical Sciences Ascending Postdoctoral Research Fellowship (MPS-Ascend) program and the Launching Early-Career Academic Pathways in the Mathematical and Physical Sciences (LEAPS-MPS) 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 40 percent of the OMA portfolio is available to support new research grants. The remaining 60 percent supports multidisciplinary research infrastructure and education activities needed by the MPS community.

**DIRECTORATE FOR SOCIAL, BEHAVIORAL, AND ECONOMIC SCIENCES (SBE)** **$319,660,000**
**+$37,600,000 / 13.3%**

**SBE Funding**
(Dollars in Millions)

| | FY 2020 Actual[1] | FY 2020 CARES Act Actual | FY 2021 Estimate[1] | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|---|
| Division of Behavioral and Cognitive Sciences (BCS) | $98.64 | $4.00 | $99.41 | $113.16 | $13.75 | 13.8% |
| Division of Social and Economic Sciences (SES) | 99.87 | 5.50 | 102.83 | 117.08 | 14.25 | 13.9% |
| National Ctr. for Science and Engineering Statistics (NCSES) | 55.20 | - | 55.48 | 61.48 | 6.00 | 10.8% |
| SBE Office of Multidisciplinary Activities (SMA) | 26.64 | - | 24.34 | 27.94 | 3.60 | 14.8% |
| **Total** | **$280.35** | **$9.50** | **$282.06** | **$319.66** | **$37.60** | **13.3%** |

[1] Funding for FY 2020 and FY 2021 is adjusted for comparability to reflect the movement of I-Corps[TM] to TIP in FY 2022. See the R&RA Overview for more details.

## 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 on finding new ways to improve quality of life for all Americans. SBE provides approximately 65 percent of the federal funding for basic research at academic institutions in the social, behavioral, and economic sciences. 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, 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 biospecimen analysis, 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 STEM education; and U.S. competitiveness in science, engineering, technology, and research and development.

SBE's FY 2022 Request is shaped by three guiding principles:

1. Support fundamental research that advances key national priorities. The research emphases include enhancing national security and preparedness; understanding, mitigating, and adapting to climate 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 in emerging industries; reliability of information networks; and improving quality of life for communities across the country.

2. Support NCSES, the Nation's premier source for information on the science and engineering enterprise. The 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.
3. 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, or broadening opportunity, 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.

The FY 2022 Request of $319.66 million represents an increase of $37.60 million, or 13.3 percent over the FY 2021 Estimate. SBE will prioritize and maximize support in its disciplinary and interdisciplinary programs that support Administration and NSF-wide priorities including activities that contribute to advanced manufacturing research; AI with an emphasis on supporting minority-serving institutions (MSIs); United States Global Research Change Program (USGCRP); and understanding the causes and effects of Online Influence.

The FY 2022 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 activities include BRAIN; National AI Research Institutes; Predictive Intelligence for Pandemic Prevention (PIPP); SaTC; Smart and Connected Communities (S&CC); 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.

SBE will also support racial equity efforts by continuing foundational research activities and targeted BP investments that seek to increase participation of underrepresented groups as well as to advance understanding of institutional, organizational and group factors; affective, behavioral, cultural, and social factors; and economic and policy-related factors that affect BP and equity. Specific SBE investments include SPRF-BP, B2, SBP, and increased AI funding for MSIs.

In FY 2022, SBE will continue to support foundational research in the Big Ideas including FW-HTF, URoL, HDR, NNA and NSF INCLUDES.

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

The URoL Big Idea, which all NSF directorates and offices participate in, includes foundational SBE research on topics such as human genetic variation; the emergence of phenotype from gene-environment interactions; the human microbiome and its co-evolution with its human hosts; epigenetics of cognition and behavior; human networks in evolving environments, and the ethical and social implications and societal acceptance of new scientific technologies, such as tools for genetic engineering and synthetic biology.

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

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

In FY 2022, 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.

Finally, SBE's FY 2022 Request includes continued support for NCSES. The Center is established in law with a mandate to serve as the central federal resource for collecting, analyzing, and distributing objective data on science, engineering, technology, and research and development. Consistent with recent Executive Orders that highlight the importance of objective and trustworthy data, SBE support will help NCSES modernize systems and data tools, develop a new website, and address requirements of the Foundations for Evidence-Based Policy Act (Evidence Act). SBE is also committed to supporting NSF's transition to meeting other requirements associated with the Evidence Act, including having NCSES's Director serve as the Foundation's Statistical Official and Chair the Advisory Committee on Data for Evidence Building until the Chief Statistician of the United States is appointed.

**Major Investments**

**SBE Major Investments**
(Dollars in Millions)

| Area of Investment[1,2] | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| Advanced Manufacturing | $0.75 | $0.50 | $3.50 | $3.00 | 600.0% |
| Artificial Intelligence | 16.04 | 14.59 | 19.59 | 5.00 | 34.3% |
| Build and Broaden | 1.37 | 8.00 | 8.00 | - | - |
| Climate: USGCRP | 19.61 | 17.18 | 25.14 | 7.96 | 46.3% |
| NCSES | 55.20 | 55.48 | 61.48 | 6.00 | 10.8% |
| SaTC | 4.00 | 4.00 | 4.00 | - | - |
| Strengthening American Infrastructure | 1.15 | 6.00 | 8.00 | 2.00 | 33.3% |

[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 continue 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. SBE's FY 2022 funding estimate includes increased support for MSI-based research in AI.

Build and Broaden (B2) ($8.0 million): SBE will maintain investments in B2, an innovative new 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; and 4) contribute to stronger, more innovative science by diversifying research and widening the STEM pathways.

Climate: USGCRP ($25.14 million): In FY 2022, 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; increase 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 2022 increase 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.

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 2022, SBE will increase by $2.0 million 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**

**SBE Funding for Centers Programs**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| Artificial Intelligence Research Institutes | 0.64 | 0.77 | 0.77 | - | - |

For detailed information on individual centers programs, please see the NSF-Wide Investments chapter.

## Funding Profile

**SBE Funding Profile**

| | FY 2020 Actual Estimate | FY 2021 Estimate | FY 2022 Estimate |
|---|---|---|---|
| **Statistics for Competitive Awards:** | | | |
| Number of Proposals | 4,252 | 4,300 | 4,300 |
| Number of New Awards | 1,081 | 1,020 | 1,150 |
| Regular Appropriation | 1,007 | 1,020 | 1,150 |
| CARES Act | 74 | | |
| Funding Rate | 25% | 24% | 27% |
| **Statistics for Research Grants:** | | | |
| Number of Research Grant Proposals | 3,171 | 3,200 | 3,200 |
| Number of Research Grants | 767 | 700 | 790 |
| Regular Appropriation | 693 | 700 | 790 |
| CARES Act | 74 | | |
| Funding Rate | 24% | 22% | 25% |
| Median Annualized Award Size | $144,236 | $144,200 | $144,200 |
| Average Annualized Award Size | $154,442 | $154,400 | $154,400 |
| Average Award Duration, in years | 2.4 | 2.4 | 2.4 |

SBE supports investment in core research and education activities as well as research infrastructure. In FY 2022, 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 2022, SBE expects to award approximately 1,150 competitive grants, including nearly 800 research grants.

## Program Monitoring and Evaluation

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

## People Involved in SBE Activities

**Number of People Involved in SBE Activities**

| | FY 2020 Actual Estimate | FY 2020 CARES Act Actual Estimate | FY 2021 Estimate | FY 2022 Estimate |
|---|---|---|---|---|
| Senior Researchers | 2,004 | 110 | 2,000 | 2,300 |
| Other Professionals | 379 | 40 | 380 | 430 |
| Postdoctoral Associates | 185 | 3 | 190 | 220 |
| Graduate Students | 1,473 | 71 | 1,500 | 1,700 |
| Undergraduate Students | 1,155 | 31 | 1,200 | 1,300 |
| **Total Number of People** | **5,196** | **255** | **5,270** | **5,950** |

**DIVISION OF BEHAVIORAL AND COGNITIVE SCIENCES (BCS)** **$113,160,000**
**+$13,750,000 / 13.8%**

**BCS**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| **Total** | **$98.64** | **$99.41** | **$113.16** | **$13.75** | **13.8%** |
| **Research** | **89.79** | **94.47** | **108.22** | **13.75** | **14.6%** |
| CAREER | 6.68 | 5.00 | 5.00 | - | - |
| **Education** | **0.76** | **0.44** | **0.44** | **-** | **-** |
| **Infrastructure** | **8.08** | **4.50** | **4.50** | **-** | **-** |
| Research Resources | 8.08 | 4.50 | 4.50 | - | - |

## 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 critical bases for improving disaster response 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. Through its Science of Learning and Augmented Intelligence program, BCS research explores how new technologies, especially artificial intelligence, can enhance human cognition and productivity.

BCS 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 87 percent of the BCS portfolio is available to support new research grants. The remaining 13 percent supports research grants made in prior years and the research infrastructure needed by this community.

**DIVISION OF SOCIAL AND ECONOMIC SCIENCES (SES)** **$117,080,000**
**+$14,250,000 / 13.9%**

**SES Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| **Total** | **$99.87** | **$102.83** | **$117.08** | **$14.25** | **13.9%** |
| **Research** | **94.45** | **96.84** | **111.09** | **14.25** | **14.7%** |
| CAREER | 6.49 | 5.00 | 5.00 | - | - |
| **Education** | **0.10** | **0.50** | **0.50** | **-** | **-** |
| **Infrastructure** | **5.32** | **5.49** | **5.49** | **-** | **-** |
| NNIN | 0.40 | 0.40 | 0.40 | - | - |
| Research Resources | 4.92 | 5.09 | 5.09 | - | - |

**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 or 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 legal 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.

In general, about 75 percent of the SES portfolio is available to support new research grants. The remaining 25 percent supports research grants made in prior years and the research infrastructure needed by this community.

**NATIONAL CENTER FOR SCIENCE AND ENGINEERING STATISTICS (NCSES)** **$61,480,000**
**+$6,000,000 / 10.8%**

**NCSES Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| **Total** | **$55.20** | **$55.48** | **$61.48** | **$6.00** | **10.8%** |
| **Research** | **0.29** | **-** | **-** | **-** | **N/A** |
| CAREER | 0.25 | - | - | - | N/A |
| **Infrastructure** | **54.91** | **55.48** | **61.48** | **6.00** | **10.8%** |

**About NCSES**

NCSES is one of the federal government's thirteen 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.

The FY 2022 Request supports NCSES's core data collection and analytic activities, including nationally representative surveys of U.S. investment in R&D across all sectors of the economy, innovation, the education of scientists and engineers, and the science and engineering workforce. This also includes preparation of the aforementioned *SEI and WMPD* reports. In FY 2022, NCSES will continue initiatives related to:

- Standing up America's DataHub—an NCSES research center of excellence that will move NCSES toward a future in which it can securely share and link existing data to solve complex problems, such as those related to economic recovery, racial equity, or the impacts of COVID-19. The DataHub will facilitate broad and secure access to linked data and revolutionize privacy protections and data security.
- 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.
- Furthering the Nation's understanding of the impact of R&D funding on the U.S. and global scientific enterprises.
- 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.

- Improving the government's classification systems for defining cybersecurity, bioeconomy, and data science occupations.
- Using of administrative and organic data to inform efforts to increase government effectiveness and efficiency through increased data integration.
- Maintaining systems and data collection efforts for modern federal statistics.
- Modernizing systems and data tools to ease data access.
- Developing and building a new website for data and product dissemination to enhance the experience of users of NCSES information.

## SBE OFFICE OF MULTIDISCIPLINARY ACTIVITIES (SMA) $27,940,000 +$3,600,000 / 14.8%

**SMA Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| **Total** | **$26.64** | **$24.34** | **$27.94** | **$3.60** | **14.8%** |
| **Research** | **20.14** | **13.28** | **20.38** | **7.10** | **53.5%** |
| CAREER | 1.36 | - | - | - | N/A |
| Centers Funding (total) | 0.64 | 0.77 | 0.77 | 0.01 | 0.7% |
| Artificial Intelligence Research Institutes | 0.64 | 0.77 | 0.77 | 0.01 | 0.7% |
| **Education** | **6.50** | **11.06** | **7.56** | **-3.50** | **-31.6%** |

### 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 2022, 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 63 percent of the SMA portfolio is available to support new research grants. The remaining 27 percent supports research grants made in prior years.

**DIRECTORATE FOR TECHNOLOGY, INNOVATION, AND PARTNERSHIPS (TIP)** **$864,870,000 +$500,000,000 / 137.0%**

**TIP Funding**[1]
(Dollars in Millions)

| | FY 2020 Actual | FY 2020 CARES Act Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|---|
| Innovation Ecosystems (IE) | $98.18 | $0.80 | $110.00 | $335.00 | $225.00 | 204.5% |
| Partnerships Office (PO) | - | - | - | 50.00 | 50.00 | N/A |
| Technology Frontiers (TF) | - | - | - | 150.00 | 150.00 | N/A |
| Translational Impact (TI) | 254.13 | 2.75 | 254.87 | 329.87 | 75.00 | 29.4% |
| **Total** | **$352.31** | **$3.55** | **$364.87** | **$864.87** | **$500.00** | **137.0%** |

[1] FY 2020 and FY 2021 funding is adjusted for comparability to reflect the movement of activities to TIP in FY 2022. See the R&RA Overview for more details.

## About TIP

In close collaboration with all of NSF's directorates and offices, as well as with other stakeholders in the Nation's research, innovation, and education enterprise, the Directorate for Technology, Innovation, and Partnerships (TIP) will (i) advance science and engineering research and innovation leading to breakthrough technologies as well as solutions to national and societal challenges, sustaining and enhancing U.S. competitiveness on a global stage; (ii) accelerate the translation of fundamental discoveries from lab to market, advancing the U.S. economy; and (iii) create education pathways for every American to pursue new, high-wage, good-quality jobs, supporting a diverse workforce of researchers, practitioners, and entrepreneurs. Building on NSF's longstanding leadership in scientific and engineering research and education, TIP will effectively serve as a cross-cutting platform that leverages, energizes, and rapidly brings to the market and to society the innovations that result from all of NSF's investments. Further, TIP will open up new possibilities for research and education by catalyzing strategic partnerships linking academia, industry, government, philanthropy, investors, and civil society to cultivate 21st-century local, regional, and national innovation ecosystems, ensuring U.S. leadership in critical technologies as well as national and societal challenges. TIP investments strongly align with Administration priorities, including the Build Back Better and Racial Equity pillars, and with Congressional priorities.

This FY 2022 Request to Congress for TIP aligns with the American Jobs Plan. The American Jobs Plan would provide limited-duration scale-up of TIP activities to accelerate and enhance their overall impact, including pathways for every American to pursue new, high-wage, good-quality jobs, whereas the FY 2022 Request to Congress specifies a path toward long-term sustainment of the Directorate and its investments.

TIP will work with all of NSF's directorates and offices to advance the impacts of NSF-funded research by accelerating the translation of fundamental science and engineering discoveries into innovative new technologies and solutions. TIP will provide an optimized lab-to-market platform, funding the highly successful Partnerships for Innovation (PFI), Small Business Innovation Research (SBIR), and Small Business Technology Transfer (STTR) programs, which are moved from ENG to TIP. By operating in close coordination with one another, these programs will allow NSF-funded researchers to pursue additional prototyping, technology demonstration, and scale-up work, including licensing of NSF-funded research outputs. They will also give rise to the startups and small businesses that have the potential to lead to new markets and economies of scale.

TIP will further cultivate new innovation ecosystems at the scale of individual communities and regions throughout the U.S., advancing use-inspired, solution-oriented research and innovation in a range of technology areas (e.g., artificial intelligence, quantum information science, advanced wireless, advanced manufacturing, semiconductors) as well as in a diverse set of national-challenge areas of priority to the Administration and Congress (e.g., climate change and biotechnology). Coupled with these innovation ecosystems is entrepreneurial education through the NSF Innovation Corps (I-Corps™) program as well as the NSF Entrepreneurial Fellowships; these investments will develop future leaders capable of maturing promising ideas and technologies from lab to market.

Along the way, TIP will serve as a central resource to catalyze and scale public and private partnerships agency-wide. Specifically, TIP will provide 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 all areas of science, engineering, and education. TIP will aim to expand the reach of NSF partnerships and exponentially increase the return on investments across all of NSF's directorates and offices.

In FY 2022, TIP investments will advance the frontiers of emerging industries as well as other national-priority areas, and they will result in the creation of new, high-wage, good-quality jobs.

**Major Investments**

TIP will be organizationally structured to house three divisions (IE, TF, and TI) and one office (PO), as detailed by the table shown on the previous page. Across these divisions and office, investment in the following areas is envisioned.

**TIP Investments**[1]
(Dollars in Millions)

| Area of Investment | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| Accelerating Public and Private Partnerships | - | - | $50.00 | $50.00 | N/A |
| Convergence Accelerator | 60.23 | 70.00 | 70.00 | - | - |
| NSF Entrepreneurial Fellows | - | - | 20.00 | 20.00 | N/A |
| **Lab-to-Market** | | | | | |
| PFI | 22.07 | 22.81 | 30.00 | 7.19 | 31.5% |
| I-Corps™ | 37.95 | 40.00 | 40.00 | - | - |
| SBIR/STTR, including Operations | 232.06 | 232.06 | 274.64 | 42.58 | 18.3% |
| Racial Equity | | | 20.00 | N/A | N/A |

[1] FY 2020 and 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 PO, will establish 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 (e.g., at institutions of higher education) and the inclusion of diverse institution types such as minority-serving institutions.
- Convergence Accelerator (CA): TIP will invest in new research tracks informed by community responses to a Request for Information, current national priorities, and other external stakeholder input. The CA will continue to leverage foundational advances by other NSF directorates and offices, nurture

multi-disciplinary and multi-sector teams, and accelerate solutions-oriented research and piloting in specific areas of national importance such as emerging industries.

- 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.
- Lab-to-Market Platform: TIP will establish an optimized lab-to-market approach leveraging existing programs at NSF. Specifically:
  - PFI: Provides researchers funded by NSF from all disciplines of science and engineering 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; PFI supports additional prototyping, technology demonstration, and scale-up work, including licensing of NSF-funded research outputs.
  - I-Corps™: Connects NSF-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.
- Racial Equity: Across its full portfolio of investments, TIP will include Racial Equity as a foundational design principle. In addition, as one form of translational impact, TIP will partner with other NSF directorates and offices to build upon the Foundation's education and broadening participation research portfolio to advance organizational change.

**TIP Funding for Centers Programs**

**TIP Funding for Centers Programs**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| Regional Innovation Accelerators | - | - | 200.00 | - | N/A |
| **Total** | **-** | **-** | **$200.00** | **-** | **N/A** |

Regional Innovation Accelerators (RIAs): TIP will build and expand capacities for innovation at the level of individual communities and/or regions by launching Regional Innovation Accelerators that tackle use-inspired, solutions-oriented research and innovation in a range of technology areas (e.g., artificial intelligence, quantum information science, advanced wireless, advanced manufacturing, semiconductors) as well as in a diverse set of national-challenge areas (e.g., climate change and biotechnology) of priority to the Administration and Congress. For detailed information about the RIAs, please see the divisional narratives below as well as the NSF-Wide Investments chapter on Centers Programs.

**TIP Funding for NSF-Wide Investments**

TIP will advance science and engineering research and innovation leading to breakthrough technologies; paving the way for new, high-wage, good-quality jobs; and sustaining and enhancing U.S. competitiveness on a global stage for decades to come. TIP funding in NSF-wide investments corresponding to emerging industries are shown in the table below.

**TIP Funding for NSF-Wide Investments[1]**
(Dollars in Millions)

| Area of Investment[2,3] | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|
| Advanced Manufacturing | $26.58 | $24.63 | $54.63 |
| Advanced Wireless Research | 0.60 | 0.55 | 30.55 |
| Artificial Intelligence | 67.66 | 61.55 | 121.55 |
| Biotechnology | 9.27 | 9.06 | 69.06 |
| Climate: Clean Energy Technology | 48.47 | 52.47 | 52.47 |
| Microelectronics and Semiconductors | 17.71 | 20.23 | 50.23 |
| Quantum Information Science | 15.47 | 18.42 | 48.42 |

[1] FY 2020 and 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 narratives.

## Program Monitoring and Evaluation

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

## People Involved in TIP Activities

**Number of People Involved in TIP Activities**

| | FY 2020 Actual Estimate | FY 2020 CARES Act Actual Estimate | FY 2021 Estimate | FY 2022 Estimate |
|---|---|---|---|---|
| Senior Researchers | 2,486 | 33 | 2,600 | 5,800 |
| Other Professionals | 1,331 | 25 | 1,400 | 3,000 |
| Postdoctoral Associates | 130 | - | 140 | 700 |
| Graduate Students | 286 | 4 | 300 | 3,600 |
| Undergraduate Students | 174 | 9 | 180 | 3,000 |
| **Total Number of People** | **4,407** | **71** | **4,620** | **16,100** |

**DIVISION OF INNOVATION ECOSYSTEMS (IE)** **$335,000,000**
**+$225,000,000 / 204.5%**

**IE Funding**[1]
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| **Total** | **$98.18** | **$110.00** | **$335.00** | **$225.00** | **204.5%** |
| **Research** | **98.18** | **110.00** | **325.00** | **215.00** | **195.5%** |
| Convergence Accelerator | 60.23 | 70.00 | 70.00 | - | - |
| Centers Funding (Total) | - | - | 150.00 | 150.00 | N/A |
| Regional Innovation Accelerators (RIAs) | - | - | 150.00 | 150.00 | N/A |
| **Education** | **-** | **-** | **10.00** | **10.00** | **N/A** |

[1] FY 2020 and FY 2021 funding is adjusted for comparability to reflect the movement of activities to TIP in FY 2022.

**About IE**

IE investments will build and strengthen the U.S. innovation ecosystem, engaging a broad, diverse set of individuals and organizations in the Nation's research, innovation, and education enterprise, and accelerating use-inspired, solutions-oriented efforts that will result in breakthrough technologies and enhance U.S. competitiveness and security. IE investments will bring together teams of researchers, practitioners, and users, catalyzing iterative co-design/co-creation, leading to game-changing technologies and solutions, and paving the way for new, high-wage, good-quality jobs.

Among its investments, IE supports efforts to enable NSF to accelerate use-inspired, convergent research in areas aligned with Administration and Congressional priorities. For example, the CA leverages foundational advances by other NSF directorates and offices, nurtures multi-disciplinary and multi-sector teams, and accelerates solutions-oriented research and piloting of new technologies in specific areas of national importance such as emerging industries. Likewise, in collaboration with all NSF directorates and offices, the RIAs will cultivate new innovation ecosystems at the scale of individual communities and/or regions throughout the U.S., advancing use-inspired, solution-oriented research and innovation in a range of technology areas (e.g., artificial intelligence, quantum information science, advanced wireless, advanced manufacturing, semiconductors) as well as in a diverse set of national-challenge spaces of priority to the Administration and Congress (e.g., biotechnology and climate change). The RIAs will bring together multiple disciplines, organizations, and sectors by balancing technical and geographic (i.e., local and regional challenges, capabilities, and perspectives) innovation; incentivizing partnerships between NSF, academia, industry, nonprofits, state and local governments, and venture capital; and serving as hubs for NSF's broader portfolios in their respective areas of focus.

IE also supports entrepreneurial education through the I-Corps™ program, which is moved from ENG to TIP, as well as through NSF Entrepreneurial Fellowships. I-Corps™ connects NSF-funded science and engineering research with the technological, entrepreneurial, and business communities, addressing the skill and knowledge gap associated with the transformation of basic research into deep technology ventures. In particular, 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 NSF Entrepreneurial Fellowships will embed Ph.D.-trained scientists and engineers in leading research environments that will develop the Fellows into leaders capable of maturing promising ideas and technologies from lab to market.

**PARTNERSHIPS OFFICE (PO)** **$50,000,000**

**PO Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| **Total** | **-** | **-** | **$50.00** | **$50.00** | **N/A** |
| **Research** | **-** | **-** | **50.00** | **50.00** | **N/A** |

**About PO**

To further enable NSF investments in research, innovation, and education, the PO will serve as a central resource to catalyze and scale public and private partnerships agency-wide. Specifically, the PO will provide 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 all areas of science, engineering, and education. The PO will help these partnerships expand the reach of, and exponentially increase the return on, NSF's investments across all of its directorates and offices.

NSF's partnerships unite broad and diverse communities and coalitions in the pursuit of discovery and innovation by leveraging the individual and 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, PO-facilitated partnerships will nurture STEM talent by focusing on the engagement of populations long underrepresented in STEM, along with broad organizational changes (e.g., at institutions of higher education) and the inclusion of diverse institution types such as minority-serving institutions. Through these partnerships, the PO will also advance testbeds and other infrastructure critical to furthering the research and education enterprise.

**DIVISION OF TECHNOLOGY FRONTIERS (TF) $150,000,000**

**TF Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| **Total** | **-** | **-** | **$150.00** | **$150.00** | **N/A** |
| **Research** | **-** | **-** | **140.00** | **140.00** | **N/A** |
| Centers Funding (Total) | - | - | 50.00 | 50.00 | N/A |
| Regional Innovation Accelerators (RIAs) | - | - | 50.00 | 50.00 | N/A |
| **Education** | **-** | **-** | **10.00** | **10.00** | **N/A** |

**About TF**

TF will partner with the other divisions and PO of TIP as well as with other NSF directorates and offices to identify and accelerate the translational impacts of NSF-funded research, with a particular focus on the innovative technologies that will address national and societal challenges as well as enhance U.S. competitiveness and security. TF will promote sustainable partnerships spanning government, academia, industry, philanthropy, civil society, and investors to foster game-changing technologies and solutions, along with new, high-wage, good-quality jobs.

Along with the IE division, and in collaboration with all NSF directorates and offices, TF will cultivate new innovation ecosystems at the scale of individual communities and/or regions throughout the U.S. by launching a set of RIAs. The RIAs will advance use-inspired, solutions-oriented research and innovation in a range of technology areas (e.g., artificial intelligence, quantum information science, advanced wireless, advanced manufacturing, semiconductors) as well as in a diverse set of national-challenge areas of priority to the Administration and Congress (e.g., climate change and biotechnology).

TF will also invest in NSF Entrepreneurial Fellowships to embed Ph.D.-trained scientists and engineers in leading research and innovation environments that will develop the Fellows into leaders capable of maturing promising ideas and technologies from lab to market.

**DIVISION OF TRANSLATIONAL IMPACT (TI)** **$329,870,000**
**+$75,000,000 / 29.4%**

**TI Funding[1]**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| **Total** | **$254.13** | **$254.87** | **$329.87** | **$75.00** | **29.4%** |
| **Research** | **254.13** | **254.87** | **329.87** | **75.00** | **29.4%** |
| SBIR/STTR, including Operations | 232.06 | 232.06 | 274.64 | 42.58 | 18.3% |
| SBIR | 196.04 | 199.06 | 236.39 | 37.33 | 18.8% |
| STTR | 31.10 | 28.00 | 33.25 | 5.25 | 18.8% |
| SBIR/STTR Operations | 4.93 | 5.00 | 5.00 | - | - |

[1] FY 2020 and FY 2021 funding is adjusted for comparability to reflect the movement of activities to TIP in FY 2022.

## About TI

TI investments will advance the impacts of NSF-funded research by accelerating the translation of research results to practice. In particular, the division will provide an optimized lab-to-market platform, funding the highly successful PFI, SBIR, and STTR programs, which are moved from ENG to TIP.

Through PFI, TI offers researchers with prior NSF-funded efforts spanning all disciplines of science and engineering the opportunity to explicitly enter into partnerships, especially with industry, to accelerate the translation of discoveries from the laboratory to the marketplace for broad societal and/or economic benefits. In particular, PFI supports additional prototyping, technology demonstration, and scale-up work, including licensing of NSF-funded research outputs.

Meanwhile, the SBIR and STTR programs transform scientific discovery into societal and/or economic benefit by catalyzing private-sector commercialization of deep 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 profound 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.

TI will also provide co-funding to existing investments by all of NSF's other directorates and offices, inspiring additional translation activity across the Foundation, leading to significant acceleration of the societal and/or economic impacts of NSF-funded research in a range of locales and sectors throughout the U.S.

**OFFICE OF INTERNATIONAL SCIENCE AND ENGINEERING (OISE)** **$75,320,000**
**+$24,000,000 / 46.8%**

**OISE Funding**
(Dollars in Millions)

| FY 2020 Actual | FY 2020 CARES Act Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| **$51.04** | - | **$51.32** | **$75.32** | **$24.00** | **46.8%** |

**About OISE**

OISE is the focal point for NSF's international science and engineering activities. OISE's mission is to promote an integrated, Foundation-wide international engagement strategy, and manage and coordinate internationally-focused programs that are innovative and catalytic. OISE focuses on international activities to identify research opportunities for U.S. researchers through access to international knowledge, infrastructure, and capabilities. OISE's FY 2022 Request supports this by focusing on three activities: (1) facilitating and supporting international partnerships, (2) providing opportunities for U.S. leadership to shape the global science and engineering agenda, and (3) promoting the development of a globally engaged U.S. workforce.

In FY 2022, OISE plans to relaunch a restructured Partnerships for International Research and Education (PIRE) program whose solicitation will be released in FY 2021. OISE plans to invest $14.0 million with a focused research theme related to climate change or clean energy-related research. OISE plans to coordinate with research and education directorates to facilitate the acceleration of discovery, increase scientific impact, and to strengthen U.S. leadership in science and engineering. PIRE will continue its support for high quality research and education opportunities that cannot occur without international collaboration.

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 under the purview of the Research and Education Directorates. In FY 2022, OISE will leverage the GVF with a $10.0 million investment to support large scale NSF activities, in cooperation with research and education directorates, in Administration and Agency priorities related to climate change and clean energy-related research. Through this investment, OISE will support collaborative research that will enable innovative international connections not otherwise possible for U.S. researchers and students, advance the frontiers of knowledge, and contribute to U.S. scientific leadership.

In FY 2022, 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 2022, 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 2022, 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.

OISE plans to design improvements to the IRES program using the results from an external evaluation of Track I in the FY 2022 competition. For example, OISE intends to leverage an existing registration portal for REU students to improve tracking of long-term outcomes of the program. In FY 2022, OISE will continue the pause on IRES Track III to assess it for sufficiency; IRES Track III provided support for U.S. institutional partnerships to develop and evaluate innovative models for high-impact, large-scale international research, and professional development experiences for U.S. graduate students. To date responses to this track do not appear to meet program objectives. Following a thorough analysis, OISE may terminate or restructure this track in FY 2022.

In FY 2022, OISE intends to resume in person MULTIPlying Impact Leveraging International Expertise in Research (MULTIPLIER) missions, pending COVID pandemic status, 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.

In FY 2022, 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 2020 Actual Estimate | FY 2021 Estimate | FY 2022 Estimate |
|---|---|---|---|
| **Statistics for Competitive Awards:** | | | |
| Number of Proposals | 428 | 435 | 500 |
| Number of New Awards | 74 | 75 | 85 |
| Regular Appropriation | 74 | 75 | 85 |
| CARES Act | - | | |
| Funding Rate | 17% | 17% | 17% |
| **Statistics for Research Grants:** | | | |
| Number of Research Grant Proposals | 427 | 430 | 495 |
| Number of Research Grants | 73 | 73 | 80 |
| Regular Appropriation | 73 | 73 | 80 |
| CARES Act | - | | |
| Funding Rate | 17% | 17% | 16% |
| Median Annualized Award Size | $100,091 | $150,000 | $150,000 |
| Average Annualized Award Size | $163,145 | $170,000 | $200,000 |
| Average Award Duration, in years | 3.2 | 3.2 | 3.2 |

In FY 2022, the number of research grant proposals and research grant awards are expected to increase due to the relaunch of the PIRE program and the support for large-scale international engagement activities.

## Program Monitoring and Evaluation

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

## People Involved in OISE Activities

**Number of People Involved in OISE Activities**

| | FY 2020 Actual Estimate | FY 2020 CARES Act Actual Estimate | FY 2021 Estimate | FY 2022 Estimate |
|---|---|---|---|---|
| Senior Researchers | 312 | - | 320 | 330 |
| Other Professionals | 91 | - | 90 | 100 |
| Postdoctoral Associates | 16 | - | 20 | 20 |
| Graduate Students | 71 | - | 70 | 110 |
| Undergraduate Students | 39 | - | 40 | 230 |
| **Total Number of People** | **530** | **-** | **540** | **790** |

**OFFICE OF POLAR PROGRAMS (OPP)** **$506,290,000**
**+$22,940,000 / 4.7%**

**OPP Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| **Research** | **$124.01** | **$127.16** | **$134.31** | **$7.15** | **5.6%** |
| Long Term Ecological Research (LTER) | 2.97 | 3.38 | 3.38 | - | - |
| **Education** | **0.95** | **0.75** | **0.75** | **-** | **-** |
| **Infrastructure** | **355.63** | **355.44** | **371.23** | **15.79** | **4.4%** |
| Academic Research Fleet | 0.79 | - | - | - | N/A |
| Arctic Research Support and Logistics | 50.15 | 53.00 | 58.00 | 5.00 | 9.4% |
| IceCube Neutrino Observatory (ICNO) | 3.50 | 3.50 | 3.65 | 0.15 | 4.3% |
| U.S. Antarctic Facilities and Operations | 208.02 | 207.30 | 216.02 | 8.72 | 4.2% |
| U.S. Antarctic Logistical Support | 77.00 | 77.00 | 77.10 | 0.10 | 0.1% |
| Geodetic Facility for the Advancement of GEoscience (GAGE) | 1.53 | 1.20 | 1.30 | 0.10 | 8.3% |
| Seismological Facility for the Advancement of GEoscience (SAGE) | 0.83 | 0.85 | 0.87 | 0.02 | 2.4% |
| Major Research Instrumentation (MRI) | 0.39 | - | - | - | N/A |
| Midscale Research Infrastructure Programs (MRIP) | 2.65 | - | - | - | N/A |
| Research Resources | 2.12 | 5.29 | 6.29 | 1.00 | 18.9% |
| Polar Environment, Safety, and Health (PESH) | 8.63 | 7.30 | 8.00 | 0.70 | 9.6% |
| **Total** | **$480.59** | **$483.35** | **$506.29** | **$22.94** | **4.7%** |

## 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 2022 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 2021, 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 2022, OPP is anticipating a lower operating tempo relative to the pre-COVID-19 pandemic period in both polar regions. OPP will therefore focus on investments in research that can be supported during this period of reduced field activities. This is also true for infrastructure, where only investments in critical infrastructure systems consistent with safe personnel deployments in the coming season will be made.

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 studies and workshops section below, to identify priority areas and ensure effective polar research programs:

- 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.
- 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 (NASEM).[1] The Thwaites program is jointly supported, including shared logistics, with the National 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 2020-2021, and will be resumed in 2021-2022.
- Support for climate change research and the U.S. Global Change Research Program (USGCRP) is a particular emphasis in FY 2022. Investments 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.
- Specific contributions include, for example, 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, which is a global network of chemical and biological sensors to monitor ocean health.
- 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.

**Major Investments**

- In FY 2022, OPP research funding is $134.31 million. To accommodate its core research priorities, OPP will continue to leverage interagency and international partnerships.
- Arctic programs will continue to focus on integrating sustained observations, process studies, theory, and modeling of the natural and social systems to understand and improve predictions of the changing Arctic and its role in the Earth system. This has in prior years, and will in FY 2022, include investments in polar cyberinfrastructure, data analytics, and software. A major FY 2019 investment was made in the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC),[2] an international study of the sea ice, ocean, and atmospheric interactions driving weather and climate in the central Arctic Ocean with a year-round field presence that extended into FY 2020. NSF will continue to invest

[1] www.nap.edu/catalog/21741/a-strategic-vision-for-nsf-investments-in-antarctic-and-southern-ocean-research
[2] www.mosaic-expedition.org/

in this effort as the project transitions to analysis of the data generated by the intensive observation phase.

- 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.
- Antarctic science will maintain funding in priority areas as outlined in the 2015 National Academies report and the NSF's Windows on the Universe (WoU) and Understanding the Rules of Life (URoL) Big Ideas. Antarctic core programs will maintain funding in Antarctic glaciology, astrophysics and space weather sciences, ocean and atmospheric sciences, earth sciences, and organisms and ecosystems, as well as integrated system science, instrumentation and research facilities, and cyberinfrastructure.
- 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.
- Education activities across OPP will be supported through existing programs including Improving Undergraduate STEM Education (IUSE), Research Experiences for Undergraduates (REU) Supplements, REU sites, and other polar education activities.
- Arctic research support and logistics funding is increased by $5.0 million to $58.0 million to support Arctic field science programs that can be safely recovered in the summer of 2022.
- In FY 2022, Antarctic Facilities and Operations funding is increased by $8.72 million to $216.02 million. This 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.[3]
- The U.S. Antarctic Logistical Support will be funded at $77.10 million. This will support the limited commitments for field work in the Antarctic in the first half of FY 2022 and reflects higher LC-130H sustainment costs.
- To maintain U.S. leadership in the Southern Ocean marine science, OPP will invest $8.0 million in design studies of a future state-of-the-art ice-breaking research vessel.

**OPP Funding for Major Facilities**

**OPP Funding for Major Facilities**

(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| **Total** | **$214.68** | **$212.85** | **$221.84** | **$8.99** | **4.2%** |
| IceCube Neutrino Observatory (ICNO) | 3.50 | 3.50 | 3.65 | 0.15 | 4.3% |
| U.S. Antarctic Facilities and Operations (AFO) | 208.02 | 207.30 | 216.02 | 8.72 | 4.2% |
| Academic Research Fleet (ARF) | 0.79 | - | - | - | N/A |
| Geodetic Facility for the Advancement of GEoscience (GAGE) | 1.53 | 1.20 | 1.30 | 0.10 | 8.3% |
| Seismological Facility for the Advancement of GEoscience (SAGE) | 0.83 | 0.85 | 0.87 | 0.02 | 2.4% |

For detailed information on individual facilities, please see the Major Research Facilities chapter. The Antarctic Infrastructure Modernization for Science (AIMS) project will be subsumed into the Antarctic Infrastructure Recapitalization (AIR) program, which will encompass a broader capital plan for NSF's

[3] thwaitesglacier.org/

Antarctic infrastructure. For detailed information on this, please see the Major Research Equipment and Facilities Construction chapter.

## Funding Profile

**OPP Funding Profile**

| | FY 2020 Actual Estimate | FY 2021 Estimate | FY 2022 Estimate |
|---|---|---|---|
| **Statistics for Competitive Awards:** | | | |
| Number of Proposals | 413 | 500 | 530 |
| Number of New Awards | 194 | 150 | 160 |
| Regular Appropriation | 194 | 150 | 160 |
| CARES Act | - | | |
| Funding Rate | 47% | 30% | 30% |
| **Statistics for Research Grants:** | | | |
| Number of Research Grant Proposals | 407 | 450 | 500 |
| Number of Research Grants | 190 | 130 | 140 |
| Regular Appropriation | 190 | 130 | 140 |
| CARES Act | - | | |
| Funding Rate | 47% | 29% | 28% |
| Median Annualized Award Size | $211,248 | $187,800 | $190,000 |
| Average Annualized Award Size | $303,039 | $292,800 | $295,000 |
| Average Award Duration, in years | 2.8 | 2.6 | 2.6 |

In general, about 20 percent of the OPP portfolio is available for new research grants. In FY 2022, the number of research grant proposals is expected to increase by about 100 compared to the FY 2020 Actual.

## Program Monitoring and Evaluation

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

## People Involved in OPP Activities

**Number of People Involved in OPP Activities**

| | FY 2020 Actual Estimate | FY 2021 Estimate | FY 2022 Estimate |
|---|---|---|---|
| Senior Researchers | 876 | 900 | 900 |
| Other Professionals | 455 | 500 | 500 |
| Postdoctoral Associates | 129 | 100 | 100 |
| Graduate Students | 404 | 400 | 400 |
| Undergraduate Students | 302 | 300 | 300 |
| **Total Number of People** | **2,166** | **2,200** | **2,200** |

## INTEGRATIVE ACTIVITIES (IA) $504,900,000 +$120,020,000 / 31.2%

**IA Funding**[1]
(Dollars in Millions)

| | FY 2020 Actual | FY 2020 CARES Act Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|---|
| Analysis, Modeling, and Forecasting | - | - | - | $3.00 | $3.00 | N/A |
| EPSCoR | 190.32 | 1.25 | 200.00 | 239.64 | 39.64 | 19.8% |
| Evaluation and Assessment Capability | 5.29 | - | 5.00 | 7.00 | 2.00 | 40.0% |
| Facility Operations Transition[2] | - | - | - | 12.00 | 12.00 | N/A |
| Growing Convergence Research | 15.90 | 0.30 | 16.00 | 24.17 | 8.17 | 51.1% |
| HBCU Excellence in Research | 18.05 | 0.40 | 20.00 | 33.96 | 13.96 | 69.8% |
| Major Research Instrumentation | 74.98 | - | 75.00 | 89.85 | 14.85 | 19.8% |
| Mid-scale Research Infrastructure | 30.37 | - | 32.67 | 50.00 | 17.33 | 53.0% |
| NSF 2026 | 6.42 | - | - | - | - | N/A |
| Planning and Policy Support | 4.72 | - | 2.50 | 3.00 | 0.50 | 20.0% |
| Research Experiences for Undergraduates | 0.03 | - | - | - | - | N/A |
| Research Investment Communications | 1.54 | - | 3.47 | 5.00 | 1.53 | 44.1% |
| Research Security Strategy and Policy | - | - | - | 1.00 | 1.00 | N/A |
| STC Class of 2021 | - | - | 25.00 | 30.00 | 5.00 | 20.0% |
| STC Admin | 0.61 | - | 0.50 | 0.60 | 0.10 | 20.0% |
| Science & Technology Policy Institute | 4.74 | - | 4.74 | 5.68 | 0.94 | 19.8% |
| **Total** | **$352.97** | **$1.95** | **$384.88** | **$504.90** | **$120.02** | **31.2%** |

[1] In FY 2022, the Graduate Research Fellowship Program is consolidated into the Directorate for Education and Human Resources and the NSF Convergence Accelerator moves to the Directorate for Technology, Innovation, and Partnerships. In the above, all years are shown in this new structure for comparability. See the EHR chapter and the R&RA Overview narrative for more information.

[2] In both the FY 2020 Current Plan and FY 2021 Estimate, $10.0 million was distributed to the managing directorates. See the Facilities Overview narrative for more information.

### 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 decision making.

IA stewards two Big Ideas, Growing Convergence Research (GCR) and Mid-scale Research Infrastructure (Track-1) activities between $6 million and $20 million. Jointly, these activities support innovative, transdisciplinary team science, advanced research infrastructure, use-inspired research, and emerging national research priorities.

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. IA 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 2022 Activities**

<u>Analysis, 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 to generate timely and actionable insights to inform strategy, investments, and programmatic decisions. NSF will harness big data (both structured and unstructured) and data science (including artificial intelligence 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>Established Program to Stimulate Competitive Research</u>

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

<u>Evaluation and Assessment Capability</u>

- EAC 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 2022 Request level, increased 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 increase accompanies the growth of EAC to provide needed Agency-wide support that complements the work conducted by NSF directorates and offices.

<u>Facility Operation Transition</u>

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

[1] www.nsf.gov/pubs/2018/nsb201817/nsb201817.pdf

significantly impact individual division or directorate funding. For more information see the Facilities Overview narrative in the Major Facilities chapter.

Growing Convergence Research

- 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 aims to grow the next generation of convergence researchers. In FY 2022, GCR investments will support four to seven new research collaborations and the continuation of four to seven projects begun in FY 2020. In addition, GCR will invest in research community-led activities to identify 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. GCR will incubate the capacity of research teams to address these challenges. For more information about GCR, see the narrative in the NSF-Wide Investments chapter.

Historically Black Colleges and Universities – Excellence in Research

- The HBCU-EiR program focuses on improving the research capacity and competitiveness of HBCUs by supporting new research opportunities at these institutions. IA will fund up to 70 HBCU-EiR research grants managed by NSF's S&E directorates. In addition, the program builds capacity for research teams to succeed in center-scale competitions.

Major Research Instrumentation

- MRI invests in shared-use S&E research instrumentation. Approximately 170 new awards will support instrument development and acquisition in all of NSF's S&E domains. MRI's investments also contribute to research-intensive learning environments that enhance the training of a diverse S&E workforce and facilitate partnerships between academia and the private sector.

Mid-scale Research Infrastructure

- The Mid-scale RI (Track-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 research infrastructure projects. In FY 2022, $50.0 million will be available for investment in Mid-scale RI-1 projects from the FY 2021 competition.

Planning and Policy Support (PPS)

- PPS includes funding for Proposal Management Efficiencies, which comprises activities such as the NSF biennial survey and studies of NSF's merit review process. PPS supports annual agency award activities (including the Alan T. Waterman Award and National Medal of Science) and summer science internship programs that target STEM students from underrepresented groups. PPS also provides funding to the National Academies of Science, Engineering, and Medicine (the National Academies) for the Committee on Science, Engineering, Medicine, and Public Policy (CoSEMPuP)[2], as well as studies, workshops, and letter reports spanning multiple research domains. The increase in FY 2022 invests in catalytic activities—workshops, conferences, and long-term planning exercises, focused on emerging themes and agency innovations—as well as capacity-building activities for national priorities.

[2] sites.nationalacademies.org/pga/cosepup/index.htm.

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 2022, 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

- NSF is expanding capabilities and competencies to protect the U.S. science and engineering enterprise through its Research Science Security and Policy activity. NSF is establishing new analytic capabilities to proactively identify conflicts of commitment, vulnerabilities of pre-publication research, and risks to the merit review system. To ensure clear understanding of research security issues, NSF disclosure requirements, and the tenets of beneficial international collaboration, NSF is developing training resources for staff. NSF is also partnering with the federal government interagency community to develop training resources for the research community. NSF's activities respond to the JASON report, "Fundamental Research Security," published in December 2019.

Science and Technology Centers: Integrative Partnerships Program

- The STC program supports innovative, potentially transformative, complex research and education projects that require large-scale, long-term awards. STCs engage the Nation's intellectual talent through partnerships across academia, industry, national laboratories, and government. These collaborations create synergies that enhance the training of the next generation of scientists, engineers, and educators. In FY 2022, $25.0 million supports the second year of five Class of 2021 centers and $5.0 million funds a sixth center in the Class of 2021 portfolio.
- STC Administration supports post-award management of STC awards, including site visits by review teams. FY 2022 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.

**Program Monitoring and Evaluation**

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

**ESTABLISHED PROGRAM TO STIMULATE COMPETITIVE RESEARCH (EPSCOR)** **$239,640,000**
**+$39,640,000 / 19.8%**

**EPSCoR Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| **Total** | **$190.32** | **$200.00** | **$239.64** | **$39.64** | **19.8%** |
| Research Infrastructure Improvement | 148.57 | 148.86 | 187.08 | 38.22 | 25.7% |
| Co-Funding | 40.60 | 50.00 | 51.12 | 1.12 | 2.2% |
| Outreach and Workshops | 1.15 | 1.14 | 1.44 | 0.30 | 26.3% |

## 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 15 percent of the EPSCoR portfolio is available to support new research grants. The remaining 85 percent supports grants made in prior years.

EPSCoR uses three strategic investment tools: Research Infrastructure Improvement (RII) awards, Co-Funding, and Outreach/Workshops.

<u>Research Infrastructure Improvement (RII)</u>

- RII investments support development of physical, human, and cyber-based research infrastructure in EPSCoR jurisdictions, with an emphasis on collaborations among academic researchers, the private sector, and state and local governments, to effect sustainable improvements in research infrastructure. RII projects are designed to improve the research competitiveness of jurisdictions by strengthening their academic research infrastructure in areas of S&E supported by NSF that are critical to the jurisdiction's science and technology initiatives. RII projects increase the participation of underrepresented groups in STEM, enable broader regional and topical collaborations among jurisdictions, and facilitate the enhancement of discovery, learning, and economic development in EPSCoR jurisdictions. EPSCoR facilitates the engagement of its jurisdictions in S&E priority areas.
- In FY 2022, 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 2021 and FY 2022, proposals are invited on advancing research towards emerging industries to ensure economic growth for EPSCoR jurisdictions.
- 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 PIs to further develop their individual research potential through extended collaborative visits to NASA Centers' research facilities located throughout the U.S. This activity is planned for FY 2021 and FY 2022 and targets faculty at minority-serving institutions, women's colleges, and primarily undergraduate institutions in EPSCoR jurisdictions.

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 2022; 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 2022, 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 2020 Actual Estimate | FY 2020 CARES Act Actual Estimate | FY 2021 Estimate | FY 2022 Estimate |
|---|---|---|---|---|
| Senior Researchers | 604 | 16 | 600 | 800 |
| Other Professionals | 90 | 1 | 100 | 100 |
| Postdoctoral Associates | 78 | 3 | 100 | 100 |
| Graduate Students | 449 | 10 | 500 | 600 |
| Undergraduate Students | 349 | 3 | 400 | 400 |
| K-12 Teachers | 2,543 | - | 2,700 | 3,200 |
| K-12 Students | 32,547 | - | 34,200 | 41,000 |
| **Total Number of People** | **36,660** | **33** | **38,600** | **46,200** |

**UNITED STATES ARCTIC RESEARCH COMMISSION (USARC)** **$1,650,000**
**+$50,000 / 3.1%**

**USARC Funding**
(Dollars in Millions)

| FY 2020 Actual | FY 2020 CARES Act Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| **$1.60** | - | **$1.60** | **$1.65** | **$0.05** | **3.1%** |

## About USARC

USARC was created by the Arctic Research and Policy Act of 1984, (as amended, P. L. 101-609), to establish the national policy, priorities, and goals necessary to construct a federal program plan for basic and applied Arctic scientific research. USARC advises the Interagency Arctic Research Policy Committee in developing national Arctic research projects and a five-year plan to implement those projects. USARC also supports interaction with Arctic residents, international Arctic research programs and organizations, and local institutions, including regional and local governments, in order to obtain the broadest possible view of Arctic research needs. USARC is an independent federal agency, funded through NSF's appropriation, specifically as an activity in the Research and Related Activities account.

USARC is requesting $1.65 million, $50,000 above the FY 2021 Estimate. The FY 2022 Request provides funds to advance Arctic research, and to recommend Arctic research policy that is consistent with the Administration's priorities.

The FY 2022 Request will support three FTE funded at USARC. In addition, the FY 2022 Request supports one full-time contractor and four part-time contractors. A total of seven compensated personnel are authorized per P.L. 101-609. The seven Commissioners may also receive up to 90 days of salary per year, at the Executive Schedule Level IV.

## DIRECTORATE FOR EDUCATION AND HUMAN RESOURCES (EHR) $1,287,270,000
+$177,010,000 / 15.9%

**EHR Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2020 CARES Act Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|---|
| Division of Research on Learning in Formal and Informal Settings (DRL) | $198.62 | $2.16 | $204.16 | $229.66 | $25.50 | 12.5% |
| Division of Undergraduate Education (DUE) | 269.37 | 1.38 | 270.10 | 283.10 | 13.00 | 4.8% |
| Division of Human Resource Development (HRD) | 210.77 | 0.80 | 215.36 | 307.88 | 92.52 | 43.0% |
| Division of Graduate Education (DGE)[1] | 405.48 | 0.66 | 420.64 | 466.63 | 45.99 | 10.9% |
| **Total** | **$1,084.24** | **$5.00** | **$1,110.26** | **$1,287.27** | **$177.01** | **15.9%** |

[1] In FY 2022, full funding for the Graduate Research Fellowship Program is in the EHR with funds from IA moved to the Division of Graduate Education. The table above shows all years in the new structure for comparability.

### About EHR

The work of EHR is closely aligned with the Administration's priorities of advancing equity and addressing systemic racism to remove barriers for diverse communities. Through existing programs EHR 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 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 comprised of a diverse, highly skilled U.S. STEM workforce with competitive salaries and STEM-literate public to address societal challenges that were exacerbated by the global pandemic and support a vibrant U.S. economy.

The STEM enterprise is a microcosm of society and the challenges that impact society are reflected and often magnified in STEM education at all levels. To bolster STEM education communities most challenged in FY 2021, EHR increased investments in racial equity research across the directorate while also expanding opportunities for community colleges and supplements to fund post-doctoral training in STEM education. Through EHR's investments in foundational and future-oriented STEM educational research, the results of funded research are used to inform STEM programs and practices, to ensure the prosperity of the Nation through a well-educated STEM workforce which will contribute to efforts to raise the Nation's leadership in STEM education. Like all research, results might be applied more immediately or well into the future. As such, in FY 2022, EHR will deepen efforts to build capacity for STEM education research and identify and tackle the challenges in STEM education needed to create a well-paid workforce for the emerging industries that will help drive the U.S. economy. Thus, the EHR research portfolio 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 areas that result from changes in technology, the Nation's demography, the economy, and new directions in STEM. These areas include how and what to teach students so that they are prepared to engage with AI, QIS, and computing, and how to do so in a manner, whether virtually, in-person, or in a blended format, that reduces demographic disparities. EHR's partnership with Boeing is one model for leveraging public-private partnerships to develop the STEM workforce for emerging industries. In FY 2020, EHR and Boeing focused on how to develop the workforce in model-based engineering, mechatronics, and data science/sensor analytics through the use of flexible, personalized learning systems. In FY 2022, EHR 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.

EHR allocations across divisions are designed to accomplish the collective work of the directorate, best described 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 PK-12 and informal learning environments are critical members of the future STEM and STEM-related workforce. Through its scholarship, fellowship, and traineeship programs, EHR supports the development of talent at the undergraduate and graduate levels. EHR programs such as the Advanced Technology Education (ATE) support the STEM-specific workforce, including a data-skilled workforce and the broader workforce that rely on STEM skills, thus addressing the Nation's critical need for a 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 to enter the workforce of the future.

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 program (DRK-12) and Advancing Informal STEM Learning program (AISL) 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, EHR continues to support the Historically Black Colleges and Universities Undergraduate Program (HBCU-UP), the Improving Undergraduate STEM Education (IUSE): Hispanic-Serving Institutions (HSI) Program, and the Tribal Colleges and Universities Program (TCUP) to facilitate the advancement of early career STEM professionals at Minority Serving Institutions (MSIs) and to enhance the academic experience of students studying STEM at MSIs.

As a natural extension of EHR's experience in broadening participation, EHR serves as the steward for NSF INCLUDES, one of NSF's Big Ideas. EHR continues to make advances in knowledge generation and dissemination through NSF INCLUDES to understand what interventions work and under what conditions to broaden participation in STEM. For more information about NSF INCLUDES, see the narrative in the NSF-Wide Investments chapter.

EHR also supports NSF and Administration priorities through participation in Foundation-wide activities. Through existing programs, EHR invests in NSF's Big Ideas HDR, FW-HTF, and NNA. By incorporating the Big Ideas into the NRT's priority themes, EHR invests in the development of researchers with the necessary skills to conduct convergence research. In FY 2022, EHR continues to support SaTC, and NITRD (education and workforce), all of which provide opportunities for research on the intersection of artificial intelligence and education.

EHR continues its strong emphasis on evidence-based decision making and its commitment to generating robust evidence to inform the development, management, and assessment of its programs and portfolios of investment. A multi-year learning agenda (evidence-building plan) for EHR's STEM human capital development programs will inform and guide future actions. EHR experts in evaluation will continue to collaborate with staff in NSF's Evaluation and Assessment Capability in developing NSF-wide learning agendas and with other federal agencies to share best practices, work toward the use of common metrics and instruments, strengthen evidence-building capacity for decision-making, and support transparency and accountability. A similar multi-year learning agenda was developed for NSF INCLUDES in FY 2020 and a plan for implementation is under development.

**Major Investments**

**EHR Major Investments**
(Dollars in Millions)

| Area of Investment[1,2] | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| Advanced Manufacturing | $1.45 | $2.00 | $2.00 | - | - |
| Artificial Intelligence | 6.76 | 30.00 | 50.00 | 20.00 | 66.7% |
| Biotechnology | 16.07 | 9.00 | 9.00 | - | - |
| Graduate Research Fellowship Program[3] | 284.51 | 284.52 | 318.52 | 34.00 | 11.9% |
| IUSE | 89.99 | 90.00 | 90.00 | - | - |
| Quantum Information Science | 3.98 | 4.00 | 4.00 | - | - |
| SaTC | 55.00 | 60.00 | 70.00 | 10.00 | 16.7% |
| NSF's Big Ideas | | | | | |
| *NSF INCLUDES* | *20.75* | *20.00* | *46.50* | *26.50* | *132.5%* |

[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 EHR Division of Graduate Education in FY 2022 and is restated in prior years for comparability.

- AI in Education and Workforce: EHR 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 EHR programs.
- Biotechnology: EHR invests in biotechnology through research and workforce development programs.
- GRFP: In FY 2022, funding for GRFP will be stewarded in EHR. For more information on GRFP, see the Major Investments in STEM Graduate Education narrative within the NSF-Wide Investments chapter.
- IUSE: EHR will lead the NSF-wide IUSE activity. For more information, see the IUSE narrative within the NSF-Wide Investments chapter.
- QIS: EHR invests in QIS through education and workforce development programs to prepare a diverse quantum information science and engineering workforce.
- SaTC: EHR will support SaTC activities through the CyberCorps®: Scholarship for Service (SFS) program.
- NSF INCLUDES: EHR will support NSF INCLUDES Alliances. For more information, see the NSF INCLUDES narrative within the NSF-Wide Investments chapter.

## EHR Major Investments in Broadening Participation

**Education and Human Resource Directorate Programs to Broaden Participation**
(Dollars in Millions)

| | Amount of Funding Captured | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|---|
| **Broadening Participation: Focused Programs** | | | | | | |
| ADVANCE | 100% | $18.00 | $18.00 | $20.50 | $2.50 | 13.9% |
| Alliances for Grad Ed & the Professoriate (AGEP) | 100% | 8.00 | 8.00 | 12.00 | $4.00 | 50.0% |
| Ctrs of Research Excellence in Science & Tech (CREST) | 100% | 24.00 | 24.00 | 39.00 | $15.00 | 62.5% |
| Excellence Awards in Science & Engineering (EASE)[1] | 100% | 7.33 | 5.00 | 7.64 | $2.64 | 52.8% |
| Historically Black Colleges & Universities Undergraduate Program (HBCU-UP) | 100% | 35.00 | 36.50 | 46.50 | $10.00 | 27.4% |
| Improving Undergraduate STEM Education: Hispanic Serving Institutions (IUSE:HSI) | 100% | 45.00 | 46.50 | 56.50 | $10.00 | 21.5% |
| NSF INCLUDES | 100% | 20.75 | 20.00 | 46.50 | $26.50 | 132.5% |
| Louis Stokes Alliances for Minority Participation (LSAMP) | 100% | 47.49 | 49.50 | 69.50 | $20.00 | 40.4% |
| NSF Scholarships in STEM (S-STEM)[2] | 100% | 79.91 | 132.75 | 121.85 | -10.90 | -8.2% |
| Tribal Colleges & Universities Program (TCUP) | 100% | 15.00 | 16.50 | 21.00 | $4.50 | 27.3% |
| **Subtotal, Focused Programs** | | **$300.48** | **$356.75** | **$440.99** | **$84.24** | **23.6%** |
| **Broadening Participation: Emphasis Programs[3]** | | | | | | |
| Advancing Informal STEM Learning (AISL) | 58% | 36.24 | 36.25 | 40.60 | 4.35 | 12.0% |
| Computer Science for All (CSforALL) | 62% | 9.30 | 6.20 | 6.20 | - | - |
| Discovery Research PreK-12 (DRK-12) | 56% | 53.20 | 53.20 | 53.20 | - | - |
| EHR Core Research | 62% | 41.43 | 47.52 | 60.15 | 12.63 | 26.6% |
| Graduate Research Fellowship Program (GRFP)[4] | 67% | 189.48 | 189.49 | 212.13 | 22.64 | 11.9% |
| Improving Undergraduate STEM Education (IUSE) | 64% | 57.59 | 57.60 | 57.60 | - | - |
| Innovative Technology Experiences for Students and Teachers (ITEST)[2] | 74% | 25.80 | 32.75 | 30.06 | -2.69 | -8.2% |
| Robert Noyce Teacher Scholarship Program (NOYCE) | 59% | 41.16 | 39.53 | 39.53 | - | - |
| **Subtotal, Emphasis Programs** | | **$454.22** | **$462.54** | **$499.48** | **$36.94** | **8.0%** |
| **Total, EHR Broadening Participation Programs** | | **$754.70** | **$819.29** | **$940.47** | **$121.18** | **14.8%** |

[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 EHR Major Investments, see the narratives for individual EHR divisions.

## EHR Funding for Centers Programs

**EHR Funding for Centers Programs**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| Artificial Intelligence Research Institutes | 2.03 | 7.59 | 17.59 | 10.00 | 131.8% |
| **Total** | **$2.03** | **$7.59** | **$17.59** | **$10.00** | **131.8%** |

For detailed information on individual centers programs, please see the NSF-Wide Investments chapter.

## Appropriations Language

For necessary expenses in carrying out science, mathematics and engineering education and human resources programs and activities pursuant to the National Science Foundation Act of 1950 (42 U.S.C. 1861 et seq.), including services as authorized by section 3109 of title 5, United States Code, authorized travel, and rental of conference rooms in the District of Columbia, $~~968,000,000~~1,287,270,000, to remain available until September 30, ~~2022~~2023.

**Education and Human Resources**
**FY 2022 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 2020 Appropriation | $940.00 | $5.66 | -$4.25 | $3.02 | $2.55 | $946.98 |
| FY 2021 Estimated | 968.00 | 4.25 | | | | 972.25 |
| FY 2022 Request | 1,287.27 | | | | | 1,287.27 |
| $ Change from FY 2021 Estimated | | | | | | $315.02 |
| % Change from FY 2021 Estimated | | | | | | 32.4% |

Totals exclude reimbursable amounts.

## Explanation of Carryover

Within the EHR account, $4.25 million was carried over into FY 2021, including $2.18 million in anticipated no-year recoveries.

Advanced Technological Education (ATE)
- Amount: $1.45 million
- Purpose: Funds became available late in FY 2020 after decommitment of an incremental grant commitment. Funds will be used on new ATE projects recommended for award.
- Obligation: FY 2021 Quarter 2 and Anticipated FY 2021 Quarter 3

Robert Noyce Teacher Scholarship Program (Noyce)
- Amount: $564,832
- Purpose: These funds will be used to invest in teacher preparation and/or support Noyce fellows during completion of a teaching obligation.
- Obligation: FY 2021 Quarter 2

The remaining $55,000 consists of funds from EHR for projects not funded in FY 2020.

## Funding Profile

**EHR Funding Profile**

| | FY 2020 Actual Estimate | FY 2021 Estimate | FY 2022 Estimate |
|---|---|---|---|
| **Statistics for Competitive Awards:** | | | |
| Number of Proposals | 4,337 | 4,400 | 4,700 |
| Number of New Awards | 996 | 950 | 1,300 |
| Regular Appropriation | 963 | 950 | 1,300 |
| CARES Act | 33 | | |
| Funding Rate | 23% | 22% | 28% |
| **Statistics for Research Grants:** | | | |
| Number of Research Grant Proposals | 3,322 | 3,200 | 3,500 |
| Number of Research Grants | 672 | 650 | 900 |
| Regular Appropriation | 643 | 650 | 900 |
| CARES Act | 29 | | |
| Funding Rate | 20% | 20% | 26% |
| Median Annualized Award Size | $190,546 | $260,000 | $260,000 |
| Average Annualized Award Size | $276,341 | $280,000 | $280,000 |
| Average Award Duration, in years | 2.9 | 2.9 | 2.9 |

In FY 2022, the number of research grant proposals is expected to increase by approximately 200 compared to the FY 2020 Actual, and EHR expects to award about 900 research grants accounting for the increase in overall grant funding. Average annual award size and duration are not expected to materially fluctuate in FY 2020 through FY 2022.

## People Involved in EHR Activities

**Number of People Involved in EHR Activities**

| | FY 2020 Actual Estimate | FY 2020 CARES Act Actual Estimate | FY 2021 Estimate | FY 2022 Estimate |
|---|---|---|---|---|
| Senior Researchers | 7,534 | 68 | 8,000 | 8,600 |
| Other Professionals | 2,238 | 26 | 2,200 | 2,600 |
| Postdoctoral Associates | 349 | 10 | 350 | 400 |
| Graduate Students | 11,300 | 26 | 11,300 | 13,400 |
| Undergraduate Students | 16,600 | 195 | 16,600 | 19,000 |
| K-12 Teachers | 37,800 | 2 | 37,800 | 43,300 |
| K-12 Students | 85,500 | 15 | 85,500 | 98,100 |
| **Total Number of People** | **161,321** | **342** | **161,750** | **185,400** |

**DIVISION OF RESEARCH ON LEARNING IN FORMAL AND INFORMAL SETTINGS (DRL)** **$229,660,000**
**+$25,500,000 / 12.5%**

**DRL Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| **Total** | **$198.62** | **$204.16** | **$229.66** | **$25.50** | **12.5%** |
| **Research** | **183.62** | **194.16** | **219.66** | **25.50** | **13.1%** |
| **Education** | **15.00** | **10.00** | **10.00** | **-** | **-** |

**About DRL**

DRL invests in foundational research to advance understanding about teaching and learning in STEM—including computer science and emerging fields such as data science, quantum information science, and artificial intelligence. With a focus on equity issues, 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 that will enable building of the Nation's economy.

**FY 2022 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. students pre-K-12 learn STEM, including computer science and emerging fields such as data science, quantum information science, and artificial intelligence. U.S. students benefit from a strong start beginning in early childhood, and continuing education in mathematics and other STEM disciplines. DRK-12 supports research and development of resources for teachers and schools across diverse educational settings including remote/online learning environments.
- EHR Core Research (ECR) funds enable significant progress on important basic and use-inspired basic research questions about STEM learning and teaching. ECR supports research and development addressing persistent issues in the learning and teaching of STEM content, such as equity issues in STEM education and the STEM workforce. ECR also supports future-oriented topics that envision STEM learning environments of the future, engage cutting-edge technologies in research methodologies, and evaluation of innovative models for broadening participation in STEM. In FY 2022, ECR will expand the portfolio of research on future-oriented topics in the education and training of a diverse workforce for emerging industries, push the boundaries of technology use in education including and beyond remote learning, and examine how learning will change because of advances in technology and developments in emerging industries. Researchers will need to develop new methodologies to tackle new questions. In FY 2022, EHR will continue efforts through the ECR Building Capacity in STEM Education Research initiative to develop human capital for future-oriented

STEM education research and encourage submissions from MSIs in discipline-based education and broadening participation research.

- National Artificial Intelligence Research Institutes in FY 2022: EHR will support research on AI in relation to education and the workforce, with an emphasis on supporting minority-serving institutions. The 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.

<u>Education</u>

- 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 under-represented groups. In FY 2022, CSforAll will be supported at $10.0 million in EHR, with an additional $14.50 million in support from CISE.

**DIVISION OF UNDERGRADUATE EDUCATION (DUE)** **$283,100,000**
**+$13,000,000 / 4.8%**

**DUE Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| **Total** | **$269.37** | **$270.10** | **$283.10** | **$13.00** | **4.8%** |
| **Research** | **126.05** | **128.10** | **141.10** | **13.00** | **10.1%** |
| **Education** | **143.32** | **142.00** | **142.00** | **-** | **-** |

**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. The resulting improvements in STEM education increase student learning, leading to greater retention and degree attainment by undergraduates. These 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 2021, DUE supported a new research emphasis on the learning and teaching of STEM content at 2-year institutions. We will continue this focus in FY 2022, as a diverse population of students start their STEM studies or enroll in STEM courses at 2-year colleges at some point in their careers.

**FY 2022 Summary**

<u>Research</u>
- ECR funds enable significant progress on important basic and use-inspired basic research questions about STEM learning and teaching. ECR is managed and funded across all EHR divisions. For a full description, see the write up in the DRL Division narrative.
- HSI funds will continue to support the improvement of undergraduate education at HSIs and build the capacity for STEM education and STEM education research at HSIs that have previously received little or no funding from NSF. Outreach efforts will continue to seek to engage institutions that are new to NSF.
- IUSE funding will support: mitigation of COVID-19 impacts on undergraduate education; increased understanding of and gains in diversity, equity, and inclusion in STEM education; increased use of evidence-based educational practices; 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. For more information see the IUSE narrative in 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 Noyce fellows during completion of a teaching obligation in high-need school districts.

**DIVISION OF HUMAN RESOURCE DEVELOPMENT (HRD)** **$307,880,000**
**+$92,520,000 / 43.0%**

**HRD Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| **Total** | **$210.77** | **$215.36** | **$307.88** | **$92.52** | **43.0%** |
| **Research** | **137.96** | **142.86** | **210.24** | **67.38** | **47.2%** |
| **Education** | **72.82** | **72.50** | **97.64** | **25.14** | **34.7%** |

## About HRD

HRD serves as a focal point for NSF's agency-wide commitment to broadening participation in STEM of historically underrepresented groups—minorities, women, and persons with disabilities by enhancing the quality and excellence of STEM education and research opportunities. HRD'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 HRD have a strong focus on partnerships and collaborations in support of institutional transformation and capacity building that lead to increased STEM participation of underrepresented groups. 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.

## FY 2022 Summary

Research

- AGEP funds will continue to support innovative STEM faculty career pathway models for advancing doctoral students, postdoctoral scholars and faculty who are historically underrepresented minorities (URMs) in STEM. The AGEP program will continue efforts to conduct a portfolio analysis, complete awardee site reviews, share best practices and collaborative partnerships findings, and network through the annual AGEP research conference.
- The 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. In FY 22, 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.
- ECR funds enable significant progress on important basic and use-inspired basic research questions about STEM learning and teaching. ECR is managed and funded across all EHR divisions. For a full description, see the write up in the DRL Division narrative.
- 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, supplements, and starter networks (e.g., research coordination networks) that serve as on-ramps to the NSF INCLUDES Alliances and the NSF INCLUDES National Network. For more information about NSF INCLUDES, see the NSF-Wide Investments chapter.
- 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. 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.

Education
- ADVANCE will continue to support evidence-based systemic change strategies to promote equity in STEM academic workplaces. ADVANCE will continue to evaluate the sustainability of its strategies and 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)** **$466,630,000**
**+$45,990,000 / 10.9%**

**DGE Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| **Total** | **$405.48** | **$420.64** | **$466.63** | **$45.99** | **10.9%** |
| **Research** | **16.46** | **18.12** | **20.11** | **1.99** | **11.0%** |
| **Education** | **389.03** | **402.52** | **446.52** | **44.00** | **10.9%** |

[1] 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 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 achieves this through direct investment in individuals; funding projects that spearhead the development and implementation of bold, new, and potentially transformative models for graduate education training in high priority interdisciplinary or convergent research areas; and through basic research on STEM graduate education. This research supports innovations in graduate education by exploring new ways for graduate students in research-based master's and doctoral degree programs to develop the skills, knowledge, and competencies needed to pursue a range of STEM careers in the 21st century. Special emphasis is given to training students in areas of national priority, such as cybersecurity, AI, advanced manufacturing, advanced wireless, biotechnology, and QIS. DGE also leads EHR research on the development of the STEM professional workforce. The resulting body of research expands the knowledge base that informs successful models, practices and approaches for the preparation of a STEM professional workforce ready to advance the frontiers of science and engineering and to assume leadership roles in emerging industries.

**FY 2022 Summary**

Research
- ECR funds enable significant progress on important basic and use-inspired basic research questions about STEM learning and teaching. ECR is managed and funded across all EHR divisions. For a full description, see the write up in the DRL Division narrative.

Education
- NSF GRFP will be fully funded in EHR in FY 2022 at a total funding level of $318.52 million to support 2,500 new fellowships with a cost of education allowance of $12,000 and a stipend of $34,000 per fellow. The GRFP program will continue to align awards with Administration priorities, including climate, clean energy, and emerging technologies such as AI and quantum. 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 will advance transformative programs 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, as well as assuming leadership roles across emerging industries. In FY 2022, NRT will expand to include a special focus on traineeships in AI and AI engineering. 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. Emphasis will be given to K-12 cybersecurity education, students from community colleges, veterans, and other underrepresented groups.

For more information about GRFP and NRT, see the Major Investments in STEM Graduate Education narrative within the NSF-Wide Investments chapter.

**H-1B NONIMMIGRANT PETITIONER FEES $162,470,000**

In FY 2022, H-1B Nonimmigrant Petitioner Fees are projected to be $162.47 million.

**H-1B Nonimmigrant Petitioner Fees Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change Over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| H-1B Nonimmigrant Petitioner Fees Funding | $114.78 | $177.00 | $162.47 | -$14.53 | -8.2% |

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.

- Low-income Scholarship Program: S-STEM. The S-STEM program provides institutions with funds for student scholarships to encourage and enable academically talented low-income U.S. students with unmet financial need to complete an associate, baccalaureate, or graduate degree in fields of science, technology, engineering, or mathematics. Earning these degrees enables the graduates to enter the STEM workforce or STEM graduate school. The program emphasizes the importance of recruiting students to STEM disciplines, mentoring and supporting students through degree completion, and partnering with employers to facilitate student career placement in the STEM workforce.

Since its inception, the low-income scholarship program has received more than 7,700 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 2022, 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. Approximately 90 awards are anticipated in FY 2022, with a continued emphasis on increasing involvement of community colleges, especially Hispanic-serving institutions. S-STEM activities in FY 2022 will leverage efforts in IUSE: EHR, LSAMP, and the IUSE: HSI Program to enhance persistence of students. S-STEM will continue to be a partner in the NSF INCLUDES initiative. S-STEM programming and research also will align with NRT, with the goal of understanding and enhancing effective learning environments and pathways for students on the continuum from two-year to four-year to master's and doctoral degrees.

**Private-Public Partnerships in K-12**

The American Competitiveness in the 21st Century Act (P.L. 106-313) amended P.L. 105-277 and changed the way petitioner fees were to be expended. P.L. 106-313 directed the remaining 40.5 percent of the total H-1B funding for NSF (15 percent of H-1B receipts) toward K-12 activities involving private-public partnerships in a range of areas such as materials development, student externships, and mathematics and science teacher professional development. The ITEST program was developed as a partnership activity in K-12 to increase opportunities for students and teachers to learn about, experience, and use information technologies within the context of STEM, including information technology (IT) courses. In FY 2005, P.L. 108-447 reduced the prescribed percentage of H-1B receipts available for private-public partnerships in K-12 to 10 percent (approximately 25 percent of the total H-1B funding for NSF).

- <u>Private-Public Partnerships in K-12: ITEST</u>. 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 4,300 grant proposals and made more than 520 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 25-30 awards in FY 2022.

**H-1B Financial Activities from FY 2011 - FY 2020**
(Dollars in Millions)

| | FY 2011 | FY 2012 | FY 2013 | FY 2014 | FY 2015 | FY 2016 | FY 2017 | FY 2018 | FY 2019 | FY 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Receipts** | **$106.11** | **$128.99** | **$120.94** | **$132.49** | **$143.00** | **$138.80** | **$141.07** | **$155.99** | **$156.72** | **$153.03** |
| **Unobligated Balance start of year** | **$50.15** | **$60.93** | **$99.31** | **$108.31** | **$111.39** | **$116.02** | **$74.63** | **$96.86** | **$64.68** | **$77.47** |
| **Appropriation Previously unavailable (Sequestered)** | | | | **$5.10** | **$9.54** | **$7.30** | **$6.80** | **$9.73** | **$10.30** | **$9.72** |
| **Appropriation Currently unavailable (Sequestered)** | | | | **-$9.54** | **-$7.30** | **-$6.80** | **-$9.73** | **-$10.30** | **-$9.72** | **-$9.03** |
| Obligations incurred: | | | | | | | | | | |
| Scholarships in Science, Technology, Engineering, and Mathematics | 77.67 | 72.57 | 83.98 | 92.18 | 109.34 | 140.54 | 84.38 | 156.40 | 114.76 | 79.91 |
| Private-Public Partnership in K-12[1] | 18.62 | 21.59 | 31.51 | 37.23 | 29.83 | 44.35 | 35.11 | 35.86 | 34.24 | 34.87 |
| **Total Obligations** | **$96.29** | **$94.16** | **$115.49** | **$129.41** | **$139.17** | **$184.89** | **$119.49** | **$192.26** | **$149.00** | **$114.78** |
| Unallocated Recoveries | 3.12 | 0.96 | 3.55 | - | 4.95 | 1.60 | 3.58 | 4.66 | 4.49 | 8.26 |
| **Unobligated Balance end of year** | **$63.09** | **$96.72** | **$108.31** | **$111.39** | **$122.41** | **$72.03** | **$96.86** | **$64.68** | **$77.47** | **$124.67** |

[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, $124.67 million was carried over into FY 2021.

Innovation Technology Experiences for Students
- Amount: $33.42 million
- Purpose: Since NSF receives the largest payments of H-1B visa fees in August and September, there was insufficient time to obligate the receipts on awards before the end of the fiscal year.
- Obligation: FY 2021 Quarter 1-2 and Anticipated FY 2021 Quarter 3-4

Scholarships in Science, Technology, Engineering, and Mathematics
- Amount: $89.88 million
- Purpose: Since NSF receives the largest payments of H-1B visa fees in August and September, there was insufficient time to obligate the receipts on awards before the end of the fiscal year.
- Obligation: FY 2021 Quarter 1-2 and Anticipated FY 2021 Quarter 3-4

The remaining $1.37 million remains available for H-1B account adjustments.

# MAJOR RESEARCH EQUIPMENT AND FACILITIES CONSTRUCTION

MREFC Overview .......... MREFC - 3

Antarctic Infrastructure Recapitalization .......... MREFC - 8

Daniel K. Inouye Solar Telescope .......... MREFC - 14

High Luminosity - Large Hadron Collider Upgrade .......... MREFC - 22

Mid-scale Research Infrastructure Track 2 .......... MREFC - 31

Regional Class Research Vessels .......... MREFC - 35

Vera C. Rubin Observatory .......... MREFC - 41

**MAJOR RESEARCH EQUIPMENT $249,000,000**
**AND FACILITIES CONSTRUCTION (MREFC) +$8,000,000 / 3.3%**

**Major Research Equipment and Facilities Construction Funding**

(Dollars in Millions)

| FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|
| $154.84 | $241.00 | $249.00 | $8.00 | 3.3% |

## 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)

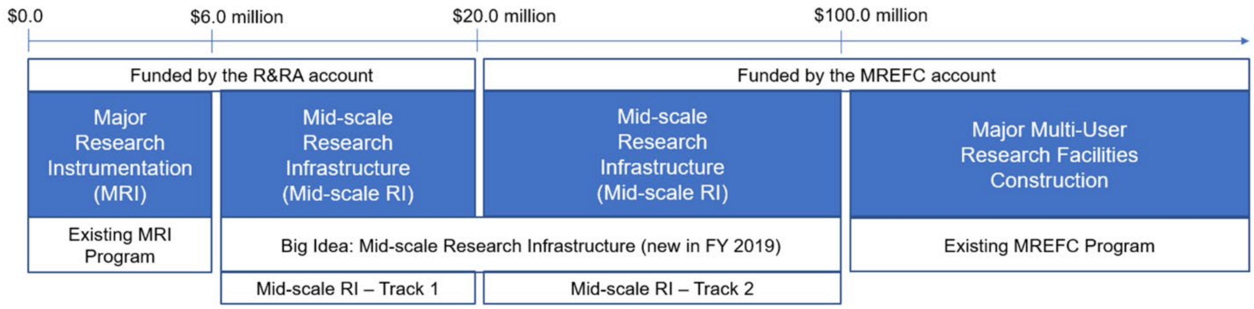
| | FY 2020 Actual | FY 2021 Estimate[1] | FY 2022 Request | FY 2023 Estimate | FY 2024 Estimate | FY 2025 Estimate | FY 2026 Estimate | FY 2027 Estimate |
|---|---|---|---|---|---|---|---|---|
| Antarctic Infrastructure Recapitalization | $48.78 | $90.00 | $90.00 | $60.00 | $60.00 | TBD | TBD | TBD |
| DKIST | - | - | - | - | - | - | - | - |
| HL-LHC Upgrade | 33.00 | 33.00 | 36.00 | 33.00 | 18.00 | - | - | - |
| Mid-scale Research Infrastructure[2] | - | 76.25 | 76.25 | 76.25 | 76.25 | 76.25 | 76.25 | 76.25 |
| NEON | 0.74 | - | - | - | - | - | - | - |
| RCRV | 25.00 | - | 5.00 | 15.00 | - | - | - | - |
| Vera C. Rubin Observatory | 46.35 | 40.75 | 40.75 | 15.00 | - | - | - | - |
| Dedicated Construction Oversight | 0.97 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| **Total** | **$154.84** | **$241.00** | **$249.00** | **$200.25** | **$155.25** | **$77.25** | **$77.25** | **$77.25** |

[1] A total of $129.35 million was carried forward from FY 2020 into FY 2021: $29.71 million for AIMS, $9.40 million for DKIST, $65.0 million for Mid-scale RI, $10.97 million for RCRV, $10.07 million for the Rubin Observatory, and $780,000 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 budget submissions.

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 NSF's merit review process. The NSF-established thresholds for Mid-scale RI – Track 2 projects and major facilities construction projects have been updated from initial presentations to provide for greater consistency with definitions in the 2017 American Innovation and Competitiveness Act (AICA), as amended by the National Defense Authorization Act for FY 2021. Information on the complete Mid-scale RI program (Tracks 1 and 2) can be found in the Mid-scale narrative in the NSF-wide Priorities chapter. Information on the MRI program can be found in the Integrative Activities narrative in the R&RA chapter.

In FY 2022, NSF requests a total of $249.00 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 Major Facilities Guide (MFG) requires that: (1) the total project cost estimate when exiting the preliminary design phase includes adequate contingency to cover foreseeable risks manageable by the recipient; (2) any cost increases not covered by contingency be accommodated first by reductions in scope with any significant scope reductions reviewed by the agency prior to implementation; and (3) if the project is approved to continue and further scope reductions become too detrimental to science, then the first 10 percent of any cost increase must be covered by the sponsoring directorate through R&RA funding. NSF holds the risk to total project cost for unforeseen events that are beyond the recipient's control. The COVID-19 pandemic constitutes such an unforeseen event for all major facility construction projects, and mitigation of this risk falls outside the "no cost overrun policy" and the use of contingency. NSF policy allows for both authorization of management reserve and re-baselining, and 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.

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[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-scoped AIMS project, caused by the need to revise the nature of Antarctic infrastructure investments in light of the impacts of COVID-19.

**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 Major Research Instrumentation (MRI) program, which is $6.0 million including cost sharing, and below the lower threshold for the MREFC account, which was then at $70.0 million. NSF evaluated community demand that resulted in the submission of approximately $10 billion in ideas for projects in the NSF cost range of $20–$100 million. After evaluating that community input, existing mechanisms, and implementation options, NSF included a dedicated funding line within the MREFC account beginning in FY 2020 for research infrastructure projects in the $20–$70 million range. The upper limit has been increased to $100 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 National Defense Authorization Act which amended the original AICA definition. This funding line supports upgrades to major facilities as well as stand-alone projects. Projects between $6.0 million and $20.0 million in total project cost are addressed by individual directorates and an NSF-wide program (Mid-scale RI-1) drawing its heritage from the NSF-wide MRI program. NSF's overall central Mid-scale Research Infrastructure program is described in the NSF-wide Priorities chapter of this budget submission.

**Dedicated Construction Oversight**

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

**COVID-19 Impacts on MREFC Projects**

As noted above, 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 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.

In FY 2020, with the approval of Congress, NSF re-programmed $19.40 million in appropriated MREFC funds from the AIMS project to the Daniel K. Inouye Solar Telescope (DKIST, $9.40 million) and to the Vera C. Rubin Observatory ($10.0 million). These funds have been allocated to management reserve for the two projects. The funds for DKIST have been fully obligated to cover costs incurred due to COVID-19, while the funds for Rubin Observatory will be obligated as needed to cover substantiated project needs that are likewise attributable to the pandemic. Funding requests for FY 2022 and out-year forecasts for all projects have been adjusted from previous estimates based on NSF's current assessment. As appropriate, re-baselining of several projects will take place during FY 2021, once the cost and schedule impacts become better known.[2] 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, $~~241,000,000~~249,000,000, to remain available until expended.

**Major Research Equipment and Facilities Construction**
**FY 2022 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 2020 Appropriation | $243.23 | $38.95 | -$129.35 | $2.01 | - | $154.84 |
| FY 2021 Estimated | 241.00 | 129.35 | | | | 370.35 |
| FY 2022 Request | 249.00 | | | | | 249.00 |
| $ Change from FY 2021 Estimated | | | | | | -$121.35 |
| % Change from FY 2021 Estimated | | | | | | -32.8% |

## Explanation of Carryover

Within the MREFC account, $129.35 million (including $3.42 million in no-year recoveries) was carried over into FY 2021.

Mid-scale Research Infrastructure Track 2 (Mid-scale RI-2)

- Amount: $65.0 million
- Purpose: Funding for Mid-scale Track 2 awards. Awards pending independent cost estimates required by Congress in the American Innovation and Competitiveness Act (AICA), and then to complete the NSF cost analysis on the new projects prior to award.

Obligation: FY 2021 Quarter 1 and Anticipated FY 2021 Quarter 3

Antarctic Infrastructure Modernization for Science (AIMS)

- Amount: $29.71 million
- Purpose: Baseline and budget contingency funding not obligated in FY 2020.
- Obligation: Anticipated FY 2021 Quarter 3 to support FY 2022 fabrications and FY 2023 construction

[2] NSF currently plans to allocate up to $53.55 million from the American Rescue Plan to fund documented COVID-19 impacts to several of the major facility construction projects.

Regional Class Research Vessel (RCRV)
- Amount: $10.97 million
- Purpose: Budget contingency funding not obligated in FY 2020.
- Obligation: Anticipated FY 2021 Quarter 3

Vera C. Rubin Observatory
- Amount: $10.07 million
- Purpose: Management reserve funding not obligated in FY 2020.
- Obligation: Anticipated FY 2021 Quarter 4 as the cost impacts of COVID-19 become better known

Daniel K. Inouye Solar Telescope (DKIST)
- Amount: $9.40 million
- Purpose: Management reserve funding not obligated in FY 2020.
- Obligation: Awarded towards mitigating impact of COVID-19 final construction in FY 2021 Quarter 1.

Dedicated Construction Oversight
- Amount: $780,000
- Purpose: Support for major facility construction oversight required under AICA and NSF policy, National Ecological Observatory Network construction close-out, and additional management reserve for DKIST, if needed.
- Obligation: Anticipated FY 2021 Quarter 4

## ANTARCTIC INFRASTRUCTURE RECAPITALIZATION (AIR) $90,000,000

**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 Revised Plan | FY 2021 Request | FY 2022 Request[1] | FY 2023 Estimate | FY 2024 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 | 120.00 |
| **AIMS+AIR TOTAL** | **$103.70** | **$78.49** | **$90.00** | **$90.00** | **$60.00** | **$60.00** | **$482.19** |

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

### Brief Description

The Antarctic Infrastructure Recapitalization 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. Near-term AIR investments have been developed and prioritized in close coordination with internal and external stakeholders, and work planned for FY 2022 can make progress even with continued COVID restrictions in place. FY 2022 funding for AIR is requested as part of a re-baselining of the Antarctic Infrastructure Modernization for Science (AIMS) project. AIMS construction will continue with a focus on meeting near-term needs, and unfunded parts of AIMS will be incorporated 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, and $90.0 million in FY 2021. The NSB authorized a Total Project Cost (TPC) of $410.40 million for AIMS. The project was in the early stages of field work when COVID restrictions required on-ice construction to be placed on hold. That extended on-ice work stoppage, as well as significant disruptions to workforce and supply chains, will significantly delay completion of the project and require a re-baselining of AIMS.

These significant schedule delays also mean that other investments in facilities and infrastructure across USAP are now emerging as priorities that cannot be deferred until after completion of AIMS. As a result, the re-baselined scope of AIMS will include the Vehicle Equipment and Operations Center (VEOC) and the Lodging Building, both of which continue to be important near-term needs. Remaining work in AIMS will not be funded in lieu of funding being used for emerging priorities in the AIR program. The re-baselined AIMS scope will not require funds in excess of the NSB-authorized TPC, and unfunded AIMS scope will be integrated and prioritized within the broader AIR program. The FY 2022 request of $90.00 million will be used to fund re-baselined AIMS scope, if necessary, and transition to a broader recapitalization of NSF's Antarctic infrastructure under the AIR program.

AIMS was envisioned to replace several major structures at McMurdo Station, Antarctica, one of three permanent stations that comprise the U.S. presence on the continent, to meet anticipated science support requirements for the next 35 to 50 years while improving operational efficiency and safety, reducing energy consumption, and containing operations costs. Completion of the VEOC and Lodging Building will make progress on these goals, and the transition to an enduring AIR program will further these goals and broaden their reach across all USAP stations and gateways. Such improvements help ensure continued U.S. leadership and influence in this strategic region. They also support critical scientific research and capabilities such as nuclear test detection, earthquake monitoring, and real-time weather data collection for global forecasting.

**Scientific Purpose**

By Presidential directive, the National Science Foundation 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, one being McMurdo Station. In 2011, a Blue-Ribbon Panel (BRP) of experts reviewed the USAP and recommended that NSF undertake a long-term capital upgrade program to redevelop the infrastructure for better long-term support of Antarctic science. AIMS initiated on-site construction activities in FY 2020 to provide a new, more efficient core infrastructure for McMurdo Station. The USAP-wide approach of AIR will strengthen NSF's response to the BRP report.

McMurdo Station's main purpose is to support both near- and deep-field science in Antarctica, including activities at Amundsen-Scott South Pole Station. Continued recapitalization of USAP stations and gateways will enable faster, more streamlined logistics and science support across the continent. AIR will also continue to replace outdated lodging facilities and upgrade utilities to support these facilities, as well as incorporating previously envisioned scope elements of AIMS (see below) too heavily impacted by the pandemic to be included in the re-baselined project. Other elements of AIR will be determined in the context of a developing vision for Antarctic science that involves higher data and communications bandwidths and a concomitant reduction in the number of people needed at McMurdo Station to execute all components of the NSF mission. Development of a detailed plan for a re-visioned, long-term AIR program is currently underway.

**Baseline History**

In 2011, the Office of Science and Technology Policy and NSF convened a Blue-Ribbon Panel 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 report entitled *Future Science Opportunities in Antarctica and the Southern Ocean*. The BRP report 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.

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 Vehicle Equipment Operations Center (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 National Science Board (NSB) authorized NSF to award a contract for AIMS in February of 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. As noted in the next section, several the AIMS scope elements will now be folded into the longer-term AIR program.

**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 construction season. It is anticipated that COVID-19 risks and severe restrictions on international travel to Antarctica through southern gateways will persist into FY 2022. In addition, NSF must prioritize basic facility and experiment maintenance, fuel distribution, and pending communications upgrades that were not executed during FY 2021 because of the necessity to minimize the staffing numbers at McMurdo during the pandemic. As a result, on-ice construction of AIMS will be deferred for another season and would be slowed significantly thereafter. These impacts delay the completion of AIMS sufficiently that other priorities must be addressed.

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. As described above, AIMS will be re-baselined to include important near-term needs while unfunded AIMS scope will be integrated and prioritized within the broader AIR program.

**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 actively in decisions regarding the necessary reach of the USAP's logistics system.
- Members of the research community actively 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 a 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.

## Governance Structure and Partnerships

NSF Governance Structure

The AIR program will be managed by NSF's Directorate for Geosciences and implemented by the Office of Polar Programs Antarctic Infrastructure and Logistics (AIL) section. For oversight of AIR, NSF tailors the best practices outlined by NSF's Major Facilities Guide (MFG), 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.

## Cost and Schedule

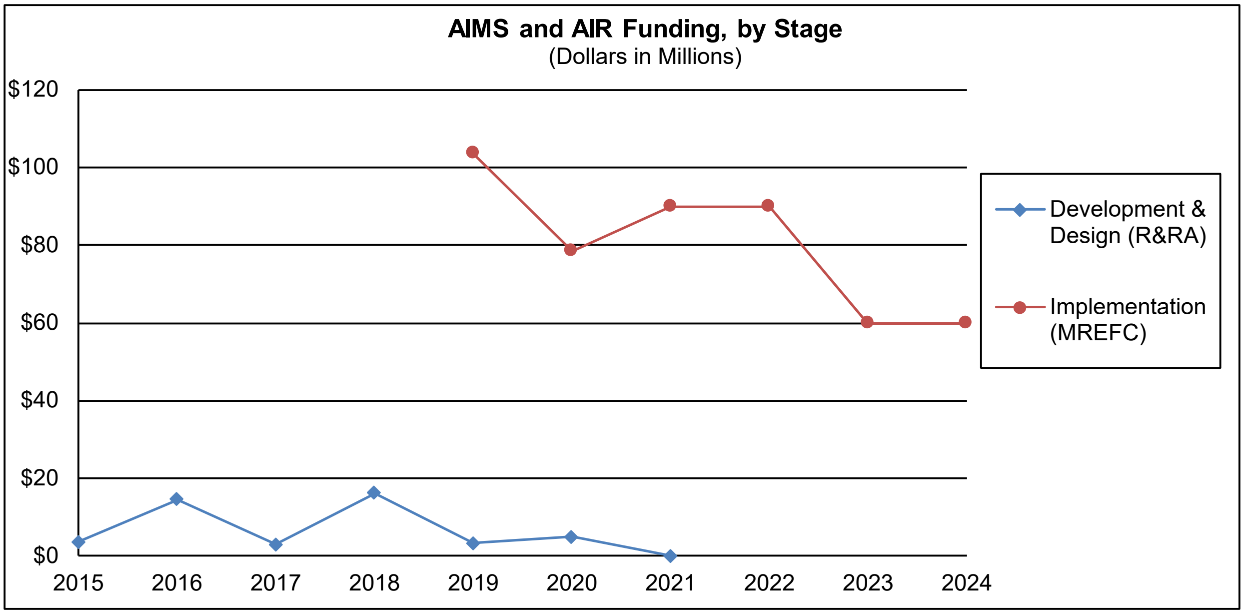
**Total Funding Requirements for AIMS and AIR**

(Dollars in Millions)

| | Cumulative Prior Years | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | ESTIMATES | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | FY 2023 | FY 2024 | FY 2025 | FY 2026 | FY 2027 |
| *R&RA:* | | | | | | | | | |
| Development & Design | $37.31 | $4.93 | - | - | - | - | - | | |
| Subtotal, R&RA | $37.31 | $4.93 | - | - | - | - | - | - | - |
| *MREFC:* | | | | | | | | | |
| AIMS Implementation[1] | $103.70 | $78.49 | $90.00 | TBD | - | - | - | - | - |
| AIR Implementation[2] | - | - | - | TBD | 60.00 | 60.00 | TBD | TBD | TBD |
| Subtotal, MREFC | $103.70 | $78.49 | $90.00 | $90.00 | $60.00 | $60.00 | - | - | - |
| **TOTAL REQUIREMENTS** | **$141.01** | **$83.42** | **$90.00** | **$90.00** | **$60.00** | **$60.00** | **-** | **-** | **-** |

[1] Includes $29.71 million carried forward into FY 2021.

[2] Outyear estimates will depend on the more complete development of a plan for AIR and are expected to be revised in the FY 2023 Budget Request.




Note: Outyear estimates will depend on the more complete development of a plan for AIR, and are expected to be revised in the FY 2023 Budget Request..

FY 2022 funds will be used to support urgent Antarctic infrastructure projects and may include procurement of construction and other materials and capital equipment. Construction components at McMurdo Station that will require re-planning include the first Lodging unit, the VEOC, and the remaining utilities distribution work. Construction of the VEOC and Lodging facility are anticipated to resume in FY 2023. This construction will be sequenced to allow for minimal impact on other emerging infrastructure needs and continuity of operations as well as critical science support.

Implementing these critical components of 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.

**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 and the Large Facilities Office, 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 is planned for FY 2021 to inform a revised cost, scope, and schedule. Readiness reviews for components of AIR will be conducted based on the scale of the individual projects.

**Risks**

The two main ongoing known risks to the AIMS project are the market price uncertainty for labor and materials and the uncertainty in the supply chain—getting appropriately skilled workers and materials from the U.S. to McMurdo Station when needed. The COVID-19 pandemic exacerbated these risks. NSF and Leidos have implemented a rigorous risk management approach that includes the identification of risks and mitigation strategies. 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. Similar inherent risks associated with Antarctica will persist for all future projects under the AIR program and these factors will inform the risk-adjusted project costs.

## DANIEL K. INOUYE SOLAR TELESCOPE (DKIST) $0

**Appropriated and Requested MREFC Funds for the Daniel K. Inouye Solar Telescope**
(Dollars in Millions)

| | Prior Years[1] | FY 2018 | FY 2019 | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Total Project Cost |
|---|---|---|---|---|---|---|---|
| Previous Authorized Total Project Cost | $308.00 | $20.00 | $16.13 | - | - | - | $344.13 |
| Increase in Authorized Total Project Cost (COVID-19) | - | - | - | 9.40 | 9.50 | - | 18.90 |
| **Current Authorized Total Project Cost** | **$308.00** | **$20.00** | **$16.13** | **$9.40** | **$9.50** | **-** | **$363.03** |

[1]Includes $146.0 million of ARRA funding.

### Brief Description

No funding is requested in FY 2022 for construction of DKIST. The planned 11-year MREFC funding profile for DKIST construction represented an NSB-authorized Total Project Cost (TPC) of $344.13 million, with FY 2019 as the final year of funding. The award authorization was then increased by $9.40 million (to $353.53 million) in FY 2020, and again by $9.50 million (to $363.03 million) in FY 2021 to allow for NSF-held management reserve for the construction project. This reserve is being awarded to the project in accordance with NSF procedures only as specific costs related to the impacts of COVID-19 are realized. Completion of construction atop Haleakalā on Maui, Hawaiʻi, originally scheduled before the end of FY 2020, is delayed by the impacts of COVID-19 into the fall of 2021. See the Project Status section for further details on COVID-19 impacts.

DKIST is a four-meter solar telescope designed to enable observations and ongoing measurements of solar magnetic fields. The four-meter mirror (the largest of any solar telescope in the world) is accompanied by a cutting-edge instrument suite for both imaging and spectropolarimetry.

When completed, DKIST will be the world's most powerful solar observatory, poised to answer fundamental questions in solar physics by providing transformative improvements over current ground-based facilities. The relevance of DKIST's science drivers was reaffirmed by the National Academies of Sciences, Engineering, and Medicine 2010 Astronomy and Astrophysics decadal survey: *New Worlds, New Horizons in Astronomy and Astrophysics*[1] as well as the 2012 Solar and Space Physics decadal survey: *Solar and Space Physics: A Science for a Technological Society*.[2] DKIST will play an important role in enhancing the "fundamental understanding of space weather and its drivers," an objective called out in the National Space Weather Strategy[3] and associated National Space Weather Action Plan,[4] both of which were released by the National Science and Technology Council in October 2015. An update to the National Space Weather Strategy has been developed through the Space Weather Operations, Research, and Mitigation Working Group of the National Science and Technology Council and was informed by community input. This update, entitled *National Space Weather Strategy and Action Plan,* was released in March 2019.[5]

### Scientific Purpose

DKIST will enable the study of magnetohydrodynamic phenomena in the solar photosphere, chromosphere, and corona at unprecedented spatial, temporal, and wavelength resolution to gain information on the creation, interaction, and ultimate annihilation of solar magnetic fields. Determining the role of magnetic

[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.obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/final_nationalspaceweatherstrategy_20151028.pdf
[4] www.obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/final_nationalspaceweatheractionplan_20151028.pdf
[5] www.trumpwhitehouse.archives.gov/wp-content/uploads/2019/03/National-Space-Weather-Strategy-and-Action-Plan-2019.pdf

fields in the outer regions of the Sun is crucial to understanding the solar dynamo, solar variability, and solar activity. Solar activity drives the constant solar wind, as well as eruption events such as flares and coronal mass ejections. These phenomena, collectively known as “space weather,” can affect civil life on Earth and may impact the terrestrial climate.

**Baseline History**

Beginning in 2001, NSF provided funds to the National Solar Observatory (NSO) for an eight-year development and design program for DKIST and its initial complement of instruments through the Division of Astronomical Sciences (AST) in MPS and through the Division of Atmospheric and Geospace Sciences (AGS) in GEO. The current design, cost, schedule, and risk were scrutinized in an NSF-conducted Preliminary Design Review held in October-November 2006.

The original total project cost to NSF, $297.93 million, was set after a Final Design Review (FDR) in May 2009, which determined that the project was fully prepared to begin construction. The NSB authorized an award for this amount, to be made at the NSF Director’s discretion, contingent upon completion of compliance with relevant environmental and cultural/historic statutes. In FY 2009, $153.0 million was appropriated to initiate construction. Funding was provided through a combination of the regular MREFC account appropriation ($7.0 million) and the American Recovery and Reinvestment Act ($146.0 million). Given the timing of the receipt of budget authority and the complexity of project contracting, the entire $153.0 million was carried over from FY 2009 and obligated in FY 2010.

The environmental compliance requirements were completed on November 20, 2009, and the NSF Director signed the Record of Decision authorizing construction in December 2009. The Hawai‘i Board of Land and Natural Resources (BLNR) approved the project’s application for a Conservation District Use Permit (CDUP) in December 2010. A contested case challenge to the 2010 CDUP issuance delayed site construction until the BLNR ruled in favor of the DKIST project and issued a new CDUP in November 2012. Full access to the site atop Haleakalā followed shortly thereafter. A ground-breaking ceremony kicking off site construction was held on December 1, 2012.

The unexpected length of the delay associated with the environmental compliance process led to a reassessment of the project schedule and total project cost in 2012. An external panel of experts reviewed the revised baseline and recommended increasing the total project cost by approximately $46.20 million. The NSB subsequently considered and authorized a revised total project cost of $344.13 million at its August 2013 meeting.

**Project Status**

The DKIST project continues to make progress on construction at the summit of Haleakalā on Maui, HI, while remaining in compliance with all local, state, and federal environmental and cultural requirements and dealing with the COVID-19 pandemic. The project management team continues to consult with various stakeholders on a regular basis including the Hawai‘i Department of Land and Natural Resources, the Hawai‘i Department of Fish and Wildlife, the U.S. Fish and Wildlife Service, the Federal Aviation Administration, the National Park Service, and Native Hawaiian cultural practitioners.

<u>Construction Highlights</u>

- In early FY 2020, the Wave Front Correction (WFC) system was installed and tested on the summit of Haleakalā. The WFC is the heart of the DKIST adaptive optics system that corrects for distortions due to the Earth’s atmosphere.
- In FY 2020, the project achieved another Level 1 milestone, first light from the Sun through the entire optical path including the WFC. As part of this first-light initiative, the Visible Broadband Imager

(VBI) instrument recorded the highest resolution images of the Sun ever made.
- In FY 2021, the project completed a periodic recoating of the primary (M1) mirror at the U.S. Air Force's Mirror Coating Facility on the summit of Haleakalā. The M1 was transported back to the DKIST support and operations building where it was reinstalled in the mirror cell assembly and successfully mounted back on the telescope.
- In FY 2021, progress was made on the Cryogenic Near Infrared Spectropolarimeter (Cryo-NIRSP) and Diffraction Limited Near Infrared Spectropolarimeter (DL-NIRSP) instruments despite the pandemic. Components of both instruments were transported to the summit, assembled, installed, and aligned within the DKIST coudé lab in preparation for integration, testing and commissioning.

In February 2020, the DKIST project undertook a re-planning exercise and reconciliation of the work completed through January 2020. As a result, the project management team determined that construction would be ~98 percent complete as of June 30, 2020, the scheduled date for the last major construction milestone (Start of Operations). The delays involved were the result of a variety of factors, including extreme weather events in early 2020 at the construction site, identified operational safety hazards that required mitigations prior to the start of operations, and re-aluminization of the primary mirror necessary to meet coronal scientific performance requirements. In accordance with NSF's Major Facilities Guide, the project management team submitted a request to NSF for a No-Cost Extension (NCE) to move the Start of Operations to September 30, 2020 allowing the completion of site construction activities. In addition, the project management team requested that the project award completion date be amended to December 31, 2020 to allow for the completion of all post-construction closeout activities. At this time, the project requested no new funding and no changes to the Total Project Cost (TPC) of $344.13 million at that time. This NCE was reviewed and approved by NSF. The extension was completely unrelated to any impacts involving the suspension of construction activities due to COVID-19.

<u>Summary of COVID-19 Impacts</u>
In response to the COVID-19 pandemic and social distancing restrictions imposed by the State of Hawai'i, the DKIST project management team, in consultation with NSO management, began restricting travel in early March 2020, and completely halted site construction on March 17, 2020. This cessation of work put the facility construction and instrument commissioning teams on standby, resulting in an increase in the cost of construction. Since this cost increase was caused by the realization of an unforeseen event beyond the control of the project, it was not an appropriate use of budget contingency and not subject to NSF's No Cost Overrun Policy. On June 22, 2020, the Acting NSF Director authorized an increase of $9.40 million to the DKIST construction award, to be allocated as management reserve for the project.[6]

On June 4, 2020, the DKIST project entered a very limited (Phase 1) restart of site construction activities which entailed two non-overlapping shifts of approximately 20 percent of the construction workforce on site, with the use of personal protective equipment (PPE) and social distancing strictly enforced. In early August 2020, the project entered a modified Phase 1 that allows for two overlapping shifts of approximately 35 personnel per shift. The project management team undertook a re-planning exercise to estimate the impacts of COVID-19 on the remaining scope, cost, and schedule. They submitted a request to NSF for supplemental funding to be drawn from the previously authorized management reserve as needed, in accordance with internal NSF procedures. Following NSF's review and approval of the request, funds were awarded in December 2020 and March 2021, exhausting the initial management reserve.

Continued pandemic impacts were sustained into 2021, further delaying the remaining construction work due to ongoing travel restrictions, labor inefficiencies, and other COVID-related constraints. These constraints have led to further delays in the integration, testing, and commissioning of several key

[6] This initial $9.40 million management reserve was funded by reprogramming FY 2020 appropriated MREFC funds not required for the Antarctic Infrastructure Modernization for Science project.

instruments and supporting systems. A second re-planning exercise by the project, completed in early 2021, identified delays until November/December 2021, leading to additional estimated costs of $9.50 million to complete the project. The NSB authorized $9.50 million in additional NSF-held management reserve in February 2021—for a total of $18.90 million in management reserve and a total award authorization of $363.03 million—along with authorizing a delay in the Start of Operations milestone to the end of CY 2021.

**Meeting Intellectual Community Needs**

DKIST is under construction so it currently has no scientific users. At the start of operations in 2021, NSO will execute a 12-month DKIST operations commissioning phase (OCP) during which the DKIST staff will begin to execute the DKIST Critical Science Plan (CSP). The CSP has been under development for several years by NSO scientific staff in consultation with the community based DKIST science working group (SWG). On May 14, 2020, NSO issued the first call for DKIST Cycle 1 OCP proposals, which were due August 14, 2020. These proposals have been reviewed for both technical feasibility and scientific merit and prioritized by the external Time Allocation Committee. The original plan was for Cycle 1 observations to begin Fall of 2020; however, this has been delayed due to the impacts of COVID-19, thus the currently accepted projects will be held until the start of operations.

**Governance Structure and Partnerships**

NSF Governance Structure
NSF oversight is provided by a program officer in AST working cooperatively with staff from MPS, the Office of Budget, Finance, and Award Management (BFA), and the Office of the General Counsel. Within BFA, the Large Facilities Office provides advice to program staff and assists with agency oversight and assurance. Representatives from the above NSF offices comprise the DKIST Integrated Project Team, which meets on a quarterly basis to discuss outstanding project issues. The MPS Facilities Team and NSF's Chief Officer for Research Facilities also provide high-level guidance and oversight support for the project.

External Governance Structure
The National Solar Observatory (NSO) is responsible for managing the construction project. NSF funds NSO operations and DKIST construction via separate cooperative support agreements (CSAs) beneath an overarching cooperative agreement (CA) with the managing organization, the Association of Universities for Research in Astronomy, Inc. (AURA). The current NSO CA covers the DKIST Construction Stage and the achievement of sustainable operations of the completed facility. The NSO associate director for DKIST is a senior NSO scientist who was a leader in the development of the science case and an expert in the field of solar adaptive optics, a critical technology for DKIST. The project manager has extensive experience in large telescope development and implementation, having served as lead telescope engineer for the International Gemini Observatory. Several councils and working groups give input from the solar and space physics communities.

Partnerships and Other Funding Sources
The DKIST project is a collaboration of scientists and engineers at more than 20 U.S. and international organizations. Other partners include the U.S. Air Force Office of Scientific Research (AFOSR) and groups in Germany, the United Kingdom, and Italy. Some partnership activities include:

- The U.S. Air Force (USAF) replaced the aluminizing chamber at their Advanced Electro-Optical System telescope on Maui and sized it to accommodate the DKIST primary mirror. An Interagency Agreement for use of the Mirror Coating Facility (MCF) was signed by NSF and USAF in FY 2017. This eliminates the need to build a dedicated aluminizing chamber for DKIST.
- Leibniz-Institut für Sonnenphysik (KIS; Freiburg, Germany) is constructing a narrow-band instrument named the Visible Tunable Filter (VTF) as an in-kind contribution.

- Queens University Belfast (Northern Ireland) is leading a consortium of institutions from the United Kingdom that will supply high-speed visible cameras to feed the DKIST instruments.

Discussions of other possible contributions for second-generation instruments, algorithm development, coordinated observations, and student exchange are ongoing.

**Cost and Schedule**

The original risk adjusted TPC was established following the Final Design Review. A revised project baseline review was held in October 2012, and NSB authorized a new baseline in August 2013. Funding is derived from American Recovery and Reinvestment Act (ARRA) appropriations ($146.0 million) and regular appropriations from the MREFC account ($198.13 million). A Monte Carlo analysis of the risk-adjusted project end date at the time of the project re-baseline indicated an 80 percent confidence level for successful completion by the end of June 2020. The project was on track for a FY 2020 end date within the authorized funding level of $344.13 million. However, the construction end date has now shifted into 2021 and may require up to $18.90 million in management reserve due to the impacts of COVID-19, increasing the authorized Total Project Cost to $363.03 million.

**Total Funding Requirements for DKIST**

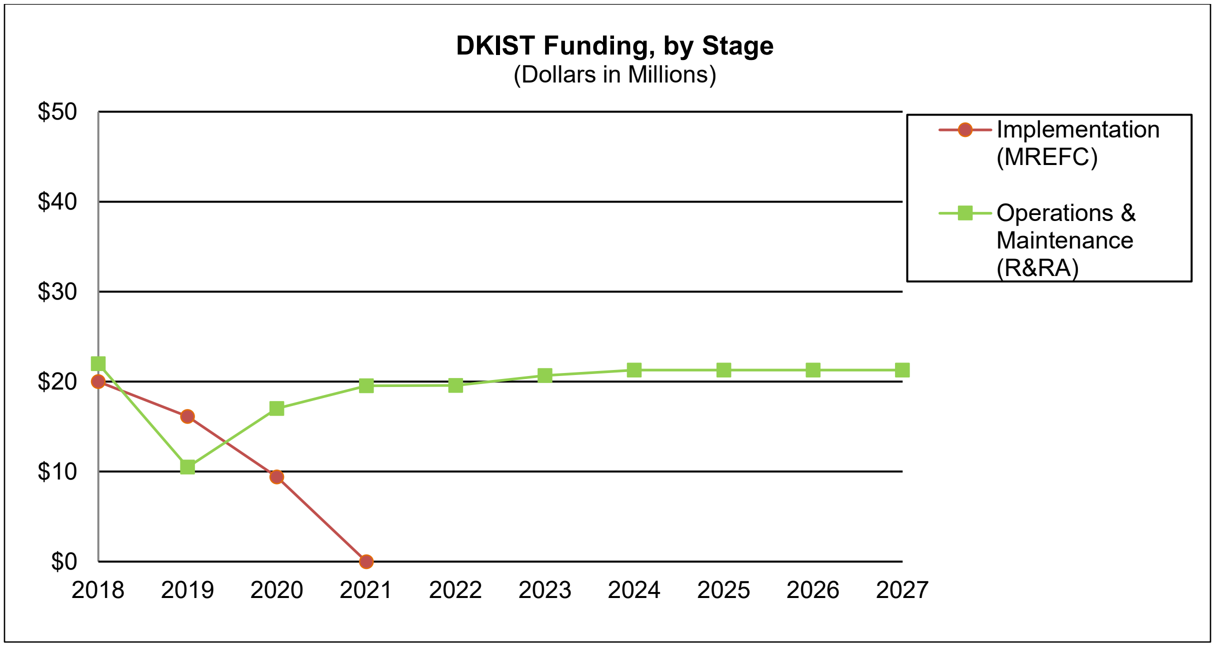
(Dollars in Millions)

| | | | | | ESTIMATES[1] | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Prior Years | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | FY 2023 | FY 2024 | FY 2025 | FY 2026 | FY 2027 |
| *R&RA:* | | | | | | | | | |
| Development & Design | $20.41 | - | - | - | - | - | - | - | - |
| Operations & Maintenance[2] | | 17.01 | 19.54 | 19.58 | 20.68 | 21.30 | 21.30 | 21.30 | 21.30 |
| ARRA | 3.10 | - | - | - | - | - | - | - | - |
| Subtotal, R&RA | $23.51 | $17.01 | $19.54 | $19.58 | $20.68 | $21.30 | $21.30 | $21.30 | $21.30 |
| *MREFC:* | | | | | | | | | |
| Implementation[3] | $198.13 | $9.40 | $9.50 | - | - | - | - | - | - |
| ARRA | 146.00 | - | - | - | - | - | - | - | - |
| Subtotal, MREFC | $344.13 | $9.40 | $9.50 | - | - | - | - | - | - |
| **TOTAL REQUIREMENTS** | **$367.64** | **$26.41** | **$29.04** | **$19.58** | **$20.68** | **$21.30** | **$21.30** | **$21.30** | **$21.30** |

[1] Outyear funding estimates for O&M are for planning purposes only. The current cooperative agreement ends September 2024.

[2] The FY 2021 Estimate includes $2.0 million to another awardee for cultural mitigation activities as agreed to during the compliance process.

[3] Includes $9.40 million carried forward into FY 2021.




**Future Operations Costs**

DKIST operations are funded through R&RA. The projected outyear funding profile for operations has increased from prior estimates based on the results of a comprehensive external mid-term review of the NSO Long-Range Plan for 2020-2024, which were presented to the NSB in February 2020. The anticipated lifetime of the facility is at least two Hale Cycles (i.e., two 22-year solar cycles) and will not exceed fifty years, after which the facility is scheduled to be decommissioned.

**Reviews**

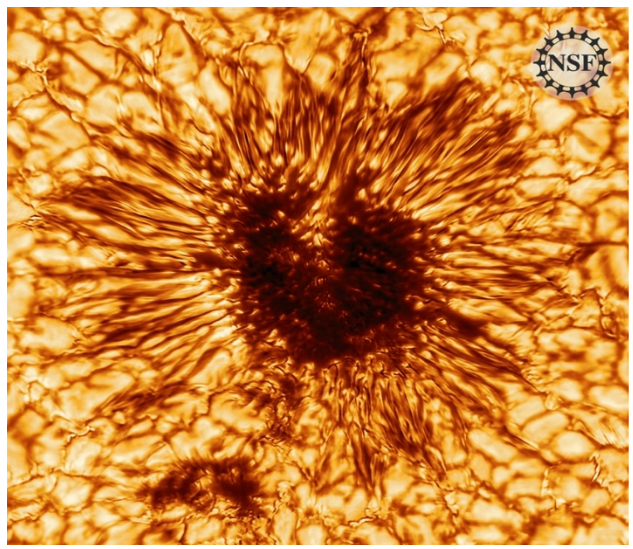
- Management, Cost, and Schedule reviews: DKIST scope, schedule, budget estimate, and risk-adjusted total project cost were scrutinized and validated at the Preliminary Design and Final Design Reviews.
- Programmatic Review: A comprehensive external panel review of construction progress took place April 8-10, 2019 in Boulder, CO. In addition to an assessment of the project's status against the Project Execution Plan, the review focused on establishing the criteria for project close-out and acceptance. The panel's final report was submitted to NSF and the results reviewed by NSF and transmitted to the project management team. NSF continues to work with the management team to address any outstanding recommendations.
- Earned Value Management (EVM) System Surveillance: In conjunction with the external panel review described above, a surveillance of the project's EVM system was conducted on April 10-11, 2019. This surveillance provided an updated assessment of the project's previously validated EVM system. The final assessment report was submitted to NSF and transmitted to the project. NSF continues to work with the project to address any outstanding recommendations.
- Final Construction Review: An external final construction review of the DKIST Project was scheduled to take place on Maui, Hawaiʻi in April 2020. The review, which was to include an in-person site visit for the review panelists, has been postponed due to the COVID-19 pandemic. NSF plans to conduct this review in Q4 of FY 2021. Because of continued travel restrictions, it is likely that this final construction review will be held virtually.

**Risks**

Project management control, interface control, and change controls are in place. The project management team also maintains a risk register that is reviewed and updated monthly.

Technical
Most of the remaining technical risks are relatively low because of the extensive development and design activities prior to construction. The CSA between NSF and AURA identifies four facility-class instruments to be delivered by the Project at the end of the Construction Stage. The Project is on track to deliver those four instruments. The VTF is a fifth instrument and is an in-kind contribution from Germany being designed and developed through a Memorandum of Understanding between AURA and KIS; therefore, the risks for this instrument remain with the German institute. KIS is currently on track to deliver the VTF instrument to DKIST prior to the start of operations.

Environmental and Cultural Compliance
AST, NSF's OGC, and the DKIST project have carefully worked through the applicable statutes, and a cultural monitor has been retained during construction. All required permits are in place and semi-annual consultations with a Native Hawaiian working group continue. Following the November 2012 issuance of the CDUP as mentioned in the Baseline History section above, several challenges to both the CDUP and the University of Hawai‘i's Haleakalā Observatory (HO) management plan made their way through the State court system. In October 2016, the Hawai‘i Supreme Court ruled against the appellant in both cases, upholding both the project's CDUP and the HO management plan. Due to NSF's robust implementation of its environmental compliance plan, on March 27, 2019, the State of Hawai‘i Division of Forestry and Wildlife determined that NSF had met all of its environmental obligations as outlined in the Habitat Conservation Plan (HCP) and Incidental Take License (ITL) and thus approved early termination of the HCP and the ITL. The DKIST Special Use Permit (SUP) for construction and commercial vehicles issued by the National Park Service (NPS) expired June 30, 2020. The NPS issued a letter explaining that DKIST has satisfactorily complied with all the provisions stated in the SUP signed May 10, 2017, and a renewed permit is therefore not required. Remaining environmental and cultural compliance risks are very low.




First DKIST image of a sunspot released December 8, 2020. It represents the highest resolution image of a sunspot ever recorded. The image was taken on January 28, 2020 with a context imager on DKIST. *Credit: NSF, NSO, AURA.*

Environmental Health and Safety
NSO has a well-developed safety program integrated into the DKIST project. The DKIST project management team has developed a site safety plan and conducts annual external safety reviews. In addition, safety updates are provided to NSF monthly, and safety is one of the topics covered in the annual external panel reviews.

COVID-19
The impacts due to COVID-19 continue to manifest as risks to the schedule for the DKIST Start of Operations level-one milestone. As mentioned previously, DKIST construction continues at a reduced staffing level and efficiency for on-site activities. For much of the pandemic, the quarantine requirement

for travelers to the State of Hawaiʻi (initially 14 days but reduced to 10 days in December 2020) limited the ability of teams from NSO headquarters, contractors, and instrument partners to complete the remaining integration, testing, and commissioning of the instruments and their supporting optical and thermal systems. However, as of October 15, 2020, the Governor of Hawaiʻi implemented the Safe Travels Hawaiʻi Program that allows travelers to bypass the quarantine requirement by obtaining a negative result on an approved pre-travel COVID-19 test. Teams from NSO and instrument partners have since been able to travel to Maui to participate in site acceptance testing and science verification activities. The current Start of Operations milestone is projected to be November 2021, which is based on current pandemic projections and the project's experience of working through the first year of pandemic conditions.

**HIGH LUMINOSITY UPGRADES TO THE LARGE HADRON COLLIDER (HL-LHC)** **$36,000,000**

**Appropriated and Requested MREFC Funds for the High Luminosity-Large Hadron Collider Upgrade**[1]
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | FY 2023 Estimate | FY 2024 Estimate | Total Project Cost |
|---|---|---|---|---|---|---|
| Previous Authorized Total Project Cost | $33.00 | $33.00 | $36.00 | $33.00 | $18.00 | $153.00 |
| Estimate prior to Rebaseline | $33.00 | $33.00 | $36.00 | $33.00 | $18.00 | $153.00 |

[1] COVID-19 impacts are not yet fully quantifiable. The situation is evolving rapidly. Schedule and cost impacts will lead to revisions of the current funding plan.

## Brief Description

The FY 2022 Request for HL-LHC is $36.0 million. This funding will support ongoing component upgrades of two distinct projects: the "A Toroidal LHC ApparatuS" (ATLAS) and "Compact Muon Solenoid" (CMS) detectors that will operate at the HL-LHC. This is the third year of a five-year construction program that began in FY 2020, near the onset of the COVID-19 pandemic. The FY 2022 Request amount supports the current NSB authorized Total Project Cost (TPC) of $153.0 million. As discussed below, assessment of the COVID-19 impacts is under way using a range of assumptions. It will be refined through a re-baselining of the HL-LHC 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.

The LHC is the world's largest and highest-energy particle accelerator. Located near Geneva, Switzerland and operated by the European Organization for Nuclear Research (CERN), the LHC is designed to accelerate and collide counter-propagating bunches of protons at a total energy of up to 14 tera-electron volts. Physicists study the debris from these collisions to learn about the elementary particles and fundamental forces that shape the universe. ATLAS and CMS are two general purpose detectors used by researchers to observe these collisions and analyze their characteristics.

## 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 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 discoveries of the last 50 years in particle physics, 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 High Luminosity Upgrade to the LHC (HL-LHC), the scientific focus has shifted to understanding the detailed properties of the Higgs boson and its coupling to other known processes to elucidate possible deviations from expectations—deviations that might indicate new physical phenomena beyond those described by the Standard Model. In addition, the HL-LHC will continue to search more broadly for new particles and interactions.

**Baseline History**

Following an agreement between NSF, DOE, and CERN ("Experiments Protocol I"), signed in December 1997, NSF began support for ATLAS and CMS detector construction and software development in 1998. NSF has subsequently supported ongoing O&M, 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 enabling 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, comprised 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 the U.S. Department of Energy (DOE), recommended U.S. participation in the detector upgrades. In fall 2014, MPS charged a subcommittee of the MPS Advisory Committee (MPS AC) to advise on an appropriate response. The subcommittee, with MPS AC endorsement, recommended NSF provide construction funding at the major facility level to enable meaningful participation by NSF-supported scientists in the HL-LHC research program. An estimated $150.0 million funding envelope 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.

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. 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; see Reviews section below).

**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 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 mid-FY 2021) about 10 percent complete, but well behind schedule due to the pandemic. Enabling 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.

Summary of COVID-19 Impacts
The pandemic is causing schedule and cost impacts to the NSF-funded scope for the LHC detector upgrades. Fabrication activities have progressed more slowly than anticipated because of pandemic restrictions on activities in university labs and workshops. Delays in the availability of custom silicon sensors and chips, which are part of each upgrade, are due to the closure during 2020 of radiation test facilities needed to validate their radiation hardness. The full extent of the impacts of the COVID-19 pandemic on this program are not quantifiable as the situation is evolving rapidly. The pandemic is expected to delay the schedules of international partners in each detector upgrade, disrupting linkages to NSF-funded activities. 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 employed in response. From these assumptions, ATLAS and CMS 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.

Cost impacts realized since MREFC-funded construction began April 1, 2020 are relatively small (less than 10 percent) 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, work restrictions within university laboratories, workshops, and test facilities and the consequent labor inefficiencies are resulting in schedule delays that grow as the pandemic continues. Effects on industrial suppliers are another source of uncertainty in projecting longer-term impacts. Site visits to vendors are currently not possible, delaying final procurement negotiations. Some vendors may have diminished capacities to meet pre-pandemic delivery forecasts. This has become especially apparent for semiconductor fabricators, where a world-wide surge in demand is straining production capacity. This is expected to affect many industries that need these products, in addition to the LHC detector upgrade activities. CERN's governing body is closely monitoring these and other impacts of the pandemic on HL-LHC plans at the international level. Their deliberations could result in revision to the HL-LHC schedule, although none have been announced so far.

**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 will commence ten years of operation in mid-2027. During that time, it is expected to produce more than 10 times the data collected by LHC operation through 2024 (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 2025 through mid-2027, although CERN may revise these plans in response to the pandemic.

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 25 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**

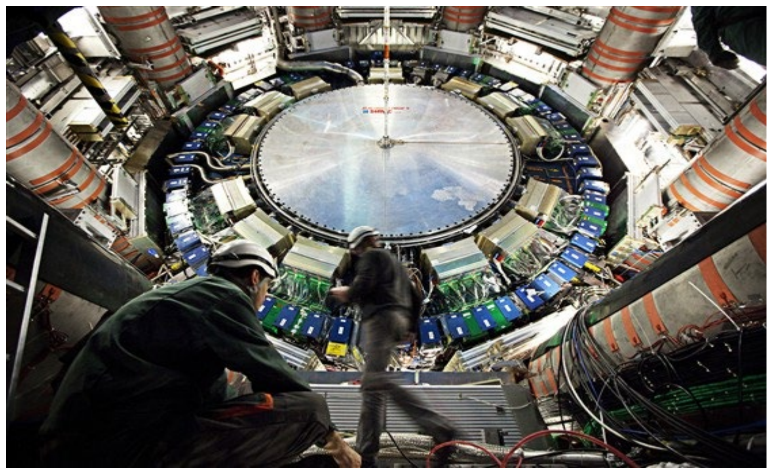
<u>NSF Governance Structure</u>
NSF oversight is handled by a program officer in the Division of Physics (PHY). Cross-foundation coordination is provided by an Integrated Project Team that includes staff from MPS, the Office of Budget, Finance, and Award Management (BFA), EHR, OISE, the Office of the Director, the Office of the General Counsel, and the Office of Legislative and Public Affairs. Within BFA, 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 Department of Energy (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 superseded 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 the projects 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 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 ATLAS and CMS 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, ATLAS and CMS 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 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 (RRBs; 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 planned for CY 2025-2027. A significant delay could have resulted in the transfer of critical NSF-funded scope to other international partners for accomplishment, resulting in lost leadership opportunities for U.S. scientists. NSF's contributions to the ATLAS and CMS upgrades represent about seven percent of the international detector upgrade program.

The major facility construction project will be completed when the NSF-funded apparatuses for both detectors are delivered and verified at CERN to be in good working order. NSF will fund the subsequent installation, integration, and system testing 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 2025-2027 (but may be revised by CERN at some future point to account for the impacts of the COVID-19 pandemic). NSF's share of installation and commissioning costs was estimated before the pandemic outbreak at about $5.0 million per detector. The annual O&M cost is forecast to remain constant during and following the HL-LHC Upgrade installation.

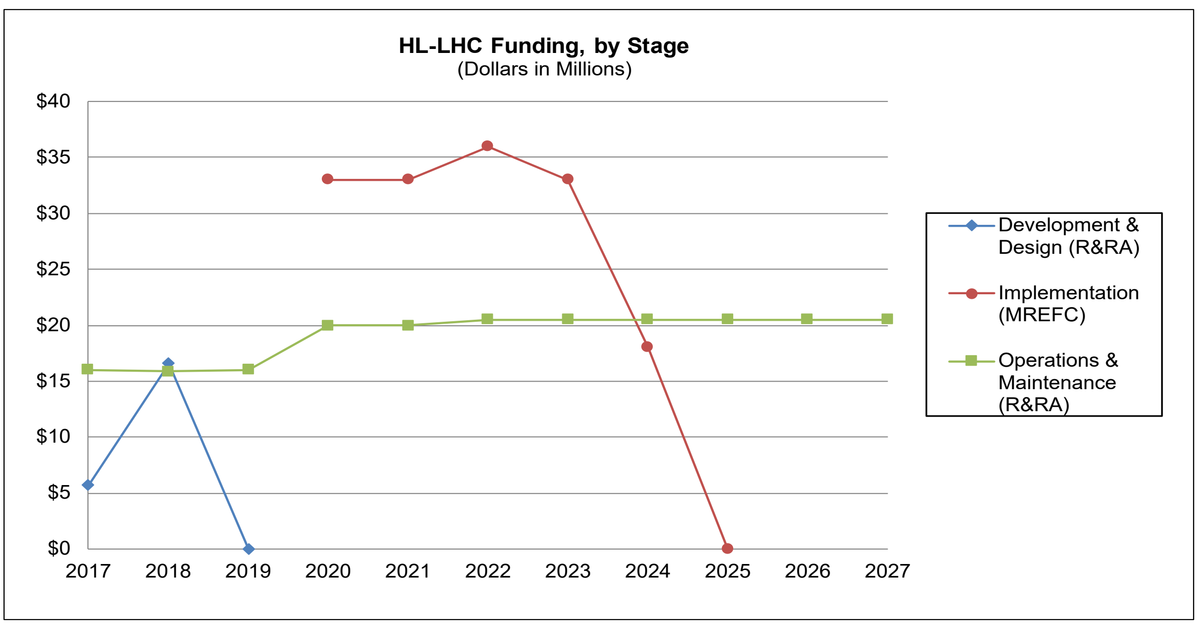
**Total Funding Requirements for HL-LHC Upgrade**[1]
(Dollars in Millions)

| | Cumulative Prior Years | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | ESTIMATES[2] FY 2023 | FY 2024 | FY 2025 | FY 2026 | FY 2027 |
|---|---|---|---|---|---|---|---|---|---|
| *R&RA:* | | | | | | | | | |
| Development & Design | $24.31 | - | - | - | - | - | - | - | - |
| Operations & Maintenance[3] | | 20.00 | 20.00 | 20.50 | 20.50 | 20.50 | 20.50 | 20.50 | 20.50 |
| Subtotal, R&RA | $24.31 | $20.00 | $20.00 | $20.50 | $20.50 | $20.50 | $20.50 | $20.50 | $20.50 |
| *MREFC:* | | | | | | | | | |
| Implementation | - | $33.00 | $33.00 | $36.00 | $33.00 | $18.00 | - | - | - |
| Subtotal, MREFC | - | $33.00 | $33.00 | $36.00 | $33.00 | $18.00 | - | - | - |
| **TOTAL REQUIREMENTS** | **$24.31** | **$53.00** | **$53.00** | **$56.50** | **$53.50** | **$38.50** | **$20.50** | **$20.50** | **$20.50** |

[1] COVID-19 impacts are not yet fully quantifiable and the situation is evolving rapidly. Schedule and cost impacts will lead to revisions of the funding

[2] Outyear funding estimates are for planning purposes only. The current cooperative agreements for O&M end in December 2021 (CMS) and January 2022 (ATLAS).

[3] This represents operations support for the current LHC facility. Installation, integration, and system testing of the upgraded detectors was planned to be coordinated by CERN during 2025-2027 (prior to the emergence of COVID-19). NSF's share of installation and commissioning costs was estimated at $5.0 million per detector, which was planned to be funded from the FY 2025-2027 O&M budgets. Evolving understanding of COVID-19 impacts may necessitate altering these plans.




## Future Operations Costs

An additional agreement between NSF, DOE, and CERN ("Experiments Protocol II"), signed in December 2015, documents the responsibilities of U.S. participants to provide normal 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 operation cost of the ATLAS and CMS detectors during HL-LHC operation (as it does today). This proportion is based on the number of NSF-supported scientists in each collaboration. NSF's external reviews of the impacts of the HL upgrades on future operating costs (held before the onset of COVID-19 pandemic) indicated that these operating cost projections are reasonable and are based on realistic assumptions. These projections will be 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. NSF conducted external reviews ("Full Life-Cycle Cost Reviews") of the impacts of future computing needs on the operations program 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. 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**

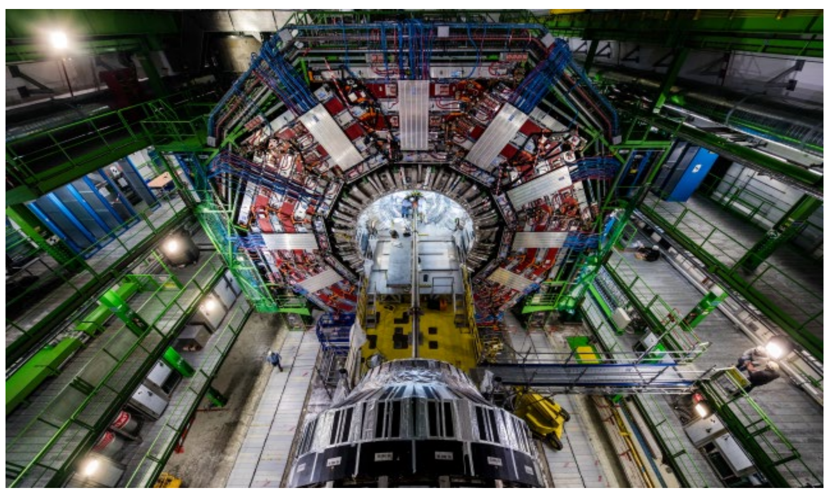
- Conceptual Design Reviews (CDR): March 2016 (ATLAS); March and April 2016 (CMS). Established the major functional elements of each detector designated for NSF support and determined that these elements would enable the principal science objectives within the estimated $150.0 million funding envelope defined by NSF in consultation with the MPS AC.
- Preliminary Design Reviews (PDR): January 2018 (ATLAS); December 2017 (CMS). Established that both projects met the PDR requirements. The review panels expressed confidence that the MREFC scope for each detector upgrade could be accomplished within its individual preliminary $75.0 million MREFC budget target. NSF subsequently carried out a comprehensive cost analysis that supported the basis of estimate for the requested construction budgets.
- Review of the O&M Plans of ATLAS and CMS for CY 2017-2021 (whose scope includes development and design activities for the detector upgrades): July 2016 (ATLAS); July 2016 (CMS).
- CERN international committee reviews: Major subsystems of the combined international effort were scientifically and technically reviewed by the CERN LHC Committee (LHCC), an international committee of technical experts, followed by a cost and schedule review by the CERN Upgrade Cost Group, an international committee of technical and financial experts, which reported to the LHCC (July 2017-April 2018).
- Final Design Reviews (FDR): September 2019 (ATLAS and CMS). Validated the construction-readiness of the upgrade plans. The FDRs established that the potential impacts of remaining pre-construction design and development are adequately bounded within the risk-adjusted budget of each collaboration. In this review process, the CMS budget was adjusted upward by $3.0 million to cover possible increased costs related to critical components under development by CERN and international partners.
- Full Life-cycle Cost Reviews: NSF held reviews of the cost impacts of the MREFC upgrades on the LHC operations program in October 2019.
- Reviews of ATLAS and CMS installation plans and software and computing R&D are planned in July 2021 to confirm the viability of scope, budget, schedule, and risk projections for these activities as part of NSF's assessment of its support for O&M during 2022-2026.
- Reviews of ATLAS and CMS HL upgrade activities are planned 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 project concludes 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. While a slip in the CERN schedule will delay scientific research, the total project cost of the NSF-funded construction projects is not anticipated to increase if there is a longer-than-expected time interval between delivery of the NSF-funded elements to CERN and the 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 changes to installation and commissioning requirements and methods. This might lead to greater installation costs or longer durations than originally anticipated. A significant delay in the start of installation, or a prolonged installation period, may increase demands on NSF's O&M support beyond 2027.

Management Risk
The FDRs established that 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 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).



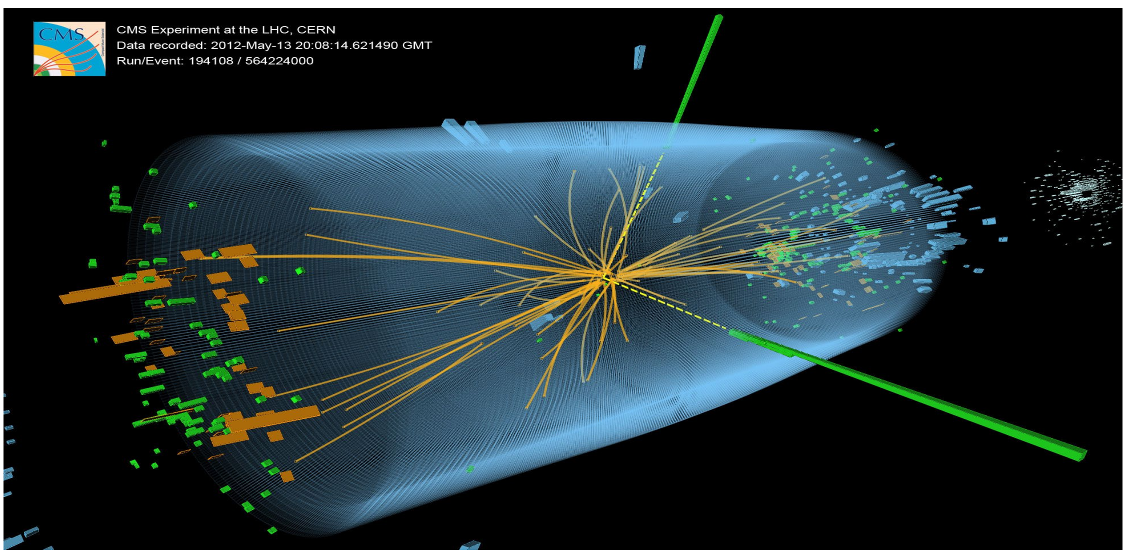
View of the CMS detector. *Credit: CERN.*

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, add 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. Ongoing and future risk assessments will take into account COVID impacts.

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).



**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)

| FY 2020 | FY 2021 Estimate | FY 2022 Request | FY 2023 Estimate | FY 2024 Estimate | FY 2025 Estimate | FY 2026 Estimate | FY 2027 Estimate |
|---|---|---|---|---|---|---|---|
| $65.00 | $76.25 | $76.25 | $76.25 | $76.25 | $76.25 | $76.25 | $76.25 |

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,[1] 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. Mid-scale RI-2 funding is intended to respond directly to that demand.

In the 2018 appropriation for NSF, report language from the House of Representatives directed "NSB, in collaboration with the National Academies of Science, Engineering, and Medicine (NASEM), to consider steps to bridge the gap between the NSF's Major Research Instrumentation Program (MRI) and the agency's MREFC account and to develop appropriate processes to address this matter through the MREFC account within a restricted funding environment." The NSB issued a report (NSB-2018-40)[2] 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 that is described in the NSF-Wide Priorities chapter of this budget submission. 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 with a new upper limit of $100.0 million was issued in December

[1] The first NSF-wide Mid-scale RI-2 solicitation called for implementation proposals with total project costs in the range from $20.0 million to $70.0 million. The long-term intent is for Mid-scale RI-2 to cover a range extending up to $100.0 million, to be maximally consistent with the definition of major multi-user research facility projects in the American Innovation and Competitiveness Act as amended by the 2021 National Defense Authorization Act.

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

2020; pre-proposals from that solicitation are currently under review, with invited full proposals due in September 2021.

Since Mid-scale RI-2 is a portfolio of implementation awards that spans 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 (STEM) 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.

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

| | Prior Years | FY 2020[2] | FY 2021 Estimate | FY 2022 Request | ESTIMATES[3] FY 2023 | FY 2024 | FY 2025 | FY 2026 | FY 2027 |
|---|---|---|---|---|---|---|---|---|---|
| *R&RA:* | | | | | | | | | |
| Development & Design | - | - | - | - | - | - | - | | |
| Subtotal, R&RA | - | - | - | - | - | - | - | - | - |
| *MREFC:* | | | | | | | | | |
| Implementation | - | - | $76.25 | $76.25 | $76.25 | $76.25 | $76.25 | $76.25 | $76.25 |
| Subtotal, MREFC | - | - | $76.25 | $76.25 | $76.25 | $76.25 | $76.25 | $76.25 | $76.25 |
| **TOTAL REQUIREMENTS** | **-** | **-** | **$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] FY 2020 funding of $65.0 million was carried over into FY 2021.

[3] 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. Because of the varied nature of potential Mid-scale RI-2 awards, the Major Facilities Guide states the following:

> "Mid-scale project oversight requirements are to be tailored based on each project's unique characteristics such as the technical scope, the type and mix of work performed (e.g., standard procurement by the Recipient, software development, or civil construction), and an assessment of the associated technical and programmatic risks. However, NSF is committed to the principle that this flexibility does not preclude the requirement for appropriate rigor on the part of NSF or the Recipient. Appropriate use of NSF major facility oversight practices will be determined on a case-by-case basis."

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

Each mid-scale project has 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 liaisons for the entire mid-scale portfolio, including the Mid-scale RI-2 program, to assure a common overall approach to these awards. 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.

In order 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 in order to tailor the oversight for each project once awards are made.

**Mid-scale RI Track 2 Status**

The final steps in the first portfolio selection are complete and 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 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:[4]

- “High Magnetic Field Beamline,” Cornell University, $32.69 million;
- “Global Ocean Biogeochemistry Array,” Monterey Bay Aquarium Research Institute, $52.94 million; and
- “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 round in February 2021. Those proposals are currently undergoing cost analyses; it is expected that the additional awards will be made prior to the end of FY 2021.

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.

**Future Operations Costs**

The Mid-scale RI-2 solicitation specifically prohibited inclusion of operations costs in the individual project budgets, but proposers were required to present operations and utilization plans as well as estimates of full lifecycle costs. For each individual proposal considered for inclusion in the award portfolio, the lead directorate was required to estimate and commit to any additional operations costs to reap the scientific benefits of an award. At a hypothetical level of ~$200.0 million in awards from the first solicitation and an upper limit to the operations cost of 10 percent of the capital costs per project per year, 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 ~$20.0 million per year by FY 2025. Given the variety of operational models, this cost would only be partially borne by NSF.[5] 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.

[4] www.nsf.gov/news/special_reports/announcements/102920.jsp

[5] 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.

**Reviews**

The Mid-scale RI-2 proposals do not go through the Conceptual/Preliminary/Final Design phases of major facility projects, with their accompanying reviews, enabling 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 developmental investments. 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 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 GAO good practices as required by the solicitation and the Major Facilities Guide. That analysis may inform modifications to the award portfolio if it reveals substantial deficiencies in the proposed cost 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 experts. The final portfolio construction also relies significantly on an evaluation of agency risks. These include, for example, a constraint that not all of the projects should have very high or very low technical risk,[6] potential cost risks identified during the review process, assessment of any potential 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.

[6] 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.

## REGIONAL CLASS RESEARCH VESSELS (RCRV) $5,000,000

**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 Request | FY 2022 Request | FY 2023 Request | Total Project Cost |
|---|---|---|---|---|---|---|---|---|
| Previous Authorized Total Project Cost | $121.88 | $105.00 | $127.09 | - | - | - | - | $353.97 |
| Current Authorized Total Project Cost (COVID-19) | - | - | - | - | - | - | - | - |
| Preliminary Estimate of COVID-19 Impact | - | - | - | - | - | 5.00 | 15.00 | 20.00 |
| **Estimate prior to Rebaseline** | **-** | **-** | **-** | **-** | **-** | **$5.00** | **$15.00** | **$373.97** |

### Brief Description

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 2019. To date, the measurable impacts of COVID-19 on the RCRV project have been relatively small, but future impacts are likely. In December 2020, the NSF Director increased the authorized Total Project Cost from the NSB-authorized value of $365.0 million to $375.0 million to prepare for COVID-19 impacts that reduced the efficiency of the construction effort and increased the time to completion. The FY 2022 Request of $5.0 million to account for pandemic impacts would increase the total appropriated RCRV funds to $358.97 million, which is still $16.03 million below the authorized TPC.[1] This narrative provides a history and project status.

### Scientific Purpose

The 2015 National Academies of Sciences, Engineering, and Medicine (the National Academies) report, Sea Change: 2015-2025 Decadal Survey of Ocean Sciences,[2] 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?
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 RCRV was designed to support research in each of those topics 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

[1] The funding profile for RCRV may change, pending possible allocation of American Rescue Plan funds.
[2] The National Academies. Sea Change: 2015-2025 Decadal Survey of Ocean Sciences, 2015. www.nap.edu/read/21655/chapter/1

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 (ARF). It is expected that an ARF that includes three RCRVs will have sufficient usage to support efficient operation, while meeting regional demands. 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.[3] In 2001, a report from the Federal Oceanographic Facilities Committee documented the need for Regional Class vessels. In 2004, NSF and the Naval Sea Systems Command (NAVSEA) entered into an interagency agreement that resulted in two candidate designs for Regional Class ships. In 2007, the Federal Oceanographic Fleet Status Report identified the need for NSF-built Regional Class vessels to meet future science demand. In 2009, another National Academies report, Science at Sea, described the desirable characteristics of a modern Regional Class vessel. These characteristics and other science community factors were considered by the review panel when the preferred NAVSEA design was later down selected. In 2012, NSF issued a solicitation for the refreshed design and potential construction of RCRV. Oregon State University (OSU) was selected and received the award in 2013. Input from external review panels, the University-National Oceanographic Laboratory System, and the National Academies Sea Change report was received during the period 2013 to 2015 and informed the final decision to pursue construction. Sea Change recommended constructing only two of the originally planned three RCRV vessels, but Congress ultimately appropriated funding to build all three.

In 2015, the National Science Board authorized inclusion of funds to initiate construction for the RCRV project in future budget requests at the NSF Director's discretion. The Final Design Review was conducted in December 2016 and the panel recommended to NSF that the project was ready to advance to the construction stage. OSU subsequently awarded a contract for construction to Gulf Island Shipyards, 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, leveraging savings from fleet rightsizing through the retirement of older and less capable vessels.

**Project Status**

OSU is managing the construction and transition to operations through a cooperative agreement with NSF, which encompasses the entire project, including tests and trials. The project is divided into four distinct phases, each to be funded through separate cooperative support agreements, with award of each phase contingent upon successful completion of the prior phase. These phases are:

Phase I: Project Refresh **- Complete**
Phase II: Shipyard Selection - **Complete**
Phase III: Construction – **In progress**
Phase IV: Transition to Operations – **Estimated Fall 2022**

The project completed Phase II in CY 2017, during which bids for construction of RCRV were solicited

[3] National Ocean Council. Federal Oceanographic Fleet Status Report, 2013. obamawhitehouse.archives.gov/sites/default/files/federal_oceanographic_fleet_status_report.pdf

and evaluated from U.S. shipyards. The project is now in Phase III construction. Keel-laying for the first RCRV, named R/V *Taani*, was completed in November 2018, for the second RCRV, name to be determined, 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 Fall 2022 and will likely begin operations in Fall 2023. The project is planning a six-month stagger between vessel deliveries, with the projection that the second RCRV will enter the ARF in early 2024 and R/V *Gilbert R. Mason* will enter in late 2024.

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 six months. Depending on the magnitude of the impacts in 2021, NSF may 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 (~~e.g.,~~ NSF, Office of Naval Research, and National Oceanic and Atmospheric Administration) will be active through all project phases. The SOC provides guidance to the OSU RCRV project team through the PM and/or the NSF Program Officer.

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.

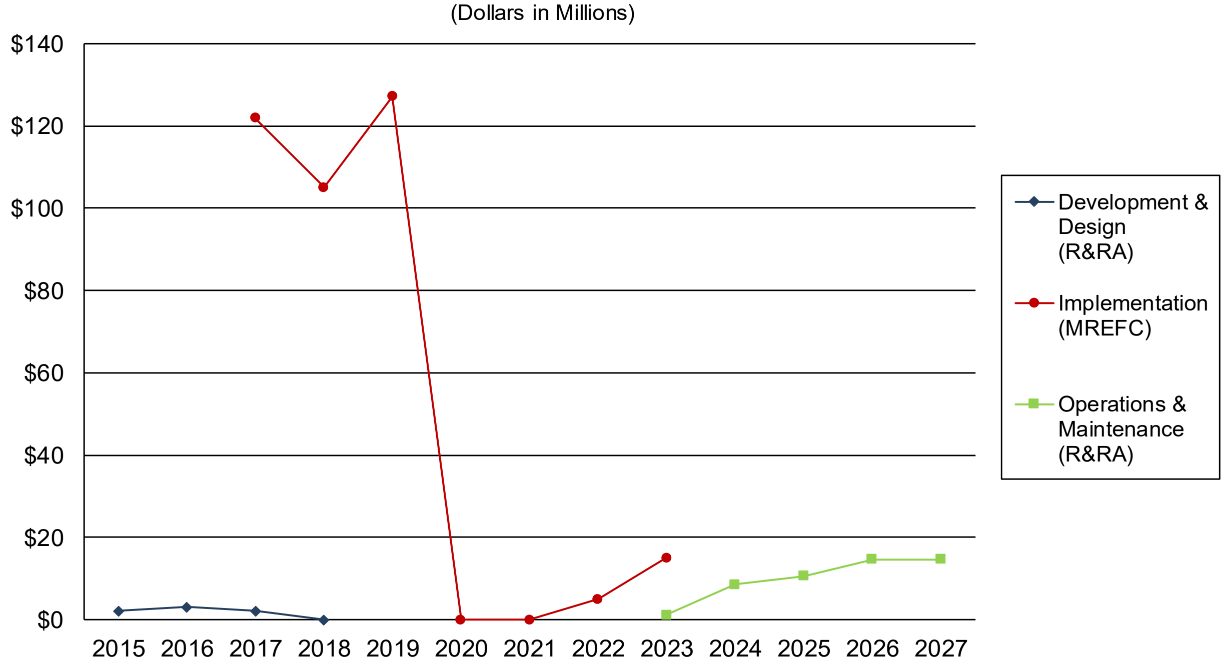
## Cost and Schedule

**Total Funding Requirements for RCRV**
(Dollars in Millions)

| | Prior Years | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | ESTIMATES FY 2023 | FY 2024 | FY 2025 | FY 2026 | FY 2027 |
|---|---|---|---|---|---|---|---|---|---|
| *R&RA:* | | | | | | | | | |
| Development & Design | $11.39 | - | - | - | - | - | - | - | - |
| Operations & Maintenance | | - | - | - | 1.23 | 8.58 | 10.58 | 14.70 | 14.70 |
| Subtotal, R&RA | $11.39 | - | - | - | $1.23 | $8.58 | $10.58 | $14.70 | $14.70 |
| *MREFC:* | | | | | | | | | |
| Implementation[1] | $353.97 | - | - | $5.00 | $15.00 | - | - | - | - |
| Subtotal, MREFC | $353.97 | - | - | $5.00 | $15.00 | - | - | - | - |
| **TOTAL REQUIREMENTS** | **$365.36** | **-** | **-** | **$5.00** | **$16.23** | **$8.58** | **$10.58** | **$14.70** | **$14.70** |

[1] Includes $11.0 million carried forward into FY 2021. Outyear estimates are for planning purposes only.

**RCRV Funding, by Stage**
(Dollars in Millions)




Total R&RA funding from FY 2017 to FY 2019 for RCRV design was $11.39 million. Total MREFC funding appropriated to support construction is currently $353.97 million.

An additional $5.0 million in FY 2022 MREFC funding is 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 out-year funding estimate in FY 2023 is the current estimate of the amount needed to address the remaining impacts due to COVID-19; it will be updated and fully documented as part of the FY 2023 request.

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 beginning in 2023 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. NSF supports approximately 70 percent of the use of the ARF, which suggests RCRV is likely to cost NSF approximately $1.23 million in FY 2023 for three months of operations of the R/V *Taani*. OSU is the selected operator for R/V *Taani.* The ultimate annual cost of approximately $14.70 million for operating three RCRVs will be balanced by cost savings from vessel retirements elsewhere in the ARF. The East Coast Oceanographic Consortium, whose members include the University of Rhode Island, the Woods Hole Oceanographic Institution, and the University of New Hampshire School of Marine Science and Ocean Engineering, along with 13 associate members, were selected to operate the second RCRV. The Gulf-Caribbean Oceanographic Consortium, whose members include the University of Southern Mississippi, the Louisiana University Marine Consortium, and 15 associate members, were selected to operate the third RCRV (R/V *Gilbert R. Mason*).

**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 was capable of delivering 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.

- Certain situations could add cost to OSU's management portion of the project. These include delayed appointments of key personnel, contracting issues, lack of management capacity due to optimistic planning, or misunderstanding of requirements. Contingency funds are included to increase OSU management capacity if needed.
- Sonar sensors, science load handling systems, and other vessel sub-systems may not perform as required. Contingency funds are included to ensure performance capabilities are met, given that many warranties are not likely to be performance-based or are otherwise limited contractually with the shipyard.

- Growth in weight and vertical center of gravity has required design changes, namely lengthening by six feet, to ensure vessel seaworthiness. This is a typical risk for ship construction (and research vessels in particular) that requires active management by OSU and the shipyard, as well as oversight by NSF, such that the ship can operate safely and effectively. This risk has been reduced through the re-design but will not be entirely eliminated until the delivered vessels are evaluated.
- 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.

Approximately $34.18 million in contingency has been allocated to date as a result of realizing known risks. 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 as a means to mitigate cost impacts from the pandemic.

## VERA C. RUBIN OBSERVATORY (RUBIN OBSERVATORY) $40,750,000

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

| | Prior Years | FY 2018 | FY 2019 | FY 2020 | FY 2021 Estimate | FY 2022 Request | FY 2023 Estimate | Total Project Cost |
|---|---|---|---|---|---|---|---|---|
| Previous Authorized Total Project Cost | $273.92 | $57.80 | $48.82 | $46.35 | $40.75 | $5.36 | - | $473.00 |
| Increase in Authorized Total Project Cost (COVID-19) | - | - | - | 10.00 | - | - | - | 10.00 |
| Preliminary Estimate of Future COVID-19 Impact | - | - | - | - | - | 35.39 | 15.00 | 50.39 |
| **Estimate prior to Rebaseline** | **$273.92** | **$57.80** | **$48.82** | **$56.35** | **$40.75** | **$40.75** | **$15.00** | **$533.39** |

### Brief Description

The FY 2022 NSF Request for Vera C. Rubin Observatory is $40.75 million. Begun in August 2014, FY 2022 represents the ninth year of support for a construction project originally planned for nine years. 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 the Department of Energy (DOE). To meet unforeseen COVID-19 related expenses, the NSF Acting Director increased the award authorization by $10.0 million (up to $483.0 million) in FY 2020 to provide an NSF-held management reserve for the near-term impacts on the construction project.[1] In FY 2020, NSF shifted the final year of construction out by one year due to COVID-19. The FY 2022 Request is the best current estimate of the project need in FY 2022 given the anticipated approximately 16-month-delay and the authorization of management reserve in FY 2020; it is based on a preliminary estimate of overall project need increasing to $533.39 million. The project is currently being re-baselined to account for the impacts of COVID-19, and NSF anticipates presenting the NSB with a recommendation for authorization of a new TPC by the end of CY 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. See the NOIRLab narrative in the Facilities Section for further details.

### Scientific Purpose

Vera C. Rubin Observatory will comprise an 8.4-meter wide-field optical telescope located in Chile, a 3.2-gigapixel camera supplied by 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. Rubin Observatory's initial 10-year survey has a cadence that will enable repeat observation of each 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.

[1] The $10.0 million in management reserve was reprogrammed 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.

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 fundamental astrophysical studies by the entire research community 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. 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. As of January 2021, the project's NSF-funded scope is 87 percent complete. The primary telescope building, mirror cell lift, and mirror coating plant construction have been completed. The M1M3 mirror and cell are completed and have been safely transported to the summit. The secondary mirror (M2) has been successfully coated at the summit facility, and staff have moved into the completed base facility. Dome installation was progressing well prior to the onset of the COVID-19 pandemic, despite significant delays caused by weather and realization of other known risks. The project had been executing activities to minimize the impact of delays on the integrated project schedule. Installation of the telescope mount assembly (TMA) on the summit had also been progressing well prior to the impacts of the COVID-19 pandemic on construction. The Auxiliary Telescope, which will be used for calibration purposes, had also seen excellent progress with its commissioning activities. NSF- and DOE-supported activities remain tightly coordinated, both at the project level and among agency program officers.

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

- 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 the recent 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 MA work will soon pause

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

again for two months while some subcontractors wait for the cancellation of Chilean COVID-19 quarantines, which currently prevent their return to the summit. The current schedule remains tentative and is subject to potential additional delays as the global pandemic continues.

- 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, potential damage to sensitive equipment during the Chilean winter, and direct expenses for new procedures and protocols required for COVID-19.
- Current projections for a potential re-baselining of the construction project include an additional ~$50 million for other potential impacts caused by the COVID-19 pandemic and are based on the estimated cost of a projected 16-month schedule delay. This would also move the final year of MREFC funding to FY 2023. A rigorous re-baseline, including a joint agency-led review by a panel of external experts, of the Rubin Observatory Construction Project is expected in FY 2021, now that site construction has resumed. The re-baseline process will result in a revised estimate of the TPC.

**Meeting Intellectual Community Needs**

While the COVID-19 pandemic forced a suspension of summit construction activity of Vera C. Rubin Observatory, the project maintained regular inspections of the site. This photo was taken during the inspection conducted on June 9, 2020. *Credit: Rubin Observatory/AURA/NSF.*

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 ten-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 Observatory's ability to locate NEOs[4] and Potentially Hazardous Asteroids (PHAs)[4] have been refined by Rubin 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).

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[3] See Ivezić et al. (2019), *The Astrophysical Journal,* 873, 111.
[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 a distance of 0.05 au (roughly 4,650,000 miles) 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

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, OISE, Office of Budget, Finance and Award Management (BFA), the Office of General Counsel, the Office of Legislative and Public Affairs, and the Office of the Director. Within BFA, the Large Facilities Office provides advice to program staff and assists with agency oversight and assurance. The MPS Facilities Team and NSF's Chief Officer for Research Facilities also provide high-level guidance and oversight support for the project. The NSF program officer works closely with counterparts in the DOE Office of High Energy Physics, who have oversight responsibility for the construction of the camera.

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 is responsible for coordinating construction activities and pre-operations activities that are executed side-by-side. Pre-operations activity is fully integrated into NOIRLab for which AURA has a separate NOIRLab Management Oversight Council. The NOIRLab Directorate works with 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 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 ($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 16 months in project completion with a cost increase above the original $473.0 million that is currently estimated to be approximately $60 million. DOE's baseline cost for the camera was fixed at $168.0 million.[7] The total construction also included approximately $39 million from non-federal sources, all of which have been expended.

The FY 2022 NSF Request level for Rubin Observatory will enable the construction project to account for the impacts of COVID-19 and continue progress throughout FY 2022. The FY 2023 level is based on the current best estimate of the total funding needed to address the delays due to COVID-19 and is expected to be updated and fully described as part of the FY 2023 Congressional Request.

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

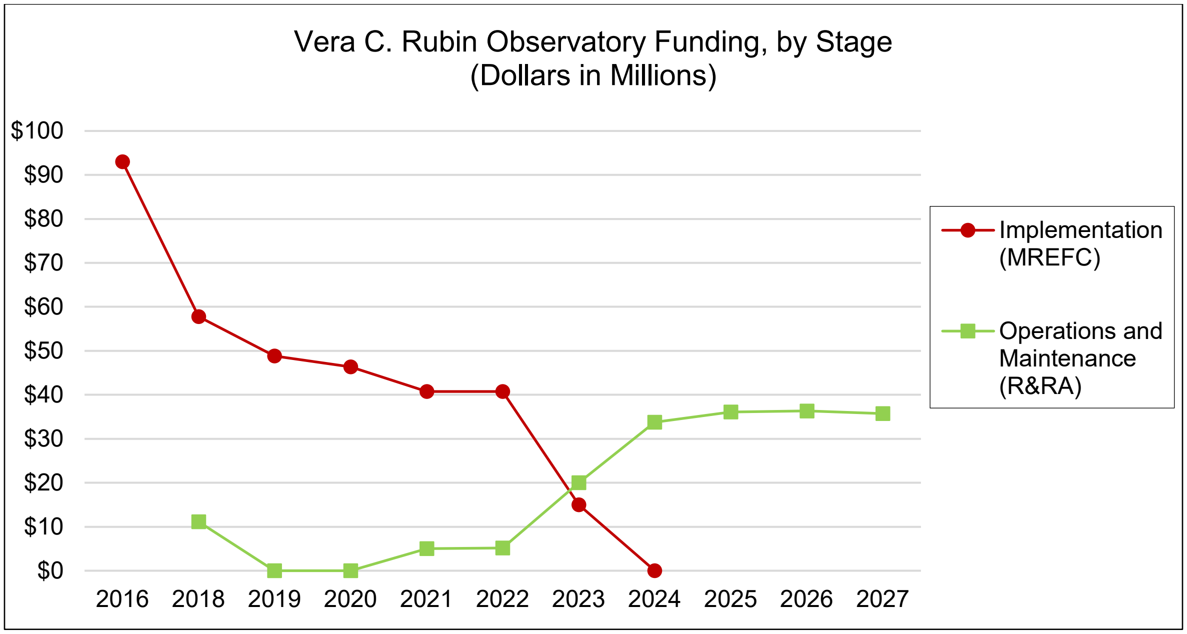
| | Cumulative Prior Years | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | ESTIMATES[1] | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | FY 2023 | FY 2024 | FY 2025 | FY 2026 | FY 2027 |
| *R&RA:* | | | | | | | | | |
| Development & Design | $57.13 | - | - | - | - | - | - | - | - |
| Operations & Maintenance[2] | | 0.01 | 5.00 | 5.20 | 19.98 | 33.80 | 36.09 | 36.34 | 35.71 |
| Subtotal, R&RA | $57.13 | $0.01 | $5.00 | $5.20 | $19.98 | $33.80 | $36.09 | $36.34 | $35.71 |
| *MREFC:* | | | | | | | | | |
| Implementation[3] | $380.55 | $56.34 | $40.75 | $40.75 | $15.00 | - | - | - | - |
| Subtotal, MREFC | $380.55 | $56.34 | $40.75 | $40.75 | $15.00 | - | - | - | - |
| **TOTAL REQUIREMENTS** | **$437.68** | **$56.35** | **$45.75** | **$45.95** | **$34.98** | **$33.80** | **$36.09** | **$36.34** | **$35.71** |

[1] Outyear funding estimates are for planning purposes only. A new cooperative support agreement for O&M is anticipated in FY 2023.

[2] This represents NSF support only and amounts to about 50 percent of the total operations cost. DOE and non-federal contributors provide the balance.

[3] Includes $10.0 million carried forward into FY 2021.

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




**Future Operations Costs**

The total annual operations cost for Rubin Observatory is currently estimated to be $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 $5.0 million requested in FY 2021. An additional $5.20 million is requested in FY 2022 to extend the pre-operations ramp-up activity period necessitated by COVID-19 delays to the construction project. A proposal to fund the balance of Rubin pre-operations and full operations funding for the period FY 2023–FY 2027 is expected from AURA as part of a NOIRLab-wide operations proposal in FY 2022 (see NOIRLab narrative).

In FY 2019, NSF and DOE jointly established a new model for in-kind contributions from international participants. 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 is expected in FY 2021.

**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 the 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 geological events and extreme weather remain as possible risks with appropriate mitigation plans.

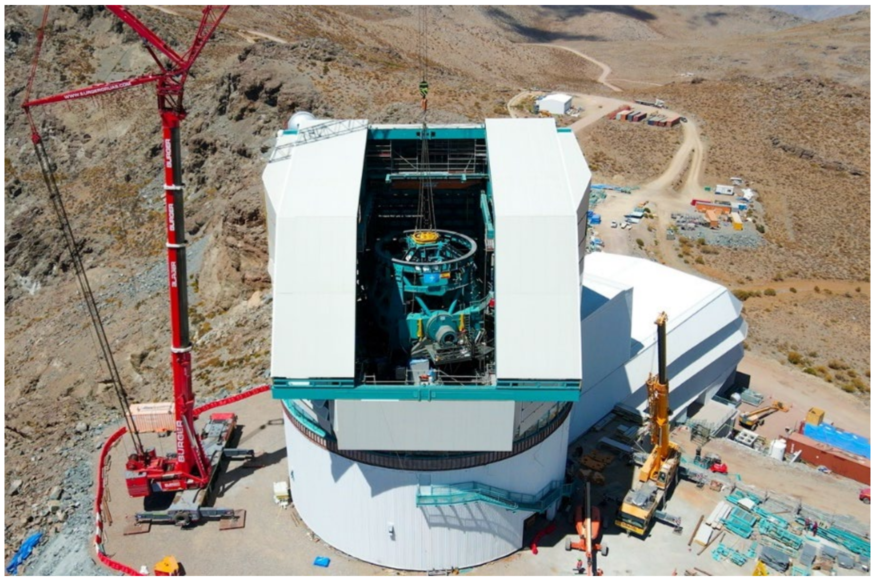
Environmental Health and Safety

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 safety policies, procedures, and protocols to adapt to working safely in the global COVID-19 pandemic. Such policies are reviewed and adjusted appropriately as conditions in various locations evolve. External reviews have given the project high marks for its safety culture.

Partnership Risk

Significant attention has been paid to partnership risk, and that risk has been mitigated by careful coordination and unified project 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 on a daily basis. 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.

<u>System Integration Risk</u>
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 (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.



The Top-End Assembly for the Telescope Mount Assembly (TMA) was lifted by crane into the observatory dome and installed on the TMA on March 2, 2021. The task was completed successfully and was a highly celebrated milestone for Rubin Observatory. *Credit: Rubin Observatory/AURA/NSF.*

## ORGANIZATIONAL EXCELLENCE $700,190,000
**+$136,760,000 / 24.3%**

**Organizational Excellence Funding Summary**
(Dollars in Millions)

| | FY 2020 Actual | FY 2020 CARES Act Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|---|
| Organizational Excellence[1] | $537.05 | $1.00 | $563.43 | $700.19 | $136.76 | 24.3% |
| Percent of NSF Total | 6.5% | N/A | 6.6% | 6.9% | 0.2% | N/A |

[1] Includes Administrative Cost Recoveries (ACRs) totaling $6.14 million for FY 2020 and $4.19 million for FY 2021. 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 2022 Request.

FY 2022 Congressional Request funding for the Organizational Excellence portfolio is $700.19 million, about seven percent of the total NSF FY 2022 Request. The increase over the FY 2021 Estimate (+$136.76 million) signifies NSF's commitment to organizational excellence reflects an extensive review of the agency's operational and administrative needs. Informed by a new pilot process for FY 2022, which included a current services analysis of the AOAM, OIG and NSB accounts and extensive internal engagement, NSF has included a course correction aimed at decreasing the reliance on the transfer authority to cover the costs of doing business year over year. Specifically, the requested level will enable NSF to establish a new directorate for Technology, Innovation, & Partnerships (TIP) and grow agency administration and operations, including additional staffing needs, with speed and scale to meet the needs of a growing $10 billion federal research agency effectively and efficiently. NSF includes in this request the necessary resources to cover the increased costs for IT, security, support services, travel, and training estimated at a current services level for the larger agency size and workload requirements. NSF anticipates continuing to move toward a hybrid work environment and includes resources for the necessary additional information technology and training for staff and supervisors to achieve this. NSF also includes funding for an anticipated cost of living adjustment for FY 2022. In addition, NSF requests increases for new activities beyond current services to provide for strategic human capital management, changes at the NSF headquarters building to respond to Coronavirus impacts, establishing a new effort for Science and Security including a Sensitive Compartmented Information Facility (SCIF) at the NSF headquarters building, and NSF-wide implementation of Program Management Improvement Accountability Act (PMIAA).

As part of the pilot process for FY 2022, NSF also changed the presentation of the Organizational Excellence portfolio in the FY 2022 Congressional justification to be organized around the major functional components instead of sorted solely by appropriation account. This new presentation aligns more accurately and transparently with how NSF plans and executes the budget for the Organizational Excellence portfolio activities funded by the AOAM, R&RA and EHR accounts. A summary of the FY 2022 Request justification by appropriation account is provided in this Overview, and the budget requests from OIG and NSB are still presented separately within the Organizational Excellence chapter.

NSF fulfills its mission chiefly through the annual merit review of approximately 43,000 proposals and the issuance of more than 12,000 new awards. In a typical year, NSF welcomes approximately 50,000 visitors, primarily merit review panelists; conducts almost 200,000 proposal reviews; and works with about 1,900 institutions in all 50 states, the District of Columbia, and three U.S. territories. 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 Organizational Excellence portfolio underpins the agency's programmatic activities and is critical to the accomplishment of NSF's Strategic Goal 1: Expand Knowledge in Science, Engineering and Learning, and Strategic Goal 2: Advance the Capability of the Nation to Meet Current and Future Challenges.[1]

NSF seeks to achieve organizational excellence through a continuous emphasis on efficiency and efficacy, as noted under NSF's Strategic Goal 3, Enhance NSF's Performance of its Mission.

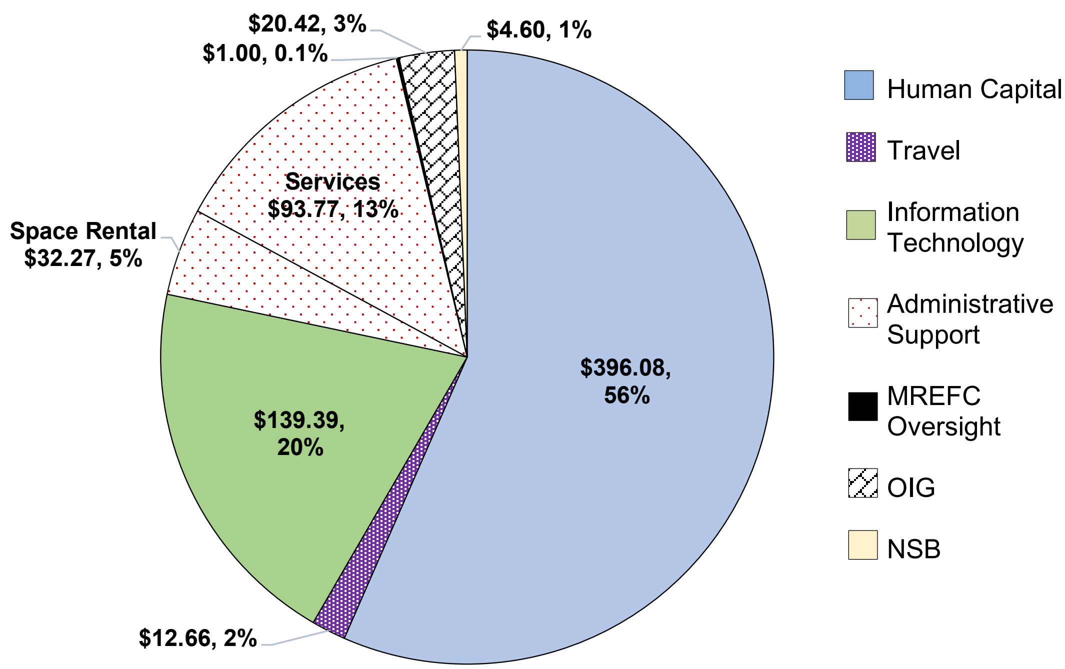
The following section of the overview presents a summary of the FY 2022 funding for the Organization Excellence portfolio by Major Component. This is followed by an overview section presenting the same information but organized by appropriation as was done in prior year budgets. This presentation by appropriation is provided for consistency and comparability to prior year budgets for Organizational Excellence and facilitate transition to the new presentation.

**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 2022 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

[1] NSF (2018). Building the Future: Investing in Discovery and Innovation – NSF Strategic Plan for Fiscal Years (FY) 2018-2022. Retrieved from: www.nsf.gov/about/performance/strategic_plan.jsp

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 chapter.

Human Capital

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. Year over year, Human Capital sees a significant increase related to the rising cost of living and requirements for salary and benefits. Between 2018 to 2021, Human Capital costs increased 19 percent even with NSF's FTE level remaining constant. For FY 2022, the typical cost of living adjustments for salary and benefits coupled with the creation of a new directorate and a requested growth in the number of federal staff FTE and IPA FTE commensurate with the growth in the total NSF Request together increase Human Capital costs over the FY 2021 Estimate by 18 percent.

*NSF Workforce*

The table below shows the agency's total workforce for FY 2022. 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 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| ***FTE Allocation*** | | | | | |
| AOAM | 1,354 | 1,372 | 1,472 | 100 | 7.3% |
| Regular | 1,315 | 1,330 | 1,430 | 100 | 7.5% |
| Pathways Interns[1] | 39 | 42 | 42 | - | - |
| IPAs | *198* | 205 | *255* | 50 | 24% |
| ***FTE Usage (Actual/Projected)*** | | | | | |
| AOAM | 1,333 | 1,372 | 1,472 | 100 | 7.3% |
| Regular | 1,314 | 1,330 | 1,430 | 100 | 7.5% |
| Pathways Interns[1] | 20 | 42 | 42 | - | - |
| Office of Inspector General | 68 | 71 | 79 | 8.00 | 11% |
| Office of the National Science Board | 17 | 17 | 17 | - | - |
| Arctic Research Commission | 3 | 3 | 3 | - | - |
| **Total, Federal Employees (FTE) Usage** | **1,421** | **1,463** | **1,571** | **108** | **7.4%** |
| IPAs (FTE) | 177 | 198 | 255 | 57 | 28.5% |
| Detailees to NSF | 3 | 3 | 3 | - | - |
| **Total, NSF Workforce (FTE)** | **1,601** | **1,664** | **1,829** | **165** | **9.9%** |

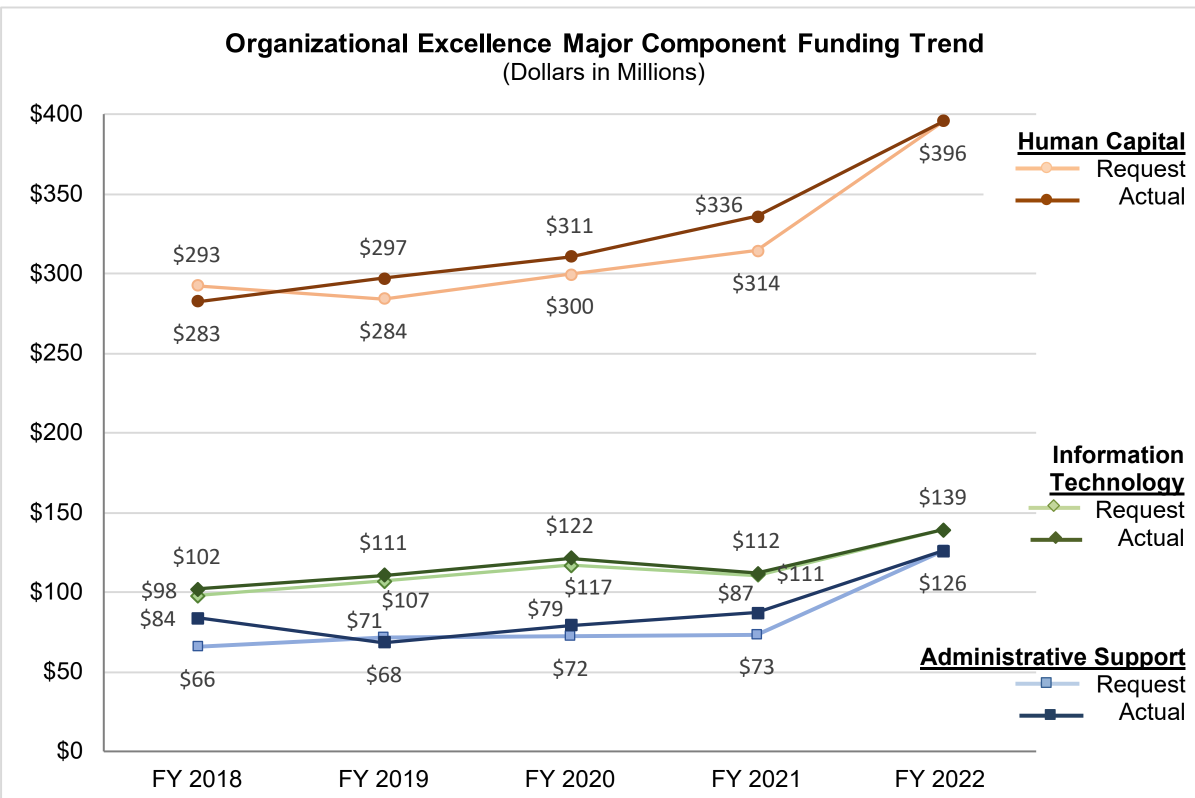
[1] The Pathways Intern program was established by Executive Order 13562, Recruiting and Hiring Students and Recent Graduates. The internship program offers part- or full-time paid internships in federal agencies to qualifying students (students in high schools, community colleges, four-year colleges, trade schools, career and technical education programs, and other qualifying technical education programs).

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, with the FY 2022 Request in line with the multi-year trend.

NSF's IT investments are increased 24 percent over the FY 2021 Estimate to improve data management and enhance IT service delivery ensuring high quality, reliable, and secure administrative applications and associated IT infrastructure support and services to meet the needs of the Foundation at its increased size and in alignment with its post pandemic posture. Further, NSF is submitting an Administrative Support budget that fully covers NSF's estimated cost of doing business. Increases are provided for Administrative Support costs for the new NSF directorate, NSF-wide PMIAA implementation, and the new effort for Science and Security. This strategy results in an FY 2022 Administrative Support budget that is increased 45 percent over the FY 2021 Estimate.

The Organizational Excellence Major Component Funding Trend graphic below shows funding trends since FY 2018 for the three major components funded by the AOAM, R&RA, and EHR accounts. This illustrates how since 2018 NSF has only had small increases for Information Technology and Administrative Support in order to account for the much larger increases for Human Capital. This also shows how in FY 2019 and FY 2020, NSF has had to rely on its transfer authority to cover the actual costs of doing business year over year. The course correction NSF presents in FY 2022 seeks to change this construct and instead include in its budget request the best estimate for the costs of NSF operations as the agency moves aggressively to support more fundamental research, improve translation of research to jobs and products, grow innovation, strengthen partnerships, and simultaneously transition to post pandemic operations.




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 MREFC chapter.

**Organizational Excellence by Major Component**
(Dollars in Millions)

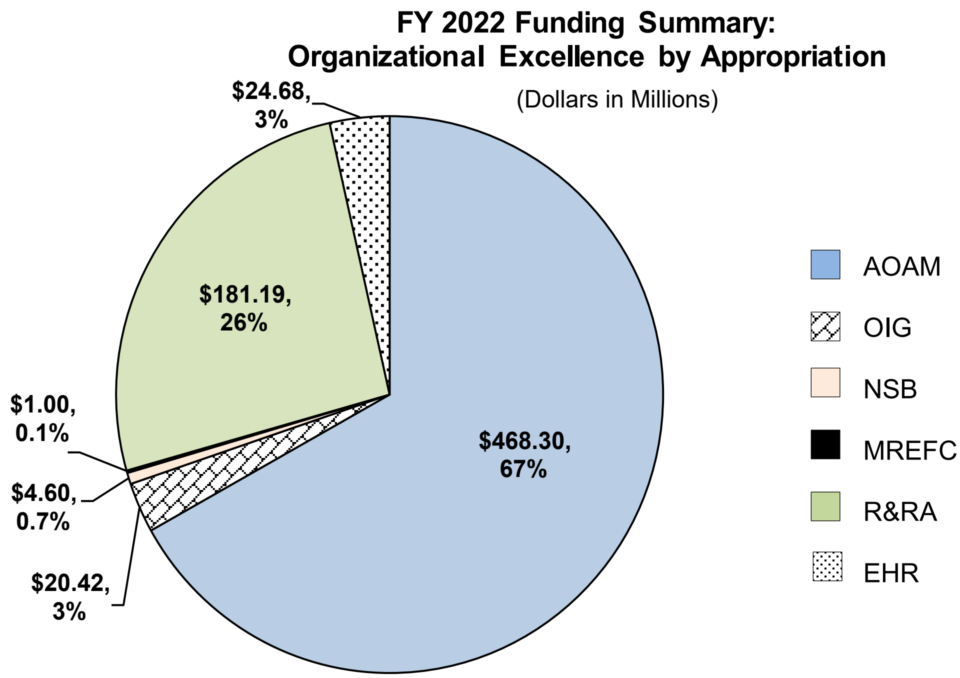
| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent | Funding Source |
|---|---|---|---|---|---|---|
| Human Capital | $310.85 | $336.05 | $396.08 | $60.03 | 17.9% | |
| Personnel Compensation & Benefits | 256.35 | 272.98 | 311.81 | 38.83 | 14.2% | AOAM[1] |
| Management of Human Capital | 7.11 | 9.33 | 15.16 | 5.83 | 62.4% | AOAM |
| IPA Appointments | 47.39 | 53.73 | 69.11 | 15.38 | 28.6% | |
| Compensation | 44.40 | 49.82 | 63.65 | 13.83 | 27.8% | R&RA/EHR |
| Per Diem | 2.99 | 3.91 | 5.46 | 1.55 | 39.6% | R&RA/EHR |
| Travel | $3.95 | $5.13 | $12.66 | $7.53 | 146.9% | |
| NSF Federal Employee Staff | 2.69 | 3.67 | 8.51 | 4.84 | 132.1% | AOAM |
| IPA Appointments | 1.26 | 1.46 | 4.15 | 2.69 | 184.2% | R&RA/EHR |
| Information Technology | $121.50 | $112.01 | $139.39 | $27.38 | 24.4% | |
| Agency Operations IT | 24.19 | 24.28 | 31.97 | 7.69 | 31.7% | AOAM |
| Administrative Applications Services & Support | 6.86 | 6.91 | 7.91 | 1.00 | 14.4% | AOAM |
| Administrative IT Operations & Infrastructure | 15.04 | 13.67 | 18.98 | 5.31 | 38.8% | AOAM |
| Administrative Security & Privacy Services | 1.78 | 3.22 | 4.51 | 1.29 | 39.9% | AOAM |
| Administrative IT Management | 0.51 | 0.48 | 0.58 | 0.10 | 21.5% | AOAM |
| Program Related Technology (PRT) | 97.31 | 87.73 | 107.42 | 19.69 | 22.4% | R&RA/EHR |
| Mission-Related Applications & Services | 60.42 | 55.93 | 68.72 | 12.79 | 22.9% | R&RA/EHR |
| Mission-Related IT Operations & Infrastructure | 28.25 | 25.01 | 30.00 | 4.99 | 20.0% | R&RA/EHR |
| Mission-Related Security & Privacy Services | 6.40 | 4.75 | 6.50 | 1.75 | 36.8% | R&RA/EHR |
| Mission-Related IT Management | 2.24 | 2.04 | 2.20 | 0.16 | 7.9% | R&RA/EHR |
| Administrative Support | $79.05 | $86.90 | $126.04 | $39.15 | 45.0% | |
| Space Rental | 29.69 | 30.81 | 32.27 | 1.46 | 4.7% | AOAM |
| Operating Expenses | 18.68 | 21.63 | 41.69 | 20.06 | 92.8% | AOAM |
| Building & Administrative Services | 15.01 | 16.42 | 26.89 | 10.47 | 63.8% | AOAM |
| Other Program Related Administration | 2.41 | 6.45 | 6.45 | - | - | |
| E-Government Initiatives | 1.37 | 1.37 | 1.38 | 0.01 | 0.7% | R&RA/EHR |
| General Planning & Evaluation Activities | 1.04 | 5.08 | 5.07 | -0.01 | -0.2% | R&RA/EHR |
| Other Organizational Excellence Activities | 13.26 | 11.59 | 18.74 | 7.15 | 61.7% | |
| Analysis, Modeling, and Forecasting | - | - | 3.00 | 3.00 | N/A | RRA-IA |
| Evaluation and Assessment Capability | 5.29 | 5.00 | 7.00 | 2.00 | 40.0% | RRA-IA |
| Major Facilities Admin Reviews and Audits | 0.80 | 2.34 | 0.99 | -1.35 | -57.7% | RRA-various |
| Planning and Policy Support | 4.72 | 2.50 | 3.00 | 0.50 | 20.0% | RRA-IA |
| Public Access Initiative | 2.45 | 1.75 | 3.75 | 2.00 | 114.3% | RRA-CISE |
| Research Security Strategy and Policy | - | - | 1.00 | 1.00 | N/A | RRA-IA |
| MREFC Oversight | $0.97 | $1.00 | $1.00 | - | - | MREFC |
| Office of Inspector General | $16.30 | $17.85 | $20.42 | $2.57 | 14.4% | OIG |
| Office of the National Science Board | $4.43 | $4.50 | $4.60 | $0.10 | 2.2% | NSB |
| **Total** | **$537.05** | **$563.43** | **$700.19** | **$136.76** | **24.3%** | |

[1] Includes Administrative Cost Recoveries (ACRs) totaling $6.14 million for FY 2020 and $4.19 million for FY 2021. 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 2022 Request.

**Organizational Excellence by Appropriation**

As stated above, though NSF moved to a new format for presenting the Organizational Excellence budget request by Major Component, the following presentation by appropriation is provided for consistency with and comparability to prior year budgets for Organizational Excellence and to facilitate the transition to the new presentation.

NSF's Organizational Excellence portfolio is funded through all of NSF's appropriation accounts.




**Organizational Excellence by Appropriation**

(Dollars in Millions)

| | FY 2020 Actual | FY 2020 CARES Act Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|---|
| Agency Operations & Award Management | $347.58 | $1.00 | $374.93 | $468.30 | $93.37 | 24.9% |
| Office of Inspector General | 16.30 | - | 17.85 | 20.42 | 2.57 | 14.4% |
| Office of the National Science Board | 4.43 | - | 4.50 | 4.60 | 0.10 | 2.2% |
| Major Research Equipment & Facilities Construction | 0.97 | - | 1.00 | 1.00 | - | - |
| Program Support: | | | | | | |
| Research & Related Activities | 143.74 | - | 143.03 | 181.19 | 38.16 | 26.7% |
| Education & Human Resources | 17.88 | - | 17.93 | 24.68 | 6.75 | 37.6% |
| **Total NSF Appropriated Funds** | **$530.91** | **$1.00** | **$559.24** | **$700.19** | **$140.95** | **25.2%** |
| Administrative Cost Recoveries (ACRs) | 6.14 | - | 4.19 | - | -4.19 | -100.0% |
| **Total Organizational Excellence** | **$537.05** | **$1.00** | **$563.43** | **$700.19** | **$136.76** | **24.3%** |

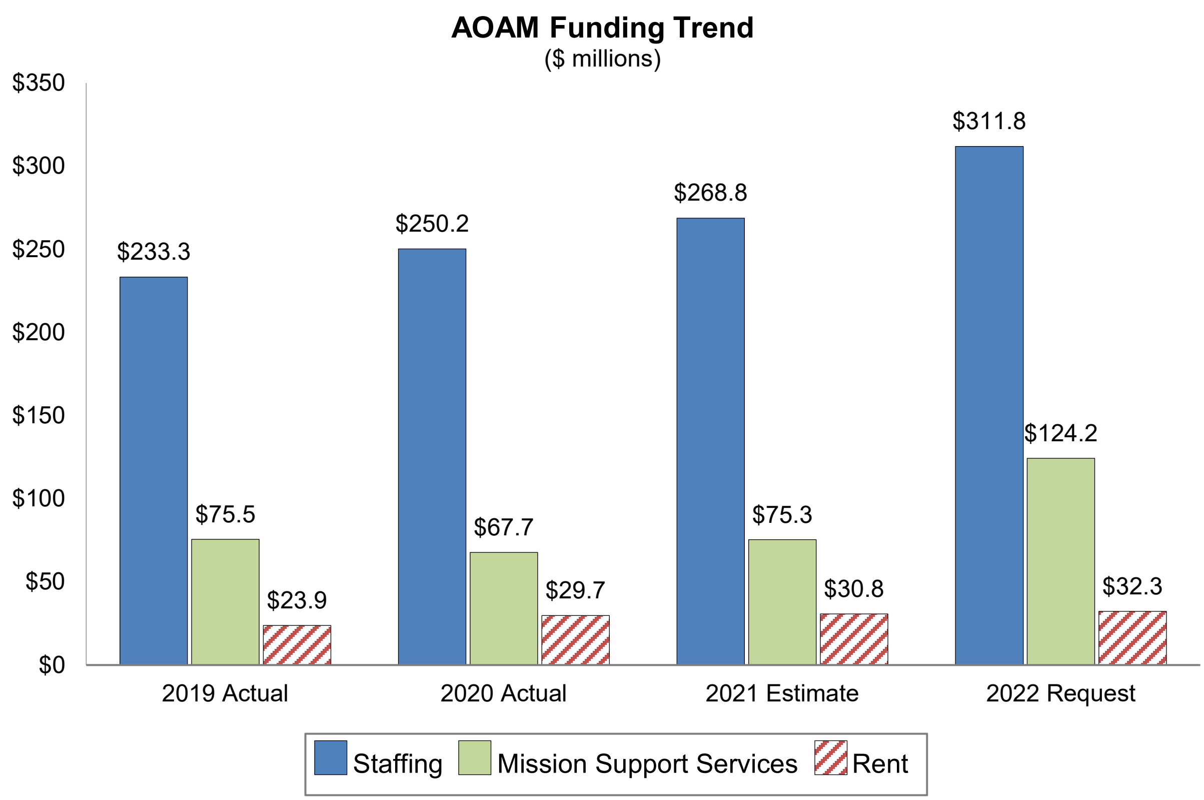
Agency Operations and Award Management (AOAM)
Investments in the AOAM account are a renewed priority in the FY 2022 request. This activity provides the fundamental framework through which the Foundation's science and engineering research and education programs are administered.

AOAM investments support NSF Strategic Goal 3: Enhance NSF's performance of its mission. AOAM's priorities are framed by two strategic objectives:

- Strategic Objective 1: Attract, retain, and empower a talented and diverse workforce; and
- Strategic Objective 2: Continually improve agency operations.

At the FY 2022 Request level, AOAM funding is $468.30 million representing 67 percent of the Organizational Excellence portfolio but only about five percent of the total NSF FY 2022 Request. 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 2.7 percent cost of living adjustment for FY 2022, similar to prior years. Nearly three quarters (73 percent) of the requested FY 2022 AOAM funds support staffing and space rental while about one quarter (27 percent) are for mission support services. This is a purposeful change in course from prior years when staffing and space rental accounted for closer to 80 percent of the AOAM total and services was around 20 percent.

The course correction sought with the FY 2022 funding levels for AOAM reverses the trend of reducing or holding flat mission support services to support increasing staffing and rent costs as illustrated in the AOAM Funding Trend graphic below. This signals NSF's intent to present a more realistic picture of the cost of doing business in its budget requests rather than relying solely on NSF's transfer authority.



**Agency Operations and Award Management Funding Summary**
(Dollars in Millions)

| | FY 2020 Actual | FY 2020 CARES Act Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|---|
| Personnel Compensation & Benefits (PC&B)[1] | $250.21 | $0.21 | $268.79 | $311.81 | $43.02 | 16.0% |
| Management of Human Capital | 7.11 | 0.20 | 9.33 | 15.16 | 5.83 | 62.4% |
| Travel | 2.69 | - | 3.67 | 8.51 | 4.84 | 132.1% |
| Information Technology | 24.19 | 0.23 | 24.28 | 31.97 | 7.69 | 31.7% |
| Space Rental | 29.69 | - | 30.81 | 32.27 | 1.46 | 4.7% |
| Operating Expenses | 18.68 | - | 21.63 | 41.69 | 20.06 | 92.8% |
| Building & Administrative Services | 15.01 | 0.36 | 16.42 | 26.89 | 10.47 | 63.8% |
| **Total** | **$347.58** | **$1.00** | **$374.93** | **$468.30** | **$93.37** | **24.9%** |

[1] PC&B levels reflect direct appropriations only. In FY 2020, $6.14 million in Administrative Cost Recoveries (ACRs) were received bringing the total PC&B obligation to $256.35 million. In FY 2021, $4.19 million in ACRs are anticipated bringing the total PC&B estimate to $272.98 million. In alignment with NSF's course correction, for FY 2022, NSF is moving away from the practice of including ACRs as a source of funds to meet its PC&B requirement. NSF's ACR estimate for FY 2022 is not factored into NSF's PC&B or AOAM budget plans for the FY 2022 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 2022 funding for the OIG is $20.42 million. The staffing and operations of the OIG are supported through a separate OIG appropriation. Details about the OIG FY 2022 Request can be found in the OIG chapter.

Office of the National Science Board

FY 2022 funding for the NSB is $4.60 million. The staffing and operations of the NSB office are supported through a separate NSB appropriation. Details about the NSB FY 2022 Request can be found in the NSB chapter.

Major Research Equipment and Facilities Construction

The FY 2022 Request includes $1.0 million within the MREFC account for oversight of NSF's major facility projects. For more information on this activity, see the MREFC chapter.

Program Support

Funding from program accounts R&RA and EHR ($205.87 million) covers approximately 29 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 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| **IPA Costs** | **$48.65** | **$55.19** | **$73.26** | **$18.07** | **32.7%** |
| IPA Compensation | 44.40 | 49.82 | 63.65 | 13.83 | 27.8% |
| IPA Per Diem | 2.99 | 3.91 | 5.46 | 1.55 | 39.6% |
| IPA Travel | 1.26 | 1.46 | 4.15 | 2.69 | 184.2% |
| **Program Related Administration** | **$99.72** | **$94.18** | **$113.87** | **$19.69** | **20.9%** |
| Program Related Technology | 97.31 | 87.73 | 107.42 | 19.69 | 22.4% |
| Other Program Related Administration | 2.41 | 6.45 | 6.45 | - | - |
| **Other Organizational Excellence Activities** | **$13.26** | **$11.59** | **$18.74** | **$7.15** | **61.7%** |
| Analysis, Modeling, and Forecasting | - | - | 3.00 | 3.00 | N/A |
| Evaluation and Assessment Capability | 5.29 | 5.00 | 7.00 | 2.00 | 40.0% |
| Major Facilities Admin Review and Audit | 0.80 | 2.34 | 0.99 | -1.35 | -57.7% |
| Planning and Policy Support | 4.72 | 2.50 | 3.00 | 0.50 | 20.0% |
| Research Resources - Public Access | 2.45 | 1.75 | 3.75 | 2.00 | 114.3% |
| Research Security Strategy and Policy | - | - | 1.00 | 1.00 | N/A |
| **Total** | **$161.63** | **$160.96** | **$205.87** | **$44.91** | **27.9%** |

## AOAM by Object Class

**AOAM by Object Class**
(Dollars in Thousands)

| | FY 2020 Actual | FY 2020 CARES Act Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|---|
| Personnel Compensation | $189,034 | $205 | $202,579 | $233,118 | $30,539 | 15.1% |
| Personnel Benefits | 60,439 | | 66,207 | 78,690 | 12,483 | 18.9% |
| Travel and Transportation of Persons | 2,724 | | 3,667 | 8,510 | 4,843 | 132.1% |
| Transportation of Things | 684 | | 288 | 424 | 136 | 47.2% |
| Rental Payments to GSA | 24,028 | | 23,670 | 25,932 | 2,262 | 9.6% |
| Rental Payments to Others | 56 | | 220 | 554 | 334 | 151.8% |
| Communications, Utilities and Misc. Charges | 1,391 | | 1,274 | 3,051 | 1,777 | 139.5% |
| Printing and Reproduction | 73 | | 599 | 882 | 283 | 47.2% |
| Advisory and Assistance Services | 39,668 | 303 | 48,876 | 65,266 | 16,390 | 33.5% |
| Other Services | 17,675 | | 18,432 | 34,736 | 16,304 | 88.5% |
| Purchases of Goods & Srvcs from Gov't. Accts | 7,758 | 129 | 6,006 | 11,563 | 5,557 | 92.5% |
| Operations and Maintenance of Equipment | 63 | | 49 | 72 | 23 | 46.9% |
| Supplies and Materials | 717 | 363 | 852 | 1,153 | 301 | 35.3% |
| Equipment | 3,272 | | 2,206 | 4,349 | 2,143 | 97.1% |
| **Total** | **$347,583** | **$1,000** | **$374,925** | **$468,300** | **$93,375** | **24.9%** |

**Personnel Compensation and Benefits:** Personnel compensation funds payroll, awards/bonuses, reimbursable details to NSF, overtime, and terminal leave. Personnel Benefits include the Government's contribution towards retirement systems, health and life insurance, thrift saving plans, special overseas allowances, unemployment insurance, transit subsidies, and employee relocations.

**Travel and Transportation of Persons:** These resources fund travel required for planning, outreach, and the increased oversight of existing awards recommended by the agency's Inspector General.

**Transportation of Things:** This category consists of household moves associated with bringing new staff to NSF.

**Rental Payments to GSA:** This category includes the rent charged by GSA for NSF's facility in Alexandria, Virginia.

**Rental Payments to Others:** This category includes rent paid for the parking structure to the owner of the new headquarters building in Alexandria.

**Communications, Utilities, and Miscellaneous Charges:** This category includes all costs for telephone and other communication lines and services, both local and long distance, and postage.

**Printing and Reproduction:** This category includes contract costs of composition and printing of NSF's publications, announcements, and forms, as well as printing of stationery and specialty items.

**Advisory and Assistance Services:** This category includes development, learning, and career enhancement opportunities offered through the NSF Academy; contracts for human capital operational activities, work life initiatives, outreach, and related services; assistance in award oversight and monitoring; and support for OMB Circular A-123 reviews.

**Other Services:** This category includes warehousing and supply services, mail handling, 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.

**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; $~~345,640,000~~468,300,000: *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 2022 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 2020 Appropriation | $337.90 | $0.15 | -$9.20 | -$0.12 | $19.85 | $348.58 |
| FY 2021 Estimated | 345.64 | 9.20 | | | 29.29 | 384.13 |
| FY 2022 Request | 468.30 | | | | | 468.30 |
| $ Change from FY 2021 Estimated | | | | | | $84.17 |
| % Change from FY 2021 Estimated | | | | | | 21.9% |

## Explanation of Carryover

Within the Agency Operations and Award Management (AOAM) account, $9.20 million ($9.06 million in two-year funds and $146,425 in recovered no-year funds) is estimated for carryover into FY 2021.

- Amount: $9.06 million
- Purpose: To complete procurement actions in process that were not able to be completed in FY 2020 and other balances due to actual expenses coming in lower than anticipated due to operational limitations related to COVID-19 including limited travel in FY 2020.
- Obligation: FY 2021 Quarter 1-2 and Anticipated FY 2021 Quarter 3-4

NSF Headquarters Relocation

- Amount: $146,245
- Purpose: Budget contingency funding not obligated in FY 2020. Funds will be used towards the cost of the SCIF project.
- Obligation: FY 2021 Quarter 1-2 and Anticipated FY 2021 Quarter 3-4

## HUMAN CAPITAL

**$396,080,000**
**+$60,030,000 / 17.9%**

**Human Capital**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent | Funding Source |
|---|---|---|---|---|---|---|
| Personnel Compensation & Benefits | $256.35 | $272.98 | $311.81 | $38.83 | 14.2% | AOAM/ACRs |
| Management of Human Capital | 7.11 | 9.33 | 15.16 | 5.83 | 62.4% | AOAM |
| IPA Compensation and Per Diem[1] | 47.39 | 53.73 | 69.11 | 15.38 | 28.6% | R&RA/EHR |
| **Total, Human Capital** | **$310.85** | **$336.05** | **$396.08** | **$60.03** | **17.9%** | |
| Total AOAM | 257.32 | 278.13 | 326.97 | 48.84 | 17.6% | |
| Total ACRs | 6.14 | 4.19 | - | -4.19 | -100.0% | |
| Total R&RA | 41.86 | 48.02 | 60.93 | 12.91 | 26.9% | |
| Total EHR | 5.53 | 5.71 | 8.18 | 2.47 | 43.3% | |

[1] 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 56 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 EHR.

The use of IPAs and VSEEs, together commonly referred to as rotators, has been a defining characteristic of NSF since its inception in 1950, as it gives NSF a direct connection to the researchers and educators working at the frontiers of science and engineering. VSEEs count as regular federal FTE and are included in the regular AOAM FTE totals. IPAs are not included in the regular AOAM FTE totals.

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 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| Regular FTE Usage (projected) | 1,314 | 1,330 | 1,430 | 100 | 7.5% |
| Student FTE Usage (projected) | 20 | 42 | 42 | - | - |
| Regular FTE Base Salary[1] | $190.13 | $195.34 | $219.54 | $24.21 | 12.4% |
| Student Salary | 0.92 | 2.01 | 2.16 | 0.15 | 7.4% |
| Other Compensation[2] | 1.93 | 2.60 | 2.78 | 0.18 | 6.9% |
| Awards | 2.41 | 7.32 | 8.64 | 1.32 | 18.0% |
| **Subtotal, FTE Compensation** | **$195.40** | **$207.26** | **$233.12** | **$25.86** | **12.5%** |
| Benefits | 59.52 | 65.18 | 77.42 | 12.24 | 18.8% |
| Other Benefits[3] | 1.43 | 0.54 | 1.27 | 0.73 | 134.6% |
| **Subtotal, Benefits** | **$60.95** | **$65.72** | **$78.69** | **$12.97** | **19.7%** |
| **Total, PC&B** | **$256.35** | **$272.98** | **$311.81** | **$38.83** | **14.2%** |
| **Source of Funds** | | | | | |
| AOAM Appropriation | $250.21 | $268.79 | $311.81 | $43.02 | 16.0% |
| Administrative Cost Recoveries[4] | 6.14 | 4.19 | - | -4.19 | -100.0% |
| **Total** | **$256.35** | **$272.98** | **$311.81** | **$38.83** | **14.2%** |

[1] Includes full support for a 2.7 percent COLA in FY 2022 ($5.88 million).

[2] Includes reimbursable details to NSF and terminal leave.

[3] Includes Federal Employee's Compensation Act (FECA) funding and transit subsidies.

[4] The ACR level for FY 2021 is estimated based on amount received in FY 2019.

The FY 2022 Request for PC&B is $311.81 million. While FY 2020 and 2021 funding for PC&B reflects funding from two sources, AOAM appropriated funds and ACRs received during the year, FY 2022 funding includes AOAM appropriated funds only; no ACRs are factored into NSF's Organizational Excellence budget plans for the FY 2022 Request.

The FY 2022 PC&B cost estimate will support the projected year-end usage of 1,430 regular FTE employees, a total of 42 Pathways intern FTE, associated cost of benefits, general workforce performance awards (GWFPA), and Senior Executive Service (SES) bonuses. The increased level of FTE is required for NSF to achieve the program objectives set forth by the Director in the FY 2022 Request, including establishing a new directorate and growing agency administration, operations, and technical support commensurate with a $10 billion federal research agency. This estimate includes funding to cover a Cost of Living Adjustment in FY 2022 of 2.7 percent. The FY 2022 Request for PC&B also contains approximately $920,000 for the Federal Transit Benefits Program. In total, NSF believes this PC&B estimate presents a realistic estimate of these costs in FY 2022 and, if appropriated 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 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| *NSF AOAM FTE Allocation* | | | | | |
| NSF AOAM -- Regular | 1,315 | 1,330 | 1,430 | 100 | 8% |
| NSF AOAM -- Pathways Intern | 39 | 42 | 42 | - | - |
| **Subtotal, FTE Allocation** | **1,354** | **1,372** | **1,472** | **100** | **7%** |
| *NSF AOAM FTE Usage* | | | | | |
| NSF AOAM -- Regular | 1,314 | 1,330 | 1,430 | 100 | 7.5% |
| NSF AOAM -- Pathways Intern | 20 | 42 | 42 | - | - |
| **Subtotal, FTE Usage** | **1,333** | **1,372** | **1,472** | **100** | **7.3%** |
| Detailees to NSF | 3 | 3 | 3 | - | - |
| **Total** | **1,336** | **$1,375** | **1,475** | **100** | **7.3%** |

NSF's FY 2022 FTE allocation is 1,472. The FY 2022 FTE estimated usage is 1,430 regular and 42 Pathways FTE. This is an increase over the FY 2021 Estimate of 100 regular FTE reflecting the creation of the new directorate and a growth in the number of federal staff FTE commensurate with the growth in the total NSF Request.

**Management of Human Capital**

**Management of Human Capital**
(Dollars in Millions)

| FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|
| **$7.11** | **$9.33** | **$15.16** | **$5.83** | **62.4%** |

The FY 2022 Request for Management of Human Capital is $15.16 million. This funding level will enable NSF to grow operational support activities, learning and development programs essential for NSF's permanent and rotator staff, and contractual support for human capital initiatives as the agency grows and establishes a new directorate. Further, the increased funding level will provide for new strategic human capital management activities supportive of a post-COVID work environment. FY 2022 investments support the following activities:

Learning and Development Programs ($4.48 million, +$1.90 million above the FY 2021 Estimate)
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. The FY 2022 Request level will increase contractor support for learning and development activities associated with the expansion of NSF and the establishment of the new directorate, as well as NSF's establishment of an agency wide hybrid

work model. In addition, in FY 2022, NSF will support the implementation of a pilot Summer Leadership Institute, which will target new IPAs coming to NSF. This pilot program is intended to provide the new IPAs with the skills and knowledge they will need to be successful upon arrival at NSF. The FY 2022 Request also includes funding to support talent teams, to identify assessments which are appropriate for NSF, and to improve internships and Pathways Programs.

<u>Operations Support ($4.10 million, +1.26 million above the FY 2021 Estimate)</u>
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. The FY 2022 funding level is guided by costs associated with these employee-driven human capital activities and NSF anticipates requirements for additional contractor support in the recruiting, hiring and onboarding of FTE associated with the expansion of NSF and the establishment of the new directorate. Also included within the FY 2022 Request is funding and plans for NSF to implement a student loan repayment program to aid with employee recruitment and retention.

<u>Strategic Human Capital Support ($3.58 million, +$1.86 million above the FY 2021 Estimate)</u>
NSF relies on strategic human capital support contracts for assistance in developing new approaches to critical human resource needs, including those identified and highlighted in NSF's Strategic Plan, Strategic Goal 3: Enhance NSF's performance of its mission, Strategic Objective 1: Human Capital - Attract, retain, and empower a talented and diverse workforce. FY 2022 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. The increased funding level will provide additional contractor support for strategic human capital initiatives associated with the expansion of NSF and the establishment of the new directorate. The additional investment is also part of a larger initiative across NSF to enable data-driven decision-making regarding FTE management.

<u>Workplace and Work-Life Support ($2.07 million, +$730,000 above the FY 2021 Estimate)</u>
The Workplace and Work-Life Support investment is focused on helping NSF's employees by providing health and family-friendly programs and activities, including the health unit, employee assistance program, and childcare subsidy. The increase for this investment will allow the agency to expand services in support of NSF's health, wellness, and work-life programs and activities that will meet the needs and demands of the larger agency in FY 2022.

<u>Human Resource Systems and Shared Services ($930,000, +$76,000 above the FY 2021 Estimate)</u>
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 2022 funding reflects the rising costs of the Interior Business Center's (IBC) shared services support for various critical personnel management systems. The FY 2022 increase will also allow for the established use of IBC's prospective candidate qualifications assessment Shared Services that will support NSF's compliance with OMB's guidance on improving the assessment process for new hires.

**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. As part of the continuing effort to enhance the administration of temporary personnel at NSF under the IPA program, in FY 2017, NSF piloted a required 10 percent cost share of the IPA's base salary and fringe benefits for all new IPA agreements.

After a successful pilot period, in FY 2020, NSF implemented the required cost share as policy effective January 31, 2020, requiring that institutions provide a minimum of 10 percent cost share for every full-time IPA agreement.[1] Total cost share increased by over $1 million between FY 2019 and FY 2020, with the percent of assignments that cost share near 90 percent. The cost share mechanism continues to maximize taxpayer value.

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 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| IPA FTE Allocation[1] | 198 | 205 | 255 | 50 | 24.4% |
| IPA FTE Usage (Actual/Projected)[1] | 177 | 198 | 255 | 57 | 28.5% |
| Research and Related Activities (R&RA) | | | | | |
| IPA Compensation | $39.23 | $44.49 | $56.25 | $11.76 | 26.4% |
| IPA Per Diem | 2.63 | 3.53 | 4.68 | 1.15 | 32.6% |
| **Subtotal, R&RA Costs** | **$41.86** | **$48.02** | **$60.93** | **$12.91** | **26.9%** |
| Education and Human Resources (EHR) | | | | | |
| IPA Compensation | 5.17 | 5.33 | 7.40 | 2.07 | 38.8% |
| IPA Per Diem | 0.37 | 0.38 | 0.78 | 0.40 | 105.3% |
| **Subtotal, EHR Costs** | **$5.53** | **$5.71** | **$8.18** | **$2.47** | **43.3%** |
| **Total[1]** | **$47.39** | **$53.73** | **$69.11** | **$15.38** | **28.6%** |

[1] IPA FTE of approximately one in FY 2020, FY 2021, and FY 2022 are included in the IPA FTE 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 2022 funding for IPA compensation and per diem costs are associated with full use of NSF's IPA FTE allocation for FY 2022. The FY 2022 IPA FTE allocation increases 50 IPA FTE over the FY 2021 Estimate reflecting the creation of the new directorate and a growth in the number of IPA FTE commensurate with the growth in the total NSF Request. Cost increases 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. For both R&RA and EHR, per IPA FTE costs in FY 2022 are estimated using amounts commensurate with current FY 2021 levels projected into FY 2022.

Information on costs associated with travel for NSF's IPAs is found within the Travel section of this chapter.

[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.

**TRAVEL** **$12,660,000**
**+$7,530,000 / 146.9%**

**NSF Travel**
(Dollars in Millions)

| | FY 2020 Actual[1] | FY 2021 Estimate[1] | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent | Funding Source |
|---|---|---|---|---|---|---|
| NSF Federal Employee Staff | $2.69 | $3.67 | $8.51 | $4.84 | 132.1% | AOAM |
| IPA Appointments | 1.26 | 1.46 | 4.15 | 2.69 | 184.2% | R&RA/EHR |
| **Total Travel** | **$3.95** | **$5.13** | **$12.66** | **$7.53** | **146.9%** | |
| Total AOAM | 2.69 | 3.67 | 8.51 | 4.84 | 132.1% | |
| R&RA | 1.14 | 1.33 | 3.81 | 2.48 | 186.5% | |
| EHR | 0.12 | 0.13 | 0.34 | 0.21 | 161.5% | |

[1] FY 2020 and FY 2021 funding for Federal Employee Staff and IPA travel is lower than normal due to travel restrictions related to COVID-19.

The FY 2022 Request level for staff and IPA travel is $12.66 million. NSF employee travel accounts for about 67 percent of this total and is provided from the AOAM account. Travel for IPA appointments, which is supported by the R&RA and EHR accounts, is the remaining 33 percent.

As part of the extensive review of the agency's operational and administrative needs used to develop the FY 2022 budget request, NSF analyzed historical travel data and projected estimated travel costs related to the amount of program activities anticipated at the FY 2022 Request level for NSF. In addition, travel restrictions in place for FY 2020 and FY 2021 due to the COVID-19 pandemic were considered to be no longer in place in FY 2022 in the formulation of NSF's FY 2022 travel budget request.

**NSF Employee Travel**

FY 2022 funding for NSF employee FTE travel is estimated at $8.51 million. NSF employee FTE travel is based on the travel activity associated with utilization of 1,430 regular FTE. It includes travel-related funding for training, site reviews, outreach activities, and post-award monitoring and oversight.

**IPA Travel**

The FY 2022 funding for IPA travel is $4.15 million representing an IPA usage level of 255 full-time equivalent (FTE) IPAs. 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

**+$27,380,000 / 24.4%**

NSF's FY 2022 Request level for IT investments total $139.39 million. Funding for NSF's IT investment is provided from the AOAM, R&RA, and EHR accounts. It is the second largest component of the Organizational Excellence portfolio, accounting for 20 percent of the total.

### NSF IT Portfolio Investments by Appropriation

**NSF IT Portfolio Investments by Appropriation**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent | Funding Source |
|---|---|---|---|---|---|---|
| Agency Operations & Award | $24.19 | $24.28 | $31.97 | $7.69 | 31.7% | AOAM |
| Program Related Technology (PRT) | 97.31 | 87.73 | 107.42 | 19.69 | 22.4% | R&RA/EHR |
| **Total** | **$121.50** | **$112.01** | **$139.39** | **$27.38** | **24.4%** | |
| Total AOAM | 24.19 | 24.28 | 31.97 | 7.69 | 31.7% | |
| Total R&RA | 85.08 | 76.47 | 92.18 | 15.71 | 20.5% | |
| Total EHR | 12.23 | 11.26 | 15.24 | 3.98 | 35.3% | |

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 (23 percent) of NSF's total IT investment at the FY 2022 Request level.

Program Related Technology (PRT) investments support NSF's programmatic activities and associated services and are funded through the R&RA and EHR accounts. PRT investments are mission-related IT 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 (77 percent) of NSF's FY 2022 Request for IT investments.

For FY 2022, funding for NSF's IT portfolio increases $27.38 million to support current and emerging business practice and organizational changes needed to establish and support the new Translation, Innovation, and Partnership directorate, implement the agency's response to COVID-19 as NSF transitions to a hybrid physical/remote workforce, and acquire, deploy, and secure the systems and technology needed to support the overall increase in NSF's mission. These factors necessitate changes to legacy systems and implementation of new applications, expansion of IT security and infrastructure capabilities, and support for new, innovative uses of tools and commercial off the shelf (COTS) products to provide capabilities. Advances supported by this request 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. Within the full FY 2022 Request, development and modernization efforts will continue, 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 data analysis tools to support NSF's mission;
- Employ innovative and advanced technology capabilities in support of agency priorities, 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;
- 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 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent | Funding Source |
|---|---|---|---|---|---|---|
| Administrative Applications Services & Support | $6.86 | $6.91 | $7.91 | $1.00 | 14.4% | AOAM |
| Mission Related Applications & Services | 60.42 | 55.93 | 68.72 | 12.79 | 22.9% | PRT |
| IT Operations & Infrastructure | 43.29 | 38.68 | 48.97 | 10.29 | 26.6% | AOAM/PRT |
| Security & Privacy Services | 8.18 | 7.97 | 11.01 | 3.04 | 38.1% | AOAM/PRT |
| IT Management | 2.75 | 2.52 | 2.78 | 0.26 | 10.5% | AOAM/PRT |
| **Total** | **$121.50** | **$112.01** | **$139.39** | **$27.39** | **24.4%** | |

<u>Administrative Applications Services and Support ($7.91 million, +$1.0 million above the FY 2021 Estimate: AOAM only)</u>

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 EHR accounts and 30 percent will be funded by the AOAM account. The AOAM portion of the FY 2022 funding supports ongoing operations and maintenance of the system, updates and enhancements to support intragovernmental transactions, as well as initial planning for the next generation of iTRAK.

- Other administrative applications services which provide for operations and maintenance of agency administrative and collaboration tools, such as the NSF website. FY 2022 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.
- Continued 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 in alignment with NSF’s Strategic Goal 3: Enhance NSF’s performance of its mission, Strategic Objective 1: Human Capital - Attract, retain, and empower a talented and diverse workforce. Funding in FY 2022 will support operations for the agency's core human capital management systems as the agency continues to invest in new capabilities and expand services to accommodate the growing workforce.

<u>Mission-Related Applications and Services ($68.72 million, +$12.79 million above the FY 2021 Estimate: 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 2022, additional costs are expected in this area, as long-term investments in Program Management Efficiencies (PME) and Website Modernization begin to move into production and will require operational support and maintenance.
  - Continuous modernization of systems and services that support the merit review process. FY 2022 efforts will continue to prioritize modernization of public-facing digital services. Specific investments include:
    - PME: This investment prioritizes the continuous modernization of citizen-facing services and data cleanup activities, including retirement of legacy technologies. In FY 2022, this initiative will focus on continued decommissioning of legacy proposal submission functions as new efforts shift to the Intelligent Automation of Grants Management Systems investment area.
    - 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. FY 2022 investments will focus on improving integration across funding and award information to help researchers identify programs and potential collaborators to enhance their proposal submissions.
    - 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 2022 efforts will extend access to federally funded reports and metadata, and pilot access to the federated cross-agency repository.
    - Intelligent Automation of Grants Management Systems: A new initiative beginning in FY 2021, this investment provides for enhancements to IT systems/applications that support the grants management lifecycle, including those related to the PME investment. Investments aligned to this initiative in FY 2022 will include efforts related to consolidation of NSF's external portals; modernization of internal applications that support the merit review process, and enhancements related to NSF's identity management capabilities and services. FY 2022

    investments will also include technology support for efforts related to NSF operational changes, with particular focus on features and functionality that will support emerging funding and award types as well as new mechanisms for collection, use, and publication of award data.
  - Improve Service Delivery: This is a new investment area for FY 2022 focusing on tools to enhance IT service delivery, potentially including enhancements to agency collaboration tools and services, such as distributed video conferencing capabilities, whiteboarding technologies, and use of smart vending machines to innovate IT support services.
  - Interactive Panel Systems (IPS) Replacement: A modernization effort continuing from FY 2021 to replace the current interactive panel system, which provides reviewers an application for collaborating with fellow panelists to review and rank proposals and recommend the proposals deemed most meritorious.
  - Innovation Management: Continues the adoption and implementation of advanced tools and technologies to support the renewed merit review process. Specifically, FY 2022 funding will further 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.
- 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 2022 funding includes investments in services and systems to centralize and streamline access to NSF data, including enhancements to the infrastructure that supports data analysis activities; enabling data-driven decision-making by expanding analytical and visualization capabilities; leveraging artificial intelligence and new technologies; and further maturing data management and delivery services. In addition, support is provided for evidence-based data-driven decision making by providing advanced analytics capabilities, such as the NSF By the Numbers Dashboard.
- 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 implementation of Unique Entity Identifier (UEI) requirements. FY 2022 efforts will also focus on enhancements to post-award merit review functions.
- Human Resource System Modernization: This is the continuation of a new investment for FY 2021 that will modernize and enhance core agency systems for strategic management of human capital and administrative resource management, including systems for Intergovernmental Personnel Act (IPA) management and performance management, as well as implement the upcoming payroll mandate, NewPay.

<u>IT Operations and Infrastructure ($48.97 million, +$10.29 million above the FY 2021 Estimate: $18.97 million in AOAM, $30.0 million in PRT)</u>
The FY 2022 Request reflects NSF's ongoing enhancements to agency capabilities related to network, infrastructure, data center, customer support, and database administration. The increase reflects NSF's continued investment in technologies and capabilities to support NSF's post-COVID work environment, including an ongoing focus on remote work. It is anticipated that future increases in staff will create an additional need for licenses, technical support services, and tools across the infrastructure investments. 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 2022 funding supports improvements to the agency's secure remote access capabilities and increased network bandwidth to facilitate NSF's ability to sustain remote operations. This investment also includes 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 2022 funding will support continued cloud migrations to increase resilience of IT services and applications and improve speed of deployment. NSF anticipates increasing costs in cloud contracts as the agency's presence in the cloud increases. It is also likely that as cloud migrations continue, some applications may have to be refactored or modified to run effectively in the cloud. All services will have to be replicated to maintain 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 the Space Rental 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 2022 funding in this area supports continuing improvements to service delivery, including expanded use of tools to diagnose and remediate IT issues and to deploy new technology capabilities to NSF staff and customers who are working remotely. As NSF proceeds to modernize to meet mission objectives, additional expenditures in this area are expected in order to expand conferencing capabilities in executive offices, team rooms, and conference rooms to support a larger and more geographically diverse hybrid workforce.
- Platform: Reflects NSF's use, management, and acquisition of hyper-converged hardware, software, and services. In FY 2022, NSF is working to migrate existing databases to the cloud, or potentially re-platforming onto a new database standard at some point in the future.
- 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 further in that section of the Administrative Support narrative.

<u>Security and Privacy Services ($11.01 million, +$3.04 million over the FY 2021 Estimate: $4.51 million in AOAM, $6.50 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 2022 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 modernize NSF's High Value Assets (HVAs) as warranted, and to expand assessment, authorization, and security monitoring activities as the agency continues to invest in new IT capabilities aligned with mission and organizational change. In the wake of recent high-profile, government-wide security issues, NSF anticipates additional investment 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. In FY 2022, NSF will be continuously assessing growth in systems and users and evaluating new tools and services, including new cloud security tools, as well as expanded security scanning and monitoring and data loss prevention technologies, that can help 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; and activities related to cybersecurity assessment and authorization, including supply chain risk management.

IT Management ($2.78 million, +$260,000 above the FY 2021 Estimate: $583,000 in AOAM, $2.20 million in PRT)
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 2022, 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 intends to begin 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 $6.77 million of non-central IT costs that are being actively tracked and are included in the FY 2022 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, EHR 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 2021 and FY 2022 levels are consistent with the funding amounts provided by the initiatives' respective managing partners.

**NSF FY 2021 Request Funding for E-Government Initiatives**

| | FY 2021 | | | Appropriations Account | |
|---|---|---|---|---|---|
| Initiative | Agency Contributions | Agency Svc. Fees | NSF Total | AOAM | R&RA |
| Grants.gov | $323,000 | - | $323,000 | - | $323,000 |
| Geospatial LoB | 25,000 | - | 25,000 | - | 25,000 |
| E-Rulemaking | - | 17,253 | 17,253 | 17,253 | - |
| 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 |
| Financial Management LoB | 139,094 | - | 139,094 | - | 139,094 |
| Budget Formulation/Execution LoB | 120,000 | - | 120,000 | - | 120,000 |
| **Total** | **$675,572** | **$747,296** | **$1,422,868** | **$48,652** | **$1,374,216** |

LoB: Line of Business

**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

**ADMINISTRATIVE SUPPORT** **$126,040,000**
**+$39,150,000 / 45.0%**

FY 2022 funding for Administrative Support is $126.04 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 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent | Funding Source |
|---|---|---|---|---|---|---|
| Space Rental | $29.69 | $30.81 | $32.27 | $1.46 | 4.7% | AOAM |
| Operating Expenses | 18.68 | 21.63 | 41.69 | 20.06 | 92.8% | AOAM |
| Building & Administrative Services | 15.01 | 16.42 | 26.89 | 10.47 | 63.8% | AOAM |
| Other Program Related Administration | 2.41 | 6.45 | 6.45 | - | - | R&RA/EHR |
| Other Organizational Excellence Activities | 13.26 | 11.59 | 18.74 | 7.15 | 61.7% | R&RA |
| **Total Administrative Support** | **$79.05** | **$86.90** | **$126.04** | **$39.15** | **45.0%** | |
| Total AOAM | 63.38 | 68.86 | 100.85 | 32.00 | 46.5% | |
| Total R&RA | 15.67 | 17.21 | 24.27 | 7.06 | 41.0% | |
| Total EHR | - | 0.83 | 0.92 | 0.09 | 10.8% | |

Each activity within Administrative Support is addressed separately below.

**Space Rental**

**Space Rental**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| Building Rental & Taxes | $23.31 | $23.14 | $25.38 | $2.24 | 9.7% |
| Utilities | 0.87 | 1.44 | 1.10 | -0.34 | -23.8% |
| Security | 4.79 | 5.70 | 5.24 | -0.46 | -8.0% |
| Parking Rental (including parking credits) | 0.72 | 0.53 | 0.55 | 0.02 | 3.7% |
| **Total** | **$29.69** | **$30.81** | **$32.27** | **$1.46** | **4.7%** |

Space Rental includes services provided by the General Services Administration (GSA) related to rent and taxes, utilities, and security provided by the Department of Homeland Security. In addition, rent paid for the parking structure to the owner of the NSF headquarters building in Alexandria is included. Parking credit estimates are applied to the FY 2022 Request level.

In FY 2022, NSF will occupy over 700,000 square feet of space, primarily in one leased office building located in Alexandria, Virginia. The FY 2022 Request for Space Rental is $32.27 million, an increase of $1.46 million above the FY 2021 Estimate. 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 anticipated to be applied to the lease and are offset by estimated decreases in utilities and security. Utilities and security cost estimates are derived from historical billing and cost per square foot calculations provided by agency partners, with adjustments for inflation.

IT expenditures related to NSF's on-site Information Technology Data Center are included in the total FY 2022 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 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| Distributed | $7.90 | $8.03 | $13.08 | $5.05 | 62.9% |
| Establish New Directorate | - | - | 5.00 | 5.00 | N/A |
| Science & Security | - | - | 5.00 | 5.00 | N/A |
| Award Monitoring | 4.82 | 5.29 | 7.32 | 2.03 | 38.4% |
| Financial Management | 3.78 | 2.84 | 5.22 | 2.38 | 83.8% |
| Reporting & Other | 2.17 | 4.47 | 5.07 | 0.60 | 13.4% |
| Renewing NSF | - | 1.00 | 1.00 | - | - |
| **Total** | **$18.68** | **$21.63** | **$41.69** | **$20.06** | **92.7%** |

The FY 2022 Request for Operating Expenses is $41.69 million. NSF's Operating Expenses can be categorized into seven main activity areas that support the agency's operational and administrative needs and includes funding for supplies and equipment; the costs necessary to expand NSF's ability to accomplish its research and education mission; 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 to sustain current services levels in FY 2022, and expand beyond current services where appropriate, for critical business and operations activities to support scale up operations for a $10 billion agency, including all the attendant requirements necessary to establish the new directorate for Technology, Innovation, and Partnerships, and continuing and additional activities supportive of a post-COVID work environment.

The key activities funded by NSF's FY 2022 Request for Operating Expenses include:

<u>Distributed ($13.08 million, +$5.05 million above the FY 2021 Estimate)</u>
Distributed AOAM funds training, equipment, communications devices, and supplies for NSF's directorates and offices. This increased funding level allows NSF to fully support a regular FTE usage of 1,430 projected for FY 2022. This is consistent with the scale up of operations for a $10 billion agency, including establishment of the new directorate, and activities supportive of post pandemic operations.

<u>Establish New Directorate ($5.0 million, +$5.0 million above the FY 2021 Estimate)</u>
The creation of a new directorate for Technology, Innovation, and Partnerships will allow the agency to continue to support innovation across all disciplines of science and engineering, at the speed that is required in today's rapidly changing landscape, and to harness the amazing technological opportunities to produce another seven decades of amazing innovations. NSF is requesting $5.0 million in AOAM in FY 2022 to

stand up the new directorate. This includes modifying the full suite of NSF's systems to create the new organization, migrate activities from existing organizations to the new one, and establish new policies and procedures across all NSF operations activities. NSF also expects its partnerships with private industry to increase, and those partnerships will be more complex than those that are bounded within federal agencies. While NSF currently already does some of these, they will become a larger part of the portfolio both in terms of forming the partnerships, managing the awards, and in maintaining oversight.

<u>Science and Security ($5.0 million, +$5.0 million above the FY 2021 Estimate)</u>
This is a new FY 2022 investment for activities related to Science and Security. In March 2020 NSF created a new position of Chief of Research Security Strategy and Policy (CRSSP) as part of its continuing effort to ensure the security of federally funded research while maintaining open international collaboration. The CRSSP team was staffed through internal re-assignments of existing NSF personnel. In FY 2021 NSF plans to continue to refine the CRSSP team efforts and contractor support service capabilities. In FY 2022, NSF will build its 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. The hub will also provide critically important training and information for research communities on this topic. The 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. To ensure clear understanding of research security issues, and NSF disclosure requirements, as well as the tenets of beneficial international collaboration, the CRSSP team plans to develop training resources for its own program officers and grant management officials. The CRSSP team also plans to develop training resources for the external research community to ensure clear understanding of research security issues as well as recommended actions to mitigate risks.

<u>Award Monitoring ($7.32 million, +$2.03 million above the FY 2021 Estimate)</u>
This investment category supports activities related to award administration and stewardship of NSF's portfolio of STEM awards. Growth in FY 2022 supports the creation of the new directorate to include associated increases in areas such as award monitoring (pre and post) and small business pre-award reviews. In addition, increases are necessary to support mid-scale research infrastructure program monitoring and business system reviews to ensure NSF awardees are able to fulfill financial and related requirements. Activities supported under Award Monitoring include:

- Grant outreach, contract close-out, and oversight of major facilities including business systems reviews, portfolio risk assessment, NSF outreach activities and guidance document development. 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 American Innovation and Competitiveness Act (AICA).
- 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 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 which 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 ($5.22 million, +$2.38 million above the FY 2021 Estimate)
Investments in this category support NSF's financial policy and reporting activities. The FY 2022 Request will provide additional financial support as we increase the scale and complexity of our financial reporting model, transactions, and financial monitoring as NSF itself increases similarly. 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. Also provides enterprise risk management support for emerging mission risks such as long-term pandemic impacts related to grants oversight, monitoring, and improper payments.

Reporting and Other ($5.07 million, +$600,000 above the FY 2021 Estimate)
This investment category supports a wide range of reporting and other activities. The FY 2022 Request will provide additional support as our reporting models increase in scale and complexity; develop contract writing system requirements to include integration with accounting and business systems and address the increased need for data analytics. Investments in this category include activities such as:

- The Automated Acquisition Management Solution (AAMS), NSF’s system for contract writing/E-procurement. This investment includes licensing, subscription services, deskside support, and training of new users while NSF works through the procurement process for a new contract writing system to better meet mission needs.
- 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. Further, the requested funding level will enable NSF to better ensure Section 508 compliance and accessibility and provide for increased budget formulation capabilities beyond that which would be funded at a current services level.
- 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-wide implementation of changes associated the Program Management Improvement Accountability Act (PMIAA) and recommendations resulting from the Gap analysis conducted across FY 2020 and FY 2021.
- Unique Entity Identifier implementation activities to support the government-wide transition from using the DUNS number to uniquely identify entities registered in the System for Award Management (SAM) to do business with the federal government to using the SAM-generated unique entity identifier

(unique entity ID or UEI). The Office of Management and Budget (OMB) directed federal agencies to finalize their transition by April 2022.

- 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 several organizations for which NSF is the cognizant agency.
- Project management support to plan, coordinate, and execute NSF activities in connection with the Digital Accountability and Transparency Act responsibilities and operations.
- Support for 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; 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>Renewing NSF ($1.0 million, no change)</u>
In FY 2022, NSF will continue efforts focused on enhancing the performance of its mission through strategic and enterprise-wide activities, building on the momentum and success of the agency-wide reform and modernization effort, Renewing NSF (RNSF). Through support and coordination of diverse and broad-based actions, RNSF is pursuing a transformation of the agency into an organization that is even more agile and responsive to the 21st-century scientific, engineering, and education enterprise. These investments will in turn allow the agency to maintain U.S. leadership in research and education across all areas of STEM. This effort is aligned with NSF's strong culture and commitment toward innovation and continuous organizational improvement. Given the demonstrated success of RNSF to date, NSF plans to transition toward a new capacity to promote and implement enterprise-scale adaptation and innovation, allowing the agency to continuously meet evolving challenges and opportunities. Through FY 2021 and FY 2022, NSF plans to continue to coordinate RNSF activities across the agency in order to drive further progress on and implementation of efforts that will catalyze enterprise-scale organizational adaptation and advance the transformative vision of a renewed NSF. While those efforts continue, the agency will also pursue a transition from RNSF to a longer-term, sustainable enterprise excellence capacity that will secure the benefits of coordinated, future-focused, continuous organizational adaptation beyond the initial effort. This transition will establish a robust, scalable mechanism to support and facilitate cross-cutting change activities, both those already surfaced in RNSF as well as those readily responsive to the potential future illustrated in the NSB’s Vision 2030 report.

**Building and Administrative Services**

**Building and Administrative Services**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| Information Dissemination | $1.95 | $2.13 | $3.38 | $1.26 | 59.2% |
| Workplace Management | 8.51 | 8.64 | 14.38 | 5.74 | 66.4% |
| Panel Support, Meeting Management, & Proposal Services | 4.56 | 5.65 | 9.12 | 3.47 | 61.5% |
| **Total** | **$15.01** | **$16.42** | **$26.89** | **$10.47** | **63.8%** |

The FY 2022 Request for building and administrative services is $26.89 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. The $10.47 million increase over the FY 2021 Estimate will help establish the new directorate; scale up operations for a $10 billion research agency; and modify facility infrastructure and activities to support a post-COVID work environment to include increased telework and remote work.

Also included is $1.30 million for zero emission vehicle (ZEV—battery electric, plug-in electric hybrid, and hydrogen fuel cell vehicles) acquisitions and deploying necessary vehicle charging and refueling infrastructure in support of the President's goal of transitioning to a fully Zero Emission Vehicle Federal fleet. These acquisitions are a significant step towards eliminating tailpipe emissions of greenhouse gases (GHG) from NSF's fleet and aligning NSF's fleet operations with the goal of achieving a fully ZEV federal fleet. This action is important because tailpipe emissions are currently the leading source of GHG emissions that threaten the planet and harm U.S. communities. NSF is coordinating all of these efforts to meet or exceed the ZEV-related goals set forth in the comprehensive plan developed pursuant to E.O. 14008, Section 205(a). Funds for NSF's ZEV activities are part of a $600 million request in the President's Budget for ZEVs and charging infrastructure that is contained within the individual budgets of 18 Federal agencies, including ZEV Federal fleet dedicated funds at the General Services Administration. This investment will be complemented by Department of Energy funding to provide technical assistance to agencies through the Federal Energy Management Program as NSF builds and grows its ZEV infrastructure. This investment serves as a down payment to support a multiyear, whole-of-government transformation to convert the Federal motor vehicle fleet to ZEVs and thereby reduce carbon emissions.

The FY 2022 funding level for building and administrative services reinforces NSF's commitment to organizational excellence and reflects NSF's prioritization of sustaining current services levels in FY 2022, and expanding beyond current services where appropriate, for critical business and operations activities.

<u>Information Dissemination ($3.38 million, +$1.26 million above the FY 2021 Estimate)</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. The FY 2022 Request provides additional resources for these investments supporting the full estimated cost necessary to manage workload requirements and maintain services for the larger agency size. 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. NSF is on track to comply with the M-19-21 Directive, Transition to Electronic Records. Further, the requested funding level will enable operations and maintenance of controlled unclassified information (CUI) marking in IT systems.
- 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.
- An organizational assessment study, to be initiated in FY 2022, to identify skill gaps and develop strategies to mitigate operational gaps within the Division of Administrative Services (DAS).

Workplace Management ($14.38 million, +$5.74 million above the FY 2021 Estimate)
Workplace Management provides funding for a wide range of core business activities and infrastructure support related to space management and facility operations; property management, including ZEVs; as well as security and emergency management. Increased funding is necessary in FY 2022 to fully support the agency at its increased capacity and in alignment with its post pandemic posture. 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. In alignment with NSF's future objectives and hybrid workforce initiative, the FY 2022 Request includes cost estimates for a phased building re-stacking and renovation initiative, office move support, and additional facility management modules. Also included is improved cleaning of high traffic areas within the building and a furniture refresh of customer service areas.
- O&M for the Integrated Workplace Management System which supports space and workplace management to include conference room scheduling and asset inventory. FY 2022 funding will enable expanded business intelligence operations comprised of maintenance best practices and outlining the sustainability approach as well as implementation of a new room reservation system.
- Activities related to property—the oversight and planning of mailroom, shipping and receiving operations; and property receipt, inventory, and tracking.
- 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. The FY 2022 Request includes increased cost estimates related to maintenance and technical security requirements of NSF's new Sensitive Compartmented Information Facility (SCIF), operations and maintenance of a new Personnel Security Case Management System, and contractor support to process increased adjudications.

Panel Support, Meeting Management, and Proposal Services ($9.12 million, +$3.47 million above the FY 2021 Estimate)
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 2022 Request provides additional resources for these investments supporting the full estimated cost necessary to manage workload requirements and maintain services for the larger agency size. Activities include:

- Management and support of agency printing devices including copier and printer maintenance and supplies.
- Print Center services for FY 2022. 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. Resources necessary to initiate a library operations modernization effort are included in the FY 2022 Request.
- 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 2022 funding provides the resources necessary to schedule, coordinate, and conduct NSF's onsite and virtual meetings and panels in a post-COVID work environment and at a level appropriate for a $10 billion research agency. Included in the FY 2022 Request is funding to streamline NSF's meeting management operations.
- 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. The FY 2022 Request includes funding for enhancements to the interface between NSF's travel management system (Concur) and financial system (iTRAK).

- An Accessibility Maturity Roadmap. NSF is anticipating an increase of technology that must be 508 compliant and accessible for remote users that have accessibility requirements. The roadmap is critical to ensure delivery of NSF technology solutions that continue to be safe and accessible for people with disabilities.

**Other Program Related Administration**

**Other Program Related Administration**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| E-Government Initiatives | $1.37 | $1.37 | $1.44 | $0.07 | 5.1% |
| General Planning & Evaluation Activities | 1.04 | 5.08 | 5.01 | -0.07 | -1.4% |
| **Total** | **$2.41** | **$6.45** | **$6.45** | **-** | **-** |

In FY 2022, $6.45 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.

<u>E-Government Initiatives ($1.44 million, +$70,000 above the FY 2021 Estimate)</u>
The FY 2022 funding level for NSF program-supported and mission-related E-Government (E-Gov) initiatives is consistent with the FY 2022 funding amounts provided by the initiatives' respective managing partners. The FY 2022 funding level reflects an increase for Grants.gov and the addition of a new Line of Business (LoB) for Hiring Assessment. The remaining program-supported initiatives (Geospatial LoB, Integrated Acquisition Environment, Human Resources LoB, Financial Management LoB, and Budget Formulation/Execution LoB) were held to their respective FY 2021 Request funding levels. 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.

<u>General Planning and Evaluation Activities ($5.01 million, -$70,000 below the FY 2021 Estimate)</u>
FY 2022 funding for general planning and evaluation activities supports investments on broad programmatic and policy matters of NSF-wide scope and benefit. This includes activities such as Renewing NSF, the verification and validation of performance information; IPA FTE in the office of Budget Finance and Award Management and the Office of the Director; and certain costs associated with the American Association for the Advancement of Science fellowships program. Also included is $160,030 for NSF's contribution to Government-wide Council funding and $141,203 to CAP Goal funding. The total FY 2022 funding level is based on the level of general planning and evaluation activities and projects that occurred in FY 2021 and anticipated activities for FY 2022.

**Other Organizational Excellence Activities**

**Other Organizational Excellence Activities**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| Analysis, Modeling, and Forecasting | - | - | $3.00 | $3.00 | N/A |
| Evaluation and Assessment Capability | 5.29 | 5.00 | 7.00 | 2.00 | 40.0% |
| Major Facilities Admin Reviews and Audits | 0.80 | 2.34 | 0.99 | -1.35 | -57.7% |
| Planning and Policy Support | 4.72 | 2.50 | 3.00 | 0.50 | 20.0% |
| Public Access Initiative | 2.45 | 1.75 | 3.75 | 2.00 | 114.3% |
| Research Security Strategy and Policy | - | - | 1.00 | 1.00 | N/A |
| **Total** | **$13.26** | **$11.59** | **$18.74** | **$7.15** | **61.7%** |

Analysis, Modeling, and Forecasting ($3.0 million, +$3.0 million over the FY 2021 Estimate)
NSF will expand its capacity to leverage modeling to generate timely and actionable insights to inform strategy, investments, and programmatic decisions. For additional information, see the IA narrative in the R&RA chapter.

Evaluation and Assessment Capability (EAC) ($7.0 million, +$2.0 million above the FY 2021 Estimate)
EAC is an integral part of NSF's operations and conducts or oversees those activities to generate useful evidence for decision making. At the FY 2022 Request level, increased funding will support studies prioritized in the Agency-wide learning agenda and focused on enabling program improvements that enhance the efficacy of NSF investments. For additional information, see the IA narrative in the R&RA chapter.

Major Facilities Administrative Reviews and Audits ($990,000, -$1.35 million below the FY 2021 Estimate)
NSF includes FY 2022 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.

Planning and Policy Support ($3.0 million, +$500,000 above the FY 2021 Estimate)
Planning and Policy Support is a foundation-wide activity in the IA budget that supports select NSF-wide policy and planning activities. The funding increase above the FY 2021 Estimate will support planning and policy-development activities to catalyze agency innovations in response to national priorities. For additional information, see the IA narrative in the R&RA chapter.

Public Access Initiative ($3.75 million, +$2.0 million above the FY 2021 Estimate)
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. Additional FY 2022 resources will support exploration of metadata approaches for data and software, along with training to refine associated workflows across all of science and engineering.

Research Security Strategy and Policy ($1.0 million, +$1.0 million over the FY 2021 Estimate)
NSF will expand capabilities and competencies to protect the U.S. science and engineering enterprise through its Research Science Security and Policy activity. For additional information, see the IA narrative in the R&RA chapter.

## OFFICE OF INSPECTOR GENERAL (OIG) **$20,420,000**

**+$2,570,000 / 14.4%**

The Appropriations Act that funds the National Science Foundation contains a separate appropriation for NSF's Office of Inspector General. Accordingly, this FY 2022 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 2022 Budget Request for OIG is $20.42 million, an increase of $2.57 million over the FY 2021 Enacted of $17.85 million.

**OIG Funding**

(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Enacted | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| **Total** | **$16.30** | **$17.85** | **$20.42** | **$2.57** | **14.4%** |
| Full-Time Equivalents (FTEs) | 68 | 71 | 79 | 8 | 11.3% |

### OIG Responsibilities and Structure

OIG provides independent oversight of NSF's programs and operations. The office promotes effectiveness, efficiency, and economy in administering the Foundation's programs and prevents and detects fraud, waste, and abuse within NSF or by individuals who receive NSF funding. By statute, NSF OIG is organizationally independent from the agency, with the Inspector General (IG) reporting directly to the National Science Board and Congress. Given the geographic breadth of the projects NSF funds, OIG needs to be equipped to conduct audits and investigations across the continental U.S., Alaska, Hawaii, Puerto Rico, and Antarctica. To fulfill its important mission, OIG employs a diverse staff of scientists, attorneys, certified public accountants, criminal investigators, management analysts, data analysts, and information technology specialists. OIG's FY 2020 appropriation was just 0.20 percent of NSF's nearly $8.3 billion appropriation and 0.05 percent of NSF's approximately $32.0 billion portfolio of active awards, yet OIG provides a much greater return on investment and serves as an invaluable safeguard against fraud, waste, abuse, and whistleblower reprisal.

OIG's work is divided into two functional areas: The Office of Audits and the Office of Investigations, which are supported by the Office of Management, Office of Counsel, and the IG's Immediate Office. Highlights of the 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~~20,420,000, of which $400,000 shall remain available until September 30, ~~2022~~2023.

**Office of Inspector General**
**FY 2022 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 2020 Appropriation | $16.50 | $0.40 | -$0.40 | -$0.20 | $16.30 |
| FY 2021 Estimated | 17.85 | 0.40 | | | 18.25 |
| FY 2022 Request | 20.42 | | | | 20.42 |
| $ Change from FY 2021 Estimated | | | | | $2.17 |
| % Change from FY 2021 Estimated | | | | | 11.9% |

Totals exclude reimbursable amounts.

## Explanation of Carryover

Within the OIG two-year account, $400,000 was carried over into FY 2021.

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 2021 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 2020, OIG audited approximately $8.50 billion in NSF funding in 27 states and Washington, D.C.—resulting in 92 audit and other engagement reports containing a total of $12.0 million in questioned costs and 739 recommendations to recover misspent funds and improve awardee and NSF operations.

In FY 2019, OA identified more than $4.90 million in questioned costs and made 252 recommendations to strengthen program and grant operations. As a result of OIG audits, NSF recouped misspent funds and required awardees to improve their management of NSF awards and subawards to prevent future misuse of taxpayer money. NSF also took other corrective actions in FY 2020 in response to recent audits, for example, NSF:
- Installed pharmacy tracking systems at all three United States Antarctic Program clinics.
- Prohibited apps that encrypt and automatically delete messages and implemented controls to identify and remove blacklisted apps from staff's mobile devices.
- Required major facilities award recipients to submit allocation plans explaining how they will allocate expenses during overlapping construction and operations stages.
- Established a process for assessing and documenting the cost and scientific impact of uncompleted major facility construction tasks and NSF's approval for moving such tasks to operations.

- Ensured that inflation factors are included in future major facility operations proposals and are reviewed and evaluated; and
- Ensured that staff have the authority and resources to implement the *Foundations for Evidence-based Policymaking Act of 2018*.

These improvements increased the effectiveness and efficiency of NSF programs and made NSF a better steward of federal funds.

<u>Areas of Risk for Potential Audit Coverage in FY 2022</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 Management Act*, the *Digital Accountability and Transparency Act* and the *Improper Payments Elimination and Reduction Act*. 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 2022, the top three current high-risk areas include:

*COVID-19 Impacts on NSF Major Research Equipment and Construction (MREFC) Projects*
COVID-19 has increased the risk to MREFC projects, including the Daniel K. Inouye Solar Telescope, Vera C. Rubin Observatory (formerly the Large Synoptic Survey Telescope), Antarctic Infrastructure Modernization for Science (AIMS), Regional Class Research Vessels, and the High-Luminosity Large Hadron Collider. As of July 2020, NSF reported COVID-19 impacts to all of these projects. For example, NSF estimated a one-year construction delay for the Vera C. Rubin Observatory at a cost increase of $40.0 to $50.0 million. Additionally, on-site work for the AIMS project was halted in March 2020, and no on-ice work is planned for the 2020-2021 season. NSF plans to re-baseline the entire AIMS project during FY 2021. In FY 2022, OIG will continue to monitor the progress on all high-risk MREFCs, and initiate audits as needed.

*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* (Pub. L. No. 114–329), 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. We will assess the adequacy of NSF's processes for identifying, planning for, and managing divestment of its major facilities.

*Mid-scale Research Infrastructure*
In its FY 2021 Budget Request, NSF requested more than $97.0 million for mid-scale projects. These projects, which cost between $6.0 and $70.0 million, include research instrumentation, equipment, and upgrades to major research facilities or other research infrastructure investments. NSF's September 2019 *Major Facilities Guide* provides guidance for these projects. We may review management requirements in mid-scale solicitations, controls for mid-scale projects, and training and experience of NSF staff responsible for making and overseeing mid-scale awards.

<u>Audits of Recipients of NSF Grant Funds</u>
Discretionary audits of NSF recipients are an essential part of OA's efforts to protect NSF funds. All statutorily mandated audits and most in-house performance audits focus on NSF's internal operations. Because the bulk of NSF's funding is provided to the academic community via grants and cooperative agreements, robust oversight of that funding is imperative. Audits of NSF recipients determine whether

awardees comply with the financial and administrative terms and conditions of the awards. They address the highest risk areas at institutions, identifying systemic issues, recapturing misused funds, and making recommendations ensuring proper stewardship of federal funds going forward.

Historically the OIG has procured audits of NSF recipients (which in FYs 2017-2019 covered between $22.0 million and $440.0 million in NSF funding) to provide this much-needed audit coverage over the recipient community. Beyond the findings specific to the institutions being audited, these audits 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 clarify the issue. The impact of this work is not limited to the entities that are audited: NSF recipients carefully monitor the results of these audits to identify situations where they need to strengthen their own policies and procedures. OA typically uses independent public accounting firms to conduct these audits. At the FY 2022 Budget Request level, OA will be able to fund 6 to 7 of these audits. OA will also conduct two desk review audits at small to medium sized institutions and continue to monitor the quality of Single Audits.

**Investigative Impact and Strategic Focus**

OIG's Office of Investigations (OI) conducts investigations of criminal, civil, and administrative wrongdoing related to NSF programs and operations, including all entities and individuals that receive NSF funds, as well as whistleblower reprisal investigations. OI also evaluates and investigates allegations of research misconduct such as data fabrication, data falsification, and plagiarism related to NSF-funded research. OI's vigilance ensures that those who seek or receive NSF funds to conduct research are held accountable and serves as a meaningful deterrent to grant fraud and research misconduct.

OI opens investigations based upon consideration of OIG's strategic goals, NSF Management Challenges, the seriousness and magnitude of the offense, the significance of programmatic vulnerability, and the high-risk status of the program or institution. From FY 2017 through FY 2020, OI's investigative oversight of NSF's approximately $32.0 billion award portfolio included 575 investigations spanning 48 states and the District of Columbia, as well as Puerto Rico, Canada, and Antarctica. OIG investigations—civil, criminal, and administrative—led to financial recoveries and savings to the federal government of nearly $31.7 million during this period. Investigators also helped protect NSF research funds through 43 debarments of individuals and entities, 14 voluntary exclusions of individuals, 15 award suspensions, and 16 award terminations. More than 40 individuals were required to take remedial training, provide certifications and assurances in communications with NSF, and prohibited from serving as an NSF reviewer, advisor, or consultant. Investigative staff also worked with NSF to remedy numerous administrative practices and procedures that insufficiently protected the integrity of NSF funding processes.

<u>Talent Plan Investigations</u>

Recent congressional hearings have focused on the theft of U.S. federally funded research and development by foreign states who use talent plans to exploit the openness of American universities and the federal research enterprises. In FY 2018, OI initiated its first criminal investigations focused on potential misuse of NSF funding by members of foreign "talent plans." The volume and complexity of such investigations has increased throughout FYs 2019 and 2020, and now accounts for nearly half of OI's workload. Although China is not the only foreign government exploiting the openness of American universities, many of our investigations concern Chinese talent plans. OI has confronted this national security threat in several ways. For instance, in FY 2019, OI hired an analyst to perform immediate, onsite translation of Chinese documents. Within one month the analyst saved OIG more than her annual salary in translation costs. Further, her knowledge of the cases and ability to quickly bring matters to the attention of the investigators saved months of investigative time and greatly increased investigation efficiency. OI's investigative work on these cases has resulted in award suspensions and terminations, the recovery of NSF funds, and many referrals to the U.S. Attorney's Office for prosecution.

In addition to conducting foreign talent plan investigations, OI:

- 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 talent plan investigations.
- Collaborates with the FBI and other investigative partners to conduct outreach to internal and external stakeholders (e.g., grantees, institutions) to explain the risks posed by talent plan membership; and
- Conducts outreach and provides education to NSF, which has resulted in the issuance of new or amended agency advisories and policies to address the threat, including prohibition of talent plan members serving as employees or Intergovernmental Personal Act (IPA) rotators, requiring IPA rotators to be U.S. citizens, and increasing disclosure requirements for researchers seeking NSF funding.
- Supports the operation of a Sensitive Compartmented Information Facility (SCIF) at NSF, which enhances the efficiency and effectiveness of foreign talent plan 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, which remain among the most at-risk programs funded by NSF. With NSF's total active SBIR/STTR awards now approximately $560.0 million, protecting SBIR/STTR funds from fraud and abuse has become even more important. OI has successfully partnered with NSF program managers to improve SBIR/STTR processes and procedures to reduce the opportunity for fraud to occur. OI also conducts SBIR/STTR-related outreach at NSF awardee workshops, which provides guidance to the small business community on how to properly handle federal funds and the consequences of not following the rules. OI's efforts have produced significant programmatic improvements and enhanced understanding throughout the research community. In addition, OI has led an OIG community working group focused on fraud in these programs to share best practices and lessons learned.

**Support Offices' Actions and Impacts**

<u>Office of Management</u>
OIG's centralized Office of Management (OM) provides support services for the entire office. This includes essential functions such as budget and finance, procurement, human resources, and training, as well as strategic planning and general administrative support. OM develops streamlined processes and uses cutting-edge tools to increase the efficiency and effectiveness of its operations. In addition, OM:

- Manages investigative intake. All Hotline complaints are handled by an intake coordinator, who annually processes more than 300 complaints and presents them to OI management.
- Provides forensic accounting and data analytics support. An in-house forensic accountant skilled in data analytics helps manage the large amounts of information that investigators receive through subpoenas and other means. The application of data analytics to vital functions such as procurement oversight and budget execution yields further management efficiencies and cost savings.
- Provides IT services, including website and SharePoint site enhancements, digital forensics, and data security, as well as ongoing support of OIG-specific hardware and software applications and databases. Digital forensics has become much more critical in investigations, as most of the evidence being captured is electronic.

<u>Office of Counsel</u>
The Office of Counsel (OC) consists of the Counsel to the IG and two assistant counsels, one of which is

part-time. It provides comprehensive legal advice and critical analysis to the IG and all OIG divisions, including legal review of externally issued OIG work products and correspondence. OC handles myriad subject areas, including audit-related support, ethics, appropriations law, acquisitions, information disclosure, privacy, personnel, and IG Act authorities. OC also supports the larger IG community through active participation in CIGIE projects and committees. On average, OC handles more than 150 actions per year, including routine reviews of reports, contracting matters, and other externally focused documents; Freedom of Information requests; and legal opinions on various matters. OC attorneys also participate in key meetings and decisions, conduct training, and publish legal updates. This level of routine involvement enables the office to identify and address potential legal issues and risk areas before they mature.

Immediate Office

The Inspector General's immediate office includes the Chief of Staff and Executive Assistant. The Chief of Staff handles all matters relating to external affairs, 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 served as the vice chair of CIGIE since 2014, and since January 2021 serves as the chair.
- NSF OIG has conducted outreach to the federal IG community, provided training to other investigative agencies, and taken the lead to establish and run four IG community working groups to:
  1. Prevent fraud within the SBIR/STTR programs.
  2. Increase the use of government-wide suspension and debarment as tools to deter and reduce instances of fraud, waste, and abuse.
  3. Foster the next generation of senior investigative leaders within the IG community; and
  4. Address emerging threats to U.S. national security through efforts by foreign governments to illegally obtain intellectual property and other research.

## Financial Discussion

**Office of Inspector General**
**Personnel Compensation and Benefits and General Operating Expenses**
(Dollars in Thousands)

| | FY 2020 Actual | FY 2021 Enacted | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|---|
| Personnel Compensation & Benefits[1] | $13,319 | $14,810 | $16,844 | $2,034 | 13.7% |
| Travel & Transportation of Persons | 85 | 225 | 230 | 5 | 2.2% |
| Advisory & Assistance Services[2] | 2,304 | 2,185 | 2,411 | 226 | 10.3% |
| Rent | 105 | 120 | 126 | 6 | 5.0% |
| Information Technology | 182 | 150 | 200 | 50 | 33.3% |
| Communications, Supplies, Equipment, and Other Services | 310 | 360 | 609 | 249 | 69.2% |
| *Training* | *195* | *140* | *232* | *92* | 65.7% |
| *Other[3]* | *71* | *161* | *304* | *143* | 88.8% |
| *CIGIE Assessment* | *44* | *59* | *73* | *14* | 23.7% |
| **Total** | **$16,305** | **$17,850** | **$20,420** | **$2,570** | **14.4%** |
| Full-Time Equivalents | 68 | 71 | 79 | 8 | 11.3% |

[1] FY 2022 includes expected within grade increases, COLA and increased performance awards.

[2] Includes the costs of the annual financial statements audit and the outsourcing of contracting services.

[3] For FY 2022, includes the cost for Sensitive Compartmented Information Facility (SCIF).

An increase of 14.4 percent from the FY 2021 Enacted level will help OIG achieve vital audit and investigative priorities. Funding at this level would support a total of eight additional FTEs.

Five FTEs to respond to challenges posed by members of foreign talent plans who receive NSF funding:

- Two criminal investigators and one investigative attorney to address the sharp increase in investigations related to foreign talent plans. Such cases make up almost 50 percent of the investigative portfolio in FY 2020, despite the fact that we implemented more stringent case-opening criteria. The number of requests for assistance from the FBI and other investigative agencies has also increased from 3 in FY 2017 to 51 in FY 2020—an increase driven entirely by foreign talent plan cases. As the Department of Justice's China Initiative continues, we expect this number to increase. The additional staff will help us meet this growing demand and reduce per-agent caseloads to a level more consistent with the community norm.
- Two auditors to conduct pro-active audits focusing on controls which can prevent talent plan members from engaging in fraudulent or other criminal activity. This strategy will require continual auditing to identify and respond to the evolving approaches used by our adversaries.

In addition, OIG is seeking three FTEs to expand coverage in several areas:

- One 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 increase in FY 2022 and beyond as NSF implements the major Antarctic Infrastructure Modernization for Science (AIMS) project, which includes significant changes to the USAP IT network.
- One investigative scientist to investigate allegations of research misconduct and whistleblower retaliation claims, and to conduct proactive reviews to identify more serious issues for investigation. We expect that the number of Whistleblower retaliation cases, which must meet extremely tight statutorily mandated timeframes, will sharply increase in FY 2022 due to pandemic-related cutbacks at NSF recipients.
- One IT specialist to address the increasing number and complexity of IT applications being used by OIG staff, particularly those related to digital forensics. Most evidence being seized from search warrants is digital and requires specialized skills and a greater commitment of IT resources. Digital forensics allows us to collect and transform data into useful information, to analyze that data in a way that is admissible in court, and to consume more data, more efficiently.

**Inspector General Reform Act Statement**

Section 6(g)(1) of the IG Act, 5 U.S.C. app. 3, was amended by the Inspector General Reform Act of 2008 (Pub. L. 110-409) to require a summary statement concerning OIG's annual budget request.

In accordance with this, we submit the following summary:

- NSF OIG's FY 2022 Budget Request is $20.42 million.
- The portion for training is $232,000.
- The portion for operation of the CIGIE is $73,000.[1]

The portion of the FY 2022 Budget Request for staff training is expected to suffice for all training needs in FY 2022. Because CIGIE's annual assessment is based on a percentage of each OIG's appropriation, the portion indicated for this purpose in the Budget Request will suffice.

[1] This is an estimate of CIGIE's annual membership assessment, which is tied to each member OIG's annual appropriation.

## OFFICE OF THE NATIONAL SCIENCE BOARD (NSB)

**$4,600,000**
**+$100,000 / 2.2%**

The FY 2022 Budget Request for the Office of the National Science Board is $4.60 million, an increase of $100,000 above the FY 2021 Enacted of $4.50 million. This FY 2022 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 2020 Actual | FY 2021 Enacted | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| **Total** | **$4.43** | **$4.50** | **$4.60** | **$0.10** | **2.2%** |
| Full-Time Equivalents (FTEs) | 17 | 17 | 17 | - | N/A |

### Appropriations Language

For necessary expenses (including payment of salaries, authorized travel, hire of passenger motor vehicles, the rental of conference rooms in the District of Columbia, and the employment of experts and consultants under section 3109 of title 5, United States Code) involved in carrying out section 4 of the National Science Foundation Act of 1950 (42 U.S.C. 1863) and Public Law 86–209 (42 U.S.C. 1880 et seq.), $~~4,500,000~~4,600,000: Provided, That not to exceed $2,500 shall be available for official reception and representation expenses.

**National Science Board**
**FY 2022 Summary Statement**
(Dollars in Millions)

| | Enacted/ Request | Expired | Obligations Actual/ Estimates |
|---|---|---|---|
| FY 2020 Appropriation | $4.50 | -$0.07 | $4.43 |
| FY 2021 Estimated | 4.50 | | 4.50 |
| FY 2022 Request | 4.60 | | 4.60 |
| $ Change from FY 2021 Estimated | | | $0.10 |
| % Change from FY 2021 Estimated | | | 2.2% |

### 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* report.

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 activities and NSF management responses; monitors audits and makes related recommendations to the Board; and oversees the Board's compliance with the Sunshine Act.

The **Committee on Strategy** (CS) provides a forum for developing the Board's strategic discussions of NSF's budget, programs, organization structure and agency vision; makes recommendations to the Board on annual Budget Requests and quadrennial Strategic Plans; and provides strategic guidance to the Board on NSF's programs.

The **Committee on National S&E Policy** (SEP) oversees development and production of the congressionally-mandated *Science and Engineering Indicators* (*Indicators*) report in collaboration with NSF's National Center for Science and Engineering Statistics (NCSES); helps ensure that the S&E information and policy resources developed by the NSB are high-quality, policy-relevant, and accessible in order to meet stakeholder needs; and helps fulfill the NSB's charge to provide ongoing information and policy advice to Congress and the President on S&E research, education, and workforce issues.

The **Committee on Awards and Facilities** (A&F) addresses strategic issues and recommends policies to the Board related to awards and MREFC projects; makes recommendations to the Board on awards and facilities; and provides lifecycle oversight on facilities and oversight on awards.

The **Committee on External Engagement** (EE) leads the NSB's communication and engagement efforts with government, industry, the public and the research and education communities, and helps the Board advance the pursuit of national policies for the promotion of research and education in S&E.

The **Subcommittee on Honorary Awards** (AWD) reviews nominations for two awards established by the Board: the Vannevar Bush Award and the Public Service Award.

Ongoing activities of the Board include review and approval of:

- Large awards, MREFC projects and other proposals as needed;
- NSF's Management Response to the Office of Inspector General Semi-annual Reports to Congress;
- Transmittal of the NSF, OIG, and NSB budget submissions to the Office of Management and Budget;
- Priority order of projects in the MREFC Account;
- Midscale Research Instrumentation-2 awards (and oversight of the Midscale Research Instrumentation-1 awards); and
- Inclusion of new projects requiring funding under the MREFC Account.

The Board also reviews and makes recommendations on:

- NSF's financial management reports,
- The operation of NSF's merit review system, and
- NSF's research infrastructure portfolio.

**Office of the National Science Board**
**Personnel Compensation and Benefits and Other Operating Expenses**
(Dollars in Thousands)

| | FY 2020 Actual | FY 2021 Enacted | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|
| Personnel Compensation & Benefits (PC&B)[1] | $3,159 | $3,173 | $3,446 | $273 | 8.6% |
| Staff Development & Training | 10 | 10 | 22 | 12 | 120.0% |
| Advisory & Assistance Services | 1,099 | 1,293 | 814 | -479 | -37.0% |
| Travel & Transportation of Persons | 134 | 0 | 280 | 280 | 0.0% |
| Communications, Supplies, & Equipment | 32 | 21 | 35 | 14 | 66.7% |
| Representation Costs | 3 | 3 | 3 | - | N/A |
| **Total** | **$4,437** | **$4,500** | **$4,600** | **$100** | **2.2%** |
| Full-Time Equivalents (FTE) | 17 | 17 | 17 | - | N/A |

[1] FY 2022 PC&B includes base salary costs and anticipated within grade and promotion increases.

## Personnel Compensation and Benefits

The Board's FY 2022 Budget Request supports a core of full-time policy, communications, administrative, legal, and executive secretariat staff. In addition to providing institutional memory for the Board, the Board Office staff provides both the resources and expertise for coordinating and conducting science and education policy analyses and developing and implementing broad communication and outreach programs. Staff also advise the Board on legal aspects of its policies and activities and provides operational and administrative support that are essential for the Board to fulfill its mission. The Request reflects planned increases in NSB office staff pay and in performance awards spending in FY 2022.

## Other Operating Expenses

The Staff Development and Training budget line supports various training events such as federal leadership training for management staff, Contracting Officer Representative (COR) training and recertification, and project management (PM) training, as well as facilitation services for staff retreats that have a professional development component. To ensure adequate COR coverage, NSB Office management increased the number of staff who are certified as CORs. This will lead to increased training and biannual recertification costs. To facilitate and manage implementation of *Vision 2030* and other NSB projects more effectively and efficiently, in FY 2020 and 2021 the NSB Office procured a PM support contract and a PM tool and provided training on the use of this tool to current staff. In the future newly hired Board Office staff will be required to receive training on this tool and PM concepts.

Increased PM capacity in the NSB Office is planned in coordination with a decrease in the need for and cost level of the PM support contract included in the Board's Advisory and Assistance Services budget line. This line also includes some of the resources needed to produce reports such as the Congressionally mandated *Science and Engineering Indicators (Indicators)*. To facilitate accessibility and use of *Indicators* data in policy decisions and analysis, 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. For *Indicators 2022,* the Board will update the state data tool and state one-pagers, develop a series of thematic reports, and release *The State of U.S. Science and Engineering* in January 2022.

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, which are anticipated to decrease as NSF migrates to an easier to maintain platform in FY 2022.

The NSB's Travel and Transportation of Persons budget line primarily covers costs related to Board member travel to NSF headquarters for the Board's four annual meetings and a member-only retreat, for oversight of NSF's large programs and facilities, and for engaging stakeholders. For example, as it implements its *Vision 2030*, the Board anticipates convening partners and stakeholders for discussions about specific action items in the Vision Roadmap. Also supported in this budget line is travel for invited speakers and participants in the NSB's activities.

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, the funding of wireless equipment, and purchase of office supplies upon return to on-site facilities.

The FY 2022 Budget Request will support the Board's efforts to strengthen the U.S. S&E enterprise through its policy and information-related activities. Specifically, the Request will help the NSB improve the usefulness of the resources it produces to ensure that Congress, the Administration, academia, private industry, and the general public continue to have access to timely, comprehensible, and objective S&E data and policy guidance.

## MAJOR RESEARCH FACILITIES

**Facilities:**


Major Research Facilities Overview ........ Facilities - 3

Academic Research Fleet (ARF) ........ Facilities - 7

Antarctic Facilities and Operations (AFO) ........ Facilities - 11

Arecibo Observatory (AO) ........ Facilities - 15

Geodetic Facility for the Advancement of GEoscience (GAGE) ........ Facilities - 20

IceCube Neutrino Observatory (ICNO) ........ Facilities - 25

International Ocean Discovery Program (IODP) ........ Facilities - 29

Large Hadron Collider (LHC) ........ Facilities - 33

Laser Interferometer Gravitational Wave Observatory (LIGO) ........ Facilities - 37

National Ecological Observatory Network (NEON) ........ Facilities - 41

National High Magnetic Field Laboratory (NHMFL) ........ Facilities - 45

Ocean Observatories Initiative (OOI) ........ Facilities - 50

Seismological Facility for the Advancement of GEoscience (SAGE) ........ Facilities - 55

**Federally Funded Research and Development Centers (FFRDCs):**

Green Bank Observatory (GBO) ........ Facilities - 60

National Center for Atmospheric Research (NCAR) ........ Facilities - 64

National Radio Astronomy Observatory (NRAO) ........ Facilities - 69

National Solar Observatory (NSO) ........ Facilities - 74

NSF's National Optical-Infrared Research Laboratory (NOIRLab) ........ Facilities - 78

**Other Facilities Funding** ........ Facilities - 85

## MAJOR RESEARCH FACILITIES

**Major Research Facilities Funding**
(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | FY 2022 Request change over: FY 2020 Actual Amount | Percent | FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|---|---|---|
| **Total Research and Related Activities** | **$921.20** | **$952.67** | **$961.81** | **$40.61** | **4.4%** | **$9.14** | **1.0%** |
| Operations and Maintenance of Existing Facilities | 636.74 | 664.22 | 666.03 | 29.29 | 4.6% | 1.81 | 0.3% |
| Federally Funded Research and Development Centers | 276.01 | 278.05 | 278.98 | 2.97 | 1.1% | 0.93 | 0.3% |
| Operations and Maintenance of Facilities under Construction | 0.01 | 5.00 | 5.20 | 5.19 | 37040.2% | 0.20 | 4.0% |
| R&RA Design Stage Activities | 8.43 | 5.40 | 11.60 | 3.17 | 37.6% | 6.20 | 114.8% |
| **Major Research Equipment and Facilities Construction** | **$153.87** | **$240.00** | **$248.00** | **$94.13** | **61.2%** | **$8.00** | **3.3%** |
| **Total, Major Research Facilities** | **$1,075.07** | **$1,192.67** | **$1,209.81** | **$134.74** | **12.5%** | **$17.14** | **1.4%** |

NSF investments in major multi-user research facilities (major facilities) provide large, state-of-the-art tools for research and education. These can include instrumentation networks, observatories, accelerators, telescopes, research vessels, aircraft, and simulators. In addition, scientific 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 award 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 Major Facilities Guide on expectations for entering the Design Stage at points beyond the Conceptual Design Phase. These recommendations are in the process of being implemented by the Office of the Director and the Large Facilities Office.

The Facility Operation Transition activity proposed in Integrative Activities (IA) is the third year of a pilot program that reflects NSF's strategic commitment to successful operations and maintenance (O&M) of new major facilities as well as balancing portfolio funding between facilities and investigator research, both of which were emphasized in the NSB's Congressionally requested 2018 report entitled "Study of

Operations and Maintenance Costs for NSF Facilities" (NSB-2018-17).[1] 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 2020, these funds supported facilities operations and maintenance costs in BIO ($3.0 million), GEO ($3.0 million), and MPS ($4.0 million); in FY 2021, these funds were distributed to BIO ($7.50 million) and MPS ($2.50 million).

All NSF's major facilities were affected by the COVID-19 pandemic. Typically, there were 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 and funded through NSF's MREFC account is provided in the MREFC chapter. The following pages contain information on the budget requests for NSF's major facilities in FY 2022.

[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.*

**NATIONAL SCIENCE FOUNDATION**
**FY 2022 BUDGET REQUEST TO CONGRESS**
**MAJOR RESEARCH FACILITIES FUNDING, BY PROJECT**
(Dollars in Millions)

| | | | | FY 2022 Request change over: | | | |
|---|---|---|---|---|---|---|---|
| | | | | FY 2020 Actual | | FY 2021 Estimate | |
| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Amount | Percent | Amount | Percent |
| **Operations and Maintenance of Major Facilities** | **$912.77** | **$947.27** | **$950.21** | **$37.44** | **4.1%** | **$2.94** | **0.3%** |
| ***Biological Sciences*** | ***$65.00*** | ***$65.00*** | ***$70.00*** | ***$5.00*** | ***7.7%*** | ***$5.00*** | ***7.7%*** |
| National Ecological Observatory Network (NEON) | 65.00 | 65.00 | 70.00 | 5.00 | 7.7% | 5.00 | 7.7% |
| ***Geosciences*** | ***$333.24*** | ***$339.18*** | ***$354.30*** | ***$21.06*** | ***6.3%*** | ***$15.12*** | ***4.5%*** |
| Academic Research Fleet[1] | 106.17 | 107.38 | 117.88 | 11.71 | 11.0% | 10.50 | 9.8% |
| Geodesy Advancing Geosciences and EarthScope (GAGE) | 13.90 | 13.95 | 14.05 | 0.15 | 1.1% | 0.10 | 0.7% |
| International Ocean Discovery Program (IODP) | 48.00 | 48.00 | 48.00 | - | - | - | - |
| National Center for Atmospheric Research (NCAR) FFRDC | 99.70 | 104.00 | 104.00 | 4.30 | 4.3% | - | - |
| Ocean Observatories Initiative (OOI) | 43.97 | 44.00 | 48.50 | 4.53 | 10.3% | 4.50 | 10.2% |
| Seismological Facilities for the Advancement of Geoscience & EarthScope (SAGE) | 21.50 | 21.85 | 21.87 | 0.37 | 1.7% | 0.02 | 0.1% |
| ***Mathematical and Physical Sciences*** | ***$304.42*** | ***$330.59*** | ***$310.59*** | ***$6.17*** | ***2.0%*** | ***-$20.00*** | ***-6.0%*** |
| Arecibo Observatory[2] | 6.51 | 45.06 | 26.00 | 19.49 | 299.2% | -19.06 | -42.3% |
| Green Bank Observatory (GBO) FFRDC[3] | 9.42 | 8.90 | 9.12 | -0.30 | -3.2% | 0.22 | 2.5% |
| Large Hadron Collider (LHC) - ATLAS and CMS | 20.00 | 20.00 | 20.50 | 0.50 | 2.5% | 0.50 | 2.5% |
| Laser Interferometer Gravitational Wave Observatory (LIGO) | 45.00 | 45.00 | 45.00 | - | - | - | - |
| National High Magnetic Field Laboratory (NHMFL)[4] | 34.59 | 25.98 | 38.91 | 4.33 | 12.5% | 12.93 | 49.8% |
| National Radio Astronomy Observatory (NRAO) FFRDC | 89.25 | 88.13 | 91.16 | 1.91 | 2.1% | 3.03 | 3.4% |
| *NRAO O&M*[5] | *41.98* | *39.45* | *40.53* | *-1.45* | *-3.5%* | *1.08* | *2.7%* |
| *Atacama Large Millimeter Array (ALMA) O&M* | *47.27* | *48.68* | *50.63* | *3.36* | *7.1%* | *1.95* | *4.0%* |
| National Solar Observatory (NSO) FFRDC | 21.79 | 24.09 | 25.46 | 3.67 | 16.8% | 1.37 | 5.7% |
| *NSO O&M* | *4.78* | *4.55* | *5.88* | *1.10* | *23.0%* | *1.33* | *29.2%* |
| *Daniel K. Inouye Solar Telescope (DKIST)*[6] | *17.01* | *19.54* | *19.58* | *2.57* | *15.1%* | *0.04* | *0.2%* |
| National Superconducting Cyclotron Laboratory (NSCL)[7] | 22.00 | 15.50 | - | -22.00 | -100.0% | -15.50 | -100.0% |
| NSF's National Optical-Infrared Astronomy Research Laboratory (NOIRLab) FFRDC | 55.86 | 57.93 | 54.44 | -1.42 | -2.5% | -3.49 | -6.0% |
| *NOIRLab O&M (Mid-Scale Observatories & Community Science and Data Center)*[8] | *33.54* | *29.95* | *26.26* | *-7.28* | *-21.7%* | *-3.69* | *-12.3%* |
| *Gemini Observatory O&M* | *22.31* | *22.98* | *22.98* | *0.67* | *3.0%* | *-* | *-* |
| *Vera C. Rubin Observatory O&M* | *0.01* | *5.00* | *5.20* | *5.19* | *37040.2%* | *0.20* | *4.0%* |
| ***Office of Polar Programs*** | ***$210.10*** | ***$212.50*** | ***$215.32*** | ***$5.22*** | ***2.5%*** | ***$2.82*** | ***1.3%*** |
| Antarctic Facilities and Operations (AFO)[9] | 203.09 | 205.50 | 208.02 | 4.93 | 2.4% | 2.52 | 1.2% |
| IceCube Neutrino Observatory (ICNO) | 7.00 | 7.00 | 7.30 | 0.30 | 4.2% | 0.30 | 4.3% |
| **Major Research Facilities Construction Investments** | **$162.30** | **$245.40** | **$259.60** | **$97.30** | **60.0%** | **$14.20** | **5.8%** |
| **R&RA Design Stage Activities[10]** | **$8.43** | **$5.40** | **$11.60** | **$3.17** | **37.6%** | **$6.20** | **114.8%** |
| **Major Research Equipment and Facilities Construction (MREFC)** | **$153.87** | **$240.00** | **$248.00** | **$94.13** | **61.2%** | **$8.00** | **3.3%** |
| **Total, Major Research Facilities** | **$1,075.07** | **$1,192.67** | **$1,209.81** | **$134.74** | **12.5%** | **$17.14** | **1.4%** |

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 2022 included in the MREFC line below. Operations and maintenance of RCRV is not anticipated to begin until FY 2023.

[2] Arecibo: Includes $28.88 million in FY 2021 and $15.0 million in FY 2022 in supplemental funding for cleanup of the Arecibo site.

[3] GBO: FY 2020 Actual includes $1.75 million from a technical deobligation/reobligation action from a previous award.

[4] NHFML: The FY 2020 Actual includes $12.0 million to fund part of FY 2021 operations costs, and excludes $14.20 million obligated in FY 2019 for FY 2020 operations.

[5] NRAO O&M: FY 2020 Actual includes one-time funding of $3.50 million for a special project associated with NSF's Spectrum Innovation Initiative.

[6] DKIST: The FY 2021 Estimate excludes funding of $2.0 million for cultural mitigation activities as agreed to during the compliance process.

[7] 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 Beams.

[8] NOIRLab: Includes $2.0 million in FY 2020 for transition activities associated with the creation of NOIRLab, as well as special projects funding of $13.63 million in FY 2020, $9.44 million in FY 2021, and $5.13 million in FY 2022.

[9] 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.

[10] Design Stage Activities include support for potential next generation multi-user facilities. This line reflects FY 2020 funding of $3.50 million and $3.60 million in FY 2021 and FY 2022 for the potential Leadership Class Computing Facility, and $4.93 million in FY 2020 for the Antarctic Infrastructure Modernization for Science (AIMS) project of the Antarctic Infrastructure Recapitalization (AIR) program, and $1.80 million in FY 2021 and $8.0 million in FY 2022 for the Antarctic Research Vessel (ARV).

**ACADEMIC RESEARCH FLEET (ARF)** **$117,880,000**
**+$10,500,000 / 9.8%**

**Academic Research Fleet Funding**
(Dollars in Millions)

| FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|
| $106.17 | $107.38 | $117.88 | $10.50 | 9.8% |

## Brief Description

ARF currently consists of 18 vessels and various submersibles/autonomous vehicles owned by the National Science Foundation, the Office of Naval Research, and U.S. universities. All the ARF ships and vehicles are operated by research universities and laboratories. The ARF is a subset of the Federal Oceanographic Fleet, with interagency collaboration under the Interagency Working Group on Facilities and Infrastructure (IWG-FI). Coordination of access to and operations of the ARF vessels and vehicles is accomplished through collaboration with the University-National Oceanographic Laboratory System (UNOLS).

## 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, as well as the remote polar regions. ARF vessels collect observational data on Earth systems that provide 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 continues successful operations despite being under strict COVID-19 risk mitigation protocols. In CY 2020, ARF experienced an initial standdown, 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. Although many planned cruises were necessarily deferred because of COVID-19 travel restrictions; ARF was able to safely accomplish approximately 50% of the originally planned work. In addition, crucial activities such as the mid-life refit of the R/V *Atlantis* and bi-annual shipyard and dry docking work were completed. The overhaul of


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

the submersible DSV *Alvin*, including an upgrade to 6,500-meter depth capability, was also continued under very strict COVID-19 protocols.

**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 estimated to be large, 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.

NSF missions represent approximately 60 percent of cruises in any given year, varying by five percent, but NSF funds about 70 percent of the total cost. In calendar year 2020, these percentages increased due to COVID-19 cruise cancellations by other agencies, causing increases in the day rate and the total cost paid by NSF. In 2019, NSF carried out approximately 1,993 days at sea and 173 cruises across all classes of ships. By contrast, in 2020, NSF carried out approximately 1,168 days at sea across all classes of vessels by the end of the calendar year. Although there were several cruises postponed or canceled due to COVID cases discovered before boarding, the strict quarantine protocols, testing, cleaning, and drastic reductions in the size of science parties coupled with the use of telepresence and satellite communication enabled high-priority work to be carried out.

**Governance Structure and Partnerships**

<u>NSF Governance Structure</u>
Oversight: 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, NSF Business Systems Reviews and participation at UNOLS Council/Committee meetings. NSF is the Cognizant Federal Agency that negotiates annual ship and technician rates. Several program directors within OCE at NSF, the National Oceanic and Atmospheric Administration (NOAA), and the Office of Naval Research (ONR) are involved in ARF activities and overall oversight.

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.

<u>Management</u>
Management of a ship operating institution's facilities varies with the scale of the operation, but the core responsibility typically resides with the Director of the institution, the Marine Superintendent, who is responsible for all aspects of the facility, and the ship's Captain, who is responsible for at-sea operations. For larger, multi-ship-operating institutions, a Chief of Marine Technicians, schedulers, and finance administrators may also be involved in facility management.

External Governance Structure

There is no formal external governance structure for the Academic Research Fleet. 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 ships 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 from becoming obsolete. Additionally, the material condition of the vessels, which is determined through the NSF Inspection Program, helps inform future Fleet modernization needs. This process resulted in the development of the Regional Class Reseach 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 2020 | FY 2021 | FY 2022 | ESTIMATES[1] | | | | |
|---|---|---|---|---|---|---|---|---|
| | Actual | Estimate | Request | FY 2023 | FY 2024 | FY 2025 | FY 2026 | FY 2027 |
| Operations & Maintenance | $106.17 | $107.38 | $117.88 | $119.11 | $128.91 | $132.58 | $132.58 | $132.58 |

[1] Outyear estimates are for planning purposes only.

Funding for the ARF includes investments in ship operations; shipboard scientific support equipment; oceanographic instrumentation and technical services; and submersible support. Funding levels reported here reflect investments by the Division of Ocean Sciences (OCE) within GEO. The increase in FY 2022 reflects lingering impacts on ship demand from the COVID-19 pandemic and increased operations in support of research on climate change. Outyear estimates include O&M costs for new RCRVs as they become operational.

**Reviews**

The NSF cooperative agreement awards with each ship-operating institution are reviewed by an external panel every five years. The current cycle of cooperative agreements ends in FY 2022. A Business Systems Review of the University of Washington, operator of R/V *Thomas G. Thompson* and R/V *Rachel Carson*, was conducted in early FY 2020. Also in FY 2020, a Business Systems Review of the Bermuda Institute for Ocean Sciences, operator of R/V *Atlantic Explorer*, commenced virtually due to COVID-19.

**Renewal/Recompetition/Termination**

NSF owns three of the ships in the ARF and uses all ships to conduct science work at sea, which requires NSF to have a ship operations award with each of the ship operating institutions. All ships received new five-year operational awards in CY 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; discussion is in progress on a Renew/Compete decision for the R/V *Sikuliaq* operations award. Of the remaining two NSF-owned ships, R/V *Oceanus* will be retired in FY 2022 and replaced by the new RCRV R/V *Taani* in FY 2023 and R/V *Endeavor* will be retired in FY 2023 and replaced by RCRV#2 in early FY 2024. Operators for those vessels have already been chosen through a competitive process. The third new RCRV, R/V *Gilbert R. Mason,* will replace R/V *Pelican* (owned by LUMCON) in late FY 2024 after retirement of R/V *Pelican* in FY 2023.

During the last five years various activities have continued in the efforts to modernization the ARF. In FY 2018, NSF's research vessel *Clifford A. Barnes* was retired and replaced by R/V *Rachel Carson*, a ship purchased and owned by the University of Washington. In FY 2017, ONR completed a mid-life refit of R/V *Thomas G. Thompson,* and they commissioned their second new Ocean Class vessel, R/V *Sally Ride*. In FY 2020, ONR completed a mid-life refit of R/V *Roger Revelle* and commenced a mid-life refit for R/V *Atlantis* which is expected to be completed in FY 2021. 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.

R/V Endeavor at the pier. *Credit: Veronica Berounsky*

## ANTARCTIC FACILITIES AND OPERATIONS (AFO) $216,020,000
**+$8,720,000 / 4.2%**

**Antarctic Facilities and Operations Funding**
(Dollars in Millions)

| | | | Change over FY 2021 Estimate | |
|---|---|---|---|---|
| FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Amount | Percent |
| $208.02 | $207.30 | $216.02 | $8.72 | 4.2% |

### Brief Description

AFO 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

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

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) of NSF's Office of Polar Programs (OPP), through its contractor Leidos, supports about 150 NSF-funded science projects each season as well as long-term observing facilities, such as the Long-Term Ecological Research sites in the Dry Valleys and in the Antarctic Peninsula marine environment, the IceCube neutrino detector, and the South Pole Telescope for sub-mm and microwave signal detection of the universe. NSF also supports several projects funded by other agencies including NASA and NOAA. For example, the Long Duration Balloon program launches major observing payloads into the upper atmosphere from a dedicated facility on the Ross Ice Shelf.

### Status of the Facility

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

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 did not support new science investigations, in order to manage COVID-19 risks and to work within the constraint of international travel restrictions. The minimal number of logistical support staff was deployed to undertake critical maintenance and support functions. Construction on-ice was halted mid-season in FY 2020, throughout 2021, and will likely remain deferred to a large extent through FY 2022. International travel restrictions are anticipated to persist into at least the initial months of FY 2022, so the 2021-22 austral summer research season will also be affected. As in FY 2020, environmental conditions prevented building an ice pier at McMurdo in FY 2021. Resupply of McMurdo was conducted by aircraft only; of South Pole Station by tractor traverse and small aircraft; and of Palmer Station via vessel.

**Meeting Intellectual Community Needs**

The Science and Technology Policy Institute conducts an annual survey of deployed researchers on behalf of AIL. The results are used to inform capital planning decisions and improvements to operations. 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 Science Section (ANT) of OPP.

The Antarctic Infrastructure Recapitalization (AIR) program is initiated in FY 2022 in response to a 2012 Blue Ribbon Panel report which recommended that NSF create a capital plan to renew the USAP's aging physical plant. This program will subsume the Antarctic Infrastructure Modernization for Science (AIMS) project, which is in the construction phase. 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. The need for this program was also informed by a 2011 NRC report and a 2015 NASEM report.[1][2]

**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 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 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 culminated in the 2012 Blue Ribbon Report which is discussed further below. [3] 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.

[1] www.nap.edu/catalog/13169/future-science-opportunities-in-antarctica-and-the-southern-ocean
[2] www.nap.edu/catalog/21741/a-strategic-vision-for-nsf-investments-in-antarctic-and-southern-ocean-research
[3] www.nsf.gov/geo/opp/usap_special_review/usap_brp/rpt/index.jsp

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.

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 2020 Actual | FY 2021 Estimate | FY 2022 Request | ESTIMATES[1] FY 2023 | FY 2024 | FY 2025 | FY 2026 | FY 2027 |
|---|---|---|---|---|---|---|---|---|
| Operations & Maintenance | $208.02 | $207.30 | $216.02 | $216.02 | $216.02 | $216.02 | $216.02 | $216.02 |

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

In FY 2022, Antarctic Facilities and Operations funding is increased by $8.72 million to $216.02 million. 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 has led to significantly higher per person deployment costs for getting grantees and contract personnel to Antarctica, and this effect will persist into the FY 2022 season and increase the overall operating cost even though the tempo will still be lower than pre-COVID-19 pandemic levels. Beyond FY 2022, 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 COVID-19 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 (PEB) 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 Blue Ribbon Panel (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.[4] The AIR program is a significant step towards addressing the report recommendations and is covered in detail in the Major Research Equipment and Facilities Construction 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 on the basis of 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

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

two-year option with Leidos was exercised in September 2020.

- In anticipation of the need to recompete the 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 2022 will be in the second 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 third of four option years.
- Currently there are no plans for divestment of this facility.

**ARECIBO OBSERVATORY (AO)** **$26,000,000**
**-$19,060,000 / 42.3%**

**Arecibo Observatory Funding**
(Dollars in Millions)

| FY 2020 Actual | FY 2021 Estimate[1] | FY 2022 Request[1] | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|
| $6.51 | $45.06 | $26.00 | -$19.06 | -42.3% |

[1] The FY 2021 Estimate includes $37.43 million and the FY 2022 Request includes $20.0 million in supplemental funding for cleanup of the Arecibo site following the collapse of the platform above the 305-meter telescope in December 2020.

## Brief Description

Arecibo Observatory is a center for multidisciplinary research and education with advanced observational facilities. 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. 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 been brought in to provide oversight of environmental and historical preservation work on NSF's behalf.

## Scientific Purpose

Despite the collapse of the 305-meter telescope platform, AO is not closed, and science continues with archival data and other facilities. The Light Detection and Ranging (LIDAR) facilities onsite 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 on site 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 is taking place over several weeks in June.

**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 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, before beginning to implement many of these repairs, AO was impacted by several events outside of its control in 2020. Beginning in early FY 2020 there were many earthquakes near the southern coast of Puerto Rico (Arecibo is closer to the northern coast), including 11 greater than magnitude 5. These caused some minimal 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 then occurred in August 2020 and another cable failed in November 2020, leading to a prolonged closure for stabilization efforts and repairs. After the November failure, NSF announced plans to begin decommissioning the telescope as there was no longer a pathway to stabilize the facility safely. Prior to implementing the decommissioning, the suspended platform experienced an uncontrolled collapse on December 1, 2020. Since then, efforts have shifted to cleanup and debris removal in a safe and environmentally sound way, 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. NSF is assessing future possibilities for AO after the collapse of the 305-meter 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, 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 will establish a backup of all AO 305-meter telescope data to TACC's Ranch, a long-term data mass storage system, 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 example being the discovery and characterization of fast radio bursts (FRBs).

[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/

One area in which AO continues to excel, regardless of instrumentation, 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 is convening 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 will focus 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 is expected to generate innovative design ideas for AO for the short (1–3 years), medium (3–10 years), or long term (10+ years).

**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 in the Office of Budget, Finance, and Award Management. 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 been brought in to provide 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]

External Governance Structure

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,

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

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. 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 2022 request is $26.0 million. AO O&M is jointly supported by AST and AGS. Additional funding was provided in FY 2021 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 are expected to continue in FY 2022 as efforts to restore AO's scientific, cultural, and educational programs ramp up based on recommendations from the June 2021 workshop and other input from the scientific and Puerto Rican communities.

**Total Obligations for AO**
(Dollars in Millions)

| | FY 2020 Actual[1] | FY 2021 Estimate | FY 2022 Request | ESTIMATES[2] | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | FY 2023 | FY 2024 | FY 2025 | FY 2026 | FY 2027 |
| Operations & Maintenance (MPS) | $3.75 | $3.79 | $3.00 | $3.00 | $3.00 | $3.00 | $3.00 | $3.00 |
| Operations & Maintenance (GEO) | 2.76 | 3.83 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| Cleanup[3] | - | 37.43 | 20.00 | - | - | - | - | - |
| **Total** | **$6.51** | **$45.06** | **$26.00** | **$6.00** | **$6.00** | **$6.00** | **$6.00** | **$6.00** |

[1] The FY 2020 Actual includes $437,500 in GEO for continuity of operations into FY 2021; $1.50 million of FY 2020 operations costs in GEO were obligated in FY 2019.

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

[3] Supplemental funding for cleanup of the Arecibo site (see narrative for details) includes $28.88 million in MPS and $8.55 million in GEO in FY 2021 and $15.0 million in MPS and $5.0 million in GEO in FY 2022.

## 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 is scheduled to take place in early Summer 2021.

## 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

[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.

hurricane repairs. The timeline for potential recompetition is uncertain, pending further definition of the scope of future AO operations.

**GEODETIC FACILITY FOR THE ADVANCEMENT OF GEOSCIENCE (GAGE)** **$14,050,000 +$100,000 / 0.7%**

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

| FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|
| $13.90 | $13.95 | $14.05 | $0.10 | 0.7% |

**Brief Description**

GAGE is a distributed, multi-user facility that enables a diverse 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 an extremely broad spectrum of geosciences disciplines that use geodetic instrumentation and data, including Earth, atmospheric, and polar sciences. GAGE data support transformative advances in our understanding of the Earth system, including crustal deformation, plate boundary processes, landscape evolution, the earthquake cycle, earthquake, 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 in year three of a five-year award, and the current capabilities provided by the facility have evolved based on input from a series of community engagement activities held in 2015, including a NSF-sponsored workshop entitled “Future Seismic and Geodetic Facility Needs in the Geosciences”.[1] The Division of Earth Sciences (EAR) in the Directorate for Geosciences is deliberating the path forward for evolving 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 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

[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
[3] www.nap.edu/catalog/25536/management-models-for-future-seismological-and-geodetic-facilities-and-capabilities

consolidated into a single facility with a single operator.[4]

To further inform its planning for the future geophysical facility, the Directorate for Geosciences commissioned from a subcommittee of its Advisory Committee a portfolio review of possible geophysical instrumentation and sensor networks that a new facility might support to address the science priorities highlighted in the decadal survey. The portfolio review highlights the capabilities that a new facility should support in order to best enable the community to address the science priorities in the 2020 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 now strategizing 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% 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 will be completed by July 2021. The remaining stations are expected to be removed from the ground by end of FY2022.

The impact of COVID-19 on GAGE has been relatively minor. Data are delivered by remote stations that generally do not require local presence of people, and data can flow while staff work remotely. In June 2020, UNAVCO began permitting GAGE staff to work at UNAVCO facilities if desired. In mid-November 2020, UNAVCO moved back to "Phase 1" operations, where only essential staff were allowed at UNAVCO facilities, with all others required to work from home.

**Meeting Intellectual Community Needs**

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. The Geophysics, Geochemistry and Petrology, GeoPRISMS, Tectonics, Geomorphology and Land Use Dynamics and Hydrological Sciences programs in EAR; the GeoPRISMS and Marine Geology and Geophysics programs in the Division of Ocean Sciences (OCE); and the Earth Science and Glaciology programs in the Antarctic Research Section of the Office of Polar Programs (OPP) and the Arctic System Sciences and Arctic Natural Sciences programs in OPP provide most of the funds for NSF-sponsored research making use of the GAGE facility. 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. Over the last year of support for GAGE:

- The volume of data requested by users increased from about 30 TB in Q2 FY 2019 to over 130 TB in Q2 FY 2020;
- Field experiments using equipment and field engineering assistance continue at an average annual level of approximately 100 projects.

NSF's awardee for the GAGE facility, UNAVCO, operates the premier internship program in the Geosciences focused on broadening participation of underrepresented students. As a result of COVID-19 restrictions, UNAVCO's internship programs were conducted fully online this past year. Their evaluation metrics suggest that student learning outcomes were similarly positive to those of the in-person internship

[4] www.nsf.gov/pubs/2020/nsf20037/nsf20037.jsp

program.

**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 DACS Grants and Agreements or Contracts Officer, and an 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., OGC staff, OD 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
While the GAGE facility is primarily funded by EAR, it also receives about $1.20 million in funding from OPP, and $1.15 million from NASA via interagency transfer each year. 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 that 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 operational and maintenance support for 58 NASA-supported stations and the GNSS network that support 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. USGS relies on GAGE stations for its ShakeAlert earthquake early warning program and its volcano hazard monitoring program. 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 2020 Actual | FY 2021 Estimate | FY 2022 Request | ESTIMATES[1] FY 2023 | FY 2024 | FY 2025 | FY 2026 | FY 2027 |
|---|---|---|---|---|---|---|---|---|
| Operations & Maintenance | $13.90 | $13.95 | $14.05 | $14.55 | $14.55 | $14.55 | $14.55 | $14.55 |

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

To serve the research needs of the broad Earth science community, GAGE is organized under three primary service areas:

Geodetic Infrastructure

- Currently, NOTA includes 1,257 continuous GPS and GNSS stations (more than 800 of which transmit data in real-time with sub-second latency) distributed across the U.S., Mexico, and the Caribbean, with focus on the active plate boundaries. The FY 2022 Request includes funds to support a network that includes about 1,100 stations.
- The GAGE facility also provides operational and maintenance support for a network of 87 borehole strainmeters and 79 borehole seismometers deployed along the San Andreas Fault and above the Cascadia subduction zone and volcanic arc. Tiltmeters (26) and pore pressure sensors (23) are also collocated with the other borehole instruments. Together, data collected by these instruments enable scientists to study the full range of deformation in the solid Earth, from the rapid shaking associated with earthquakes, through more gradual motions related to slow slip events on faults and to Earth's evolving water cycles, up to long-term plate tectonics.
- Global geodetic arrays outside of the NOTA footprint are supported by GAGE in partnership with investigators. Eight hundred continuous GPS stations from over 60 networks around the world are now maintained and monitored, and have their data compiled into the GAGE data system. In addition, GAGE provides operational and maintenance support for 58 NASA-supported stations, and the GNSS network that supports satellite orbit and clock corrections and the refinement of the ITRF. The ITRF is the foundation for high-precision global Earth science and other applications of geodesy such as land surveying.
- Community GPS/GNSS receiver and geodetic technology pool consists of over 700 GPS and GNSS receivers, ancillary equipment, and six terrestrial laser scanners, which can be used by investigators for short- and long-term deployments on research projects supported via multiple EAR and OPP science programs funded by NSF.
- GAGE supports the polar GPS network in Antarctica (ANET) and development of specialized GPS monumentation, power, and telemetry solutions for use in harsh environments. GAGE also provides portable campaign deployment geodetic instrumentation, training, and field support for experiments in the polar regions.
- Investigator Project Support includes project management, field engineering, and technical support services to plan and execute GPS surveys and permanent station installations. GAGE also maintains a staff focused on geodetic technology equipment testing services to evaluate new geodetic technologies and improve performance for science applications.

Geodetic Data Services

- Geodetic Data Services manages an archive of over 300 terabytes of data from GPS, terrestrial and airborne laser scanning, Synthetic Aperture Radar (SAR), and borehole geophysical instruments from all GAGE components including NOTA, global continuous geodetic networks, and campaign GPS observations; operates automated and manual systems to ensure the quality of all data stored in the archive; and provides systems to give the national and international research community timely access

to these data.
- The archive of SAR imagery maintained and distributed by GAGE to support interferometric SAR imagery of continuous surface deformation at scales of 100 km to 1,000 km is complementary to discrete GPS measurement of displacement. UNAVCO, as the manager of GAGE, brokers for cost-effective community access to the SAR imagery acquired by foreign SAR satellite systems.

<u>Education and Community Engagement</u>
- The GAGE Education and Community Engagement program enables audiences beyond geodesists to access and use geodetic data and research for educational purposes, including technical short courses, student internships, web-based materials, and programs for strengthening workforce development and improving diversity in the geosciences.
- Scientific community activities include scientific and technical workshops that bring together the international geodetic community and publications designed to communicate GAGE activities and results to the community.
- GAGE operates the Research Experiences in Solid Earth Science internship program, which is widely recognized as the most outstanding program for broadening participation of underrepresented students in the geosciences.

External affairs maintain outreach efforts to policymakers and planning for coordination with the international geodesy community.

In addition to the three services mentioned, EAR plans to implement recommendations from the 2019 and 2020 management 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. A pilot cloud service program was initiated in 2020 in a partnership with SAGE and EAR plans to expand this capability over the existing award period. The 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 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 will conduct a full management review of the facility in FY 2021.

**Renewal/Recompetition/Termination**

The current GAGE award will fund the facility until the end of FY 2023. NSF is considering the recommendations contained in the *Earth in Time* decadal survey as well as the interagency context in which the facility operates in formulating a strategy for continued support of this important community research resource.

## ICECUBE NEUTRINO OBSERVATORY (ICNO) $7,300,000

**+$300,000 / 4.3%**

**IceCube Neutrino Observatory Funding**
(Dollars in Millions)

| FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|
| $7.00 | $7.00 | $7.30 | $0.30 | 4.3% |

### Brief Description

The IceCube Neutrino Observatory cubic-kilometer detector has now 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.

The IceCube Laboratory building at South Pole where all data-collecting computer servers are located. *Credit: USAP Photo Library, Sven Lidstrom, NSF.*

In 2013, ICNO observed the first high-energy (over 100 Tera eV (TeV) and up to 10 Peta eV (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 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 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, a 6.3 PeV antineutrino interaction with an atomic electron in the ice, producing a W boson. 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 have continued throughout the COVID-19 pandemic period and included two staff members who carried 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 by the UW staff, operating remotely.

**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 NSF’s Office of Polar Programs (OPP) and MPS’ Division of Physics (PHY). This international team is responsible for the scientific program, and many of the collaborators contributed to the design, construction, and now operation of the detector.

ICNO is currently funded by NSF with the mid-scale research infrastructure award issued in 2019 to add seven additional strings to be deployed deep in the ice for the central DeepCore array. The original project duration was set for the 2019-2024 period, but the COVID-19 pandemic has caused a delay for one more year at least. This addition will extend ICNO's overall sensitivity to a lower energy range which will provide a bridge to studies at other neutrino observatories such as Super-Kamiokande detector in Japan and other similar (much smaller than IceCube) detectors across the world.

**Governance Structure and Partnerships**

ICNO is managed by UW and includes a broad science collaboration, currently consisting of 53 institutions worldwide (U.S.-28, Canada-2, Europe-19, Asia and Pacific-4) in 12 countries (U.S., Germany, Belgium, Sweden, Australia, Canada, Denmark, Japan, New Zealand, South Korea, Switzerland, and the United Kingdom).

Full operations and maintenance in support of scientific research began in FY 2011. The associated costs are and will continue to be shared by the partner funding agencies—U.S. (NSF) and non-U.S.—roughly proportional to the number of PhD researchers involved in the Observatory’s maintenance and operations (in 2020, this ratio was about 51% US and 49% non-US). The NSF support for operations and maintenance, research, and education and outreach is shared by the Office of Polar Programs (lead) and the Physics

[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 that generally originate outside the Solar system.

Division in MPS, 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 the Observatory. Support for the U.S. institutions working on more refined and specific data analyses, data interpretation (theory support), and instrumentation upgrades is provided through the NSF Research and Related Activities (R&RA) account in response to merit-reviewed proposals.

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, University of Wisconsin in Madison, and its sub-awardee institutions: University of Maryland in College Park, University of Delaware, Michigan State University, Pennsylvania State University, University of Alabama in Tuscaloosa, and Lawrence Berkeley National Laboratory.

Partnerships and Other Funding Sources
The ICNO construction, operations and maintenance, and scientific research are funded through a domestic and international network of public and private organizations, including the Department of Energy, Office of Science. Domestic and international partners involved in the ICNO operation are members of the IceCube Collaboration[2].

## Funding

**Total Obligations for ICNO**

(Dollars in Millions)

| | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | ESTIMATES[1] FY 2023 | FY 2024 | FY 2025 | FY 2026 | FY 2027 |
|---|---|---|---|---|---|---|---|---|
| Operations and Maintenance (GEO) | $3.50 | $3.50 | $3.65 | $3.83 | $4.02 | $4.15 | $4.15 | $4.15 |
| Operations and Maintenance (MPS) | 3.50 | 3.50 | 3.65 | 3.83 | 4.02 | 4.15 | 4.15 | 4.15 |
| **TOTAL** | **$7.00** | **$7.00** | **$7.30** | **$7.66** | **$8.04** | **$8.30** | **$8.30** | **$8.30** |

[1] Outyear estimates are for planning purposes only.

A new five-year cooperative agreement (CA) was awarded in 2021. The award increase starting in 2022 reflects the higher cost to operate the larger number of strings in the sensor array.

## Reviews

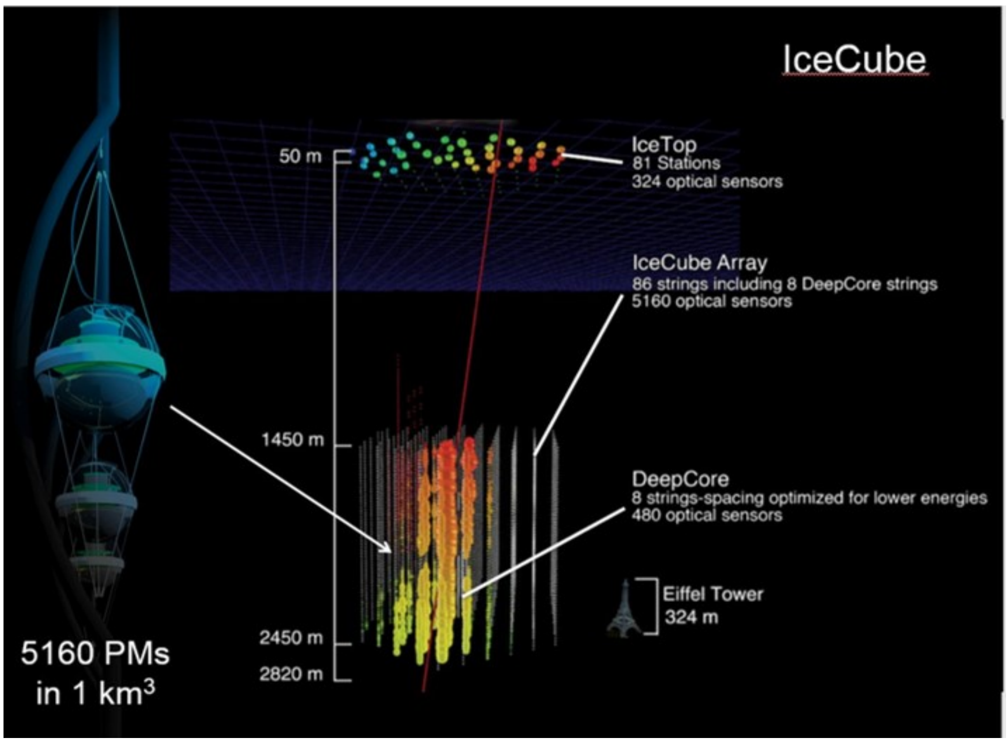
The previous CA with UW required two reviews of the ICNO/O&M activities after the second and fourth project years. The first review was completed in person in March 2019, while the second review was held virtually in March 2020. These reviews found that ICNO continues to be a very important element of the OPP and PHY Programs, rated the O&M activities as excellent, and recommended to continue operating ICNO for the remaining period of the current CA.

[2] icecube.wisc.edu/collaboration/meet-the-collaboration/

**Renewal/Recompetition/Termination**

The ICNO full operation began in 2011 with an anticipated lifetime of the detector of approximately 25-30 years. The previous ICNO O&M support was recompeted and awarded in April 2016 for five years after a thorough review of the received proposal. The renewal proposal for extending the O&M activities from April 2021 through March 2026 was received at the end of July 2020. In a November 2020 panel review all were unanimous that the current O&M effort was excellent. The new O&M award was issued in April 2021.

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 library.*

**INTERNATIONAL OCEAN DISCOVERY PROGRAM (IODP)** **$48,000,000**
**$0 / 0%**

**International Ocean Discovery Program Funding**
(Dollars in Millions)

| | | | Change over FY 2021 Estimate | |
|---|---|---|---|---|
| FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Amount | Percent |
| $48.00 | $48.00 | $48.00 | - | - |

## 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.

*JOIDES Resolution* on station conducting scientific ocean drilling during IODP Expedition 352 (July-September 2014). *Credit: Tom Fulton*.

## Scientific Purpose

IODP began in FY 2014 as the replacement for the Integrated Ocean Drilling Program, which succeeded the Ocean Drilling Program. The 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. A panel review was held in February 2020. The summary of this most recent 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.* This plan guides multidisciplinary subseafloor 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 at www.iodp.org.

The COVID-19 pandemic has had a significant impact on IODP, particularly on the operations of the *JR* facility. Following ship repair work in the first half of the calendar year, science expeditions had been planned to resume in mid-2020. However, the inability of science teams to gather and participate in the long-term research cruises has contributed to postponement or cancellation of a number of scientific voyages, although some preparatory engineering expeditions have been carried out. The earliest resumption of expeditions including an on-board science party is August 2021.

**Meeting Intellectual Community Needs**

A comprehensive online survey of the U.S. science community was undertaken from December 2016 to May 2017 under the auspices of the United States Advisory Committee (USAC) to assess 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 *JOIDES Resolution* Assessment Workshop (JRAW) to distill and analyze these survey responses, examine the science results of FY 2014 to FY 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% 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."

**Governance Structure and Partnerships**

NSF Governance Structure
The Division of Ocean Sciences in the Geosciences Directorate manages IODP operations of the *JOIDES Resolution* 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 *JOIDES Resolution* operations, the IODP Support Office, and the United States Science Support Program that funds U.S. scientist participation in IODP.

External Governance Structure
NSF provides the *JOIDES Resolution (JR)* as the light IODP drillship through an award with Texas A&M University as the *JOIDES Resolution* Science Operator (JRSO). MEXT provides the *Chikyu* as the heavy IODP drillship through the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 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 *JOIDES Resolution* Facility Board (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 *JOIDES Resolution* (via the operator—Texas A&M University), (2) the Science Support Office, and (3) the *JOIDES Resolution* 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 *JOIDES Resolution* 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 2020 Actual | FY 2021 Estimate | FY 2022 Request | ESTIMATES[1] FY 2023 | FY 2024 | FY 2025 | FY 2026 | FY 2027 |
|---|---|---|---|---|---|---|---|---|
| Operations & Maintenance | $48.00 | $48.00 | $48.00 | $48.00 | $48.00 | $48.00 | $48.00 | $48.00 |

[1] Outyear estimates are for planning purposes only. The current cooperative agreement ends September 2024.

In FY 2021, NSF expects *JOIDES Resolution* operations in support of IODP will be funded at the level of $48.0 million from NSF appropriations, with a similar amount needed in future years. An additional $11.13 million from international partners will support *JOIDES Resolution* operations.

**Reviews**

Review of FY2020 *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 February 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.

There are no specific plans for divestment currently, but NSF does not plan to operate *JOIDES Resolution* beyond 2028, which would slightly exceed the planned service life of the drillship. NSF has recently issued a Dear Colleague Letter[1] requesting 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*.

[1] www.nsf.gov/pubs/2021/nsf21043/nsf21043.jsp

## LARGE HADRON COLLIDER (LHC) – ATLAS AND CMS $20,500,000
+$500,000 / 2.5%

**Large Hadron Collider Funding**
(Dollars in Millions)

| FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|
| $20.00 | $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 at 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 discoveries of the last 50 years in particle physics. 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 in the MREFC chapter 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. 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, now nearing completion, will enable ATLAS and CMS to keep pace with LHC's performance enhancements through 2024. A two-year shutdown planned to begin in 2025 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 operation program have been relatively minor so far. Ongoing activities at CERN to prepare the ATLAS and CMS detectors for the next cycle of accelerator operations, scheduled to begin in February 2022, continue to make good progress. U.S. scientists and international colleagues conduct hands-on detector support activities that follow carefully orchestrated protocols to ensure worker safety. Additionally, NSF support for LHC detector operation is concentrated in the software and computing areas, which have continued to operate according to pre-pandemic plans and are fully meeting expectations.

**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 25 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 PHY Elementary Particle Physics and the Nuclear Physics programs.

In addition, a world-wide cyber-infrastructure, 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 92 U.S. universities and five national laboratories to access LHC data and computing resources and thus train students in both state-of-the-art science and computational techniques.

**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, the Office of Budget, Finance, and Award Management (BFA), the Office of the General Counsel (OGC), and the Office of Legislative and Public Affairs. Within BFA, the Large Facilities Office (LFO) provides advice to program staff and assists with agency oversight and assurance. The MPS facilities team and the Chief Officer for Research Facilities also provide high-level guidance, support, and oversight.

External Governance Structure

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. Each experiment is funded by more than forty different agencies, including NSF and DOE. NSF and DOE coordinate U.S. investments in LHC 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 Princeton University for CMS, and another to Stony Brook University for ATLAS. The current awards expire in December 2021 and January 2022, respectively, and the U.S. collaborations have each identified the universities that will steward NSF's anticipated subsequent five-year operations awards.

Partnerships and Other Funding Sources
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, where extraordinary efforts by CERN, the experimental collaborations, and funding agencies are planned on a global scale to support High Luminosity LHC operation beyond 2027.

**Total Obligations for LHC**

(Dollars in Millions)

| | FY 2020 | FY 2021 | FY 2022 | ESTIMATES[1] | | | | |
|---|---|---|---|---|---|---|---|---|
| | Actual | Estimate | Request | FY 2023 | FY 2024 | FY 2025 | FY 2026 | FY 2027 |
| Operations & Maintenance | $20.00 | $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 end in December 2021 (CMS) and January 2022 (ATLAS).

The FY 2022 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 will restart in February 2022 and resume full-time operation in May 2022. This follows the successful conclusion of the three-year data-taking period in December 2018, and the start 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 operation 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 in May 2019. The next joint operations reviews are planned for January 2022. The most recent JOG was held in March 2021 and another is planned for October 2021.

**Renewal/Recompetition/Termination**

Operations awards for ATLAS and CMS were renewed for five years in January and February 2017, respectively. Future renewal is being conducted through a proposal-driven process that is currently underway. NSF plans to conduct an external review and cost analysis of each detector's operations proposal in Q4 of FY 2021 and Q1 of FY 2022, respectively.

NSF has no ownership of any part of the facility. No divestment is planned at this stage. CERN has taken responsibility for disposal of all irradiated apparatus at the conclusion of experimental activity.

**LASER INTERFEROMETER GRAVITATIONAL-WAVE OBSERVATORY (LIGO)** **$45,000,000**
**$0**

**Laser Interferometer Gravitational-Wave Observatory Funding**
(Dollars in Millions)

| FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|
| $45.00 | $45.00 | $45.00 | - | - |

## Brief Description

NSF's Laser Interferometer Gravitational-Wave Observatory, 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 50 additional GW candidate sources.

## Status of the Facility

The broader scientific community is eager for more GW detections. As LIGO's event detection rate scales as the third power of its sensitivity, LIGO prioritizes efforts aimed at improving performance over extended observing. 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% 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 June 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 efforts comparable to LIGO to directly observe GWs. Both efforts lag behind LIGO 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 0-1000Hz). NANOGrav (a U.S.-Canadian effort supported by NSF), along with similar efforts in Europe and Australia, are 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 safety measures in place to ensure the safety of LIGO workers. However, this 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. Additionally, LIGO's fourth observational run, originally planned to begin in 2021, is now planned to begin no earlier than June 2022. 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 100 collaborating institutions in 18 countries with nearly 1,300 participating scientists. The LSC plays a major role in many aspects of the LIGO effort. These include establishing priorities for scientific operation, carrying out data analysis and validation of scientific results, and contributing to instrumental improvements 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 approximately $8 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, the Office of Budget, Finance, and Award Management (BFA), the Office of the General Counsel (OGC), and the Office of Legislative and Public Affairs. Within BFA, the Large Facilities Office (LFO) provides advice to program staff and assists with agency oversight and assurance. 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 are fully integrated into all LIGO activities. The LIGO management coordinates significant involvement by the user community, represented by the LSC, and collaborations 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 million MREFC project that funded 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 8. The United Kingdom (UK), Germany, and Australia provided components and services to the Advanced LIGO project that are valued at about $20 million.
- LIGO-India, if realized, would be constructed through a transfer to India of Advanced LIGO components, valued at approximately $50 million, originally intended as a second Hanford interferometer. (This transfer would enhance the source localization capabilities of the global GW network.) 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 (PHY-1834382). 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 2022. 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 2020 | FY 2021 | FY 2022 | ESTIMATES[1] | | | | |
|---|---|---|---|---|---|---|---|---|
| | Actual | Estimate | Request | FY 2023 | FY 2024 | FY 2025 | FY 2026 | FY 2027 |
| Operations & Maintenance | $45.00 | $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 2020. 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 operation in October 2018. 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 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|
| $65.00 | $65.00 | $70.00 | $5.00 | 7.7% |

### Brief Description

Funded and overseen in the Directorate for Biological Sciences (BIO), 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 will 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 or API to access NEON data. In the year prior to the onset of COVID-19, NEON staff supported 304 engagement events reaching over 8,444 individuals. Events included presentations, site tours, conference attendance, in-person and virtual workshops, trainings and outreach through social media, NEON site tours, workshops to a wide range of public and STEM audiences. The groups engaged during these events are at different educational and/or career stages (e.g., high-school, undergraduate, graduate student, postdoctoral fellows, scientists in academia, agencies), across geographic areas in the U.S., and from different demographics including underrepresented groups and Minority Serving Institutions.

Summary of COVID-19 Impacts

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 April 28, 2021, 17 of 18 DSFs were fully open; 78 field sites were fully open, 2 field sites are in limited operations, and one was closed; and the NEON Headquarters Boulder 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 Program 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), participate in the science development of the Hyperspectral Infrared Imager mission. Multiple NEON science presentations by funded researchers formed the corpus of continental-scale sessions at the 2020 Ecological Society of America meetings in addition to presentations at several other venues, such as the 2020 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**

NSF Governance Structure

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 General Counsel provides ongoing technical advice on the National Environmental Policy Act compliance and NSF’s compliance with environmental policy.

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 (OLPA), the Office of Budget, Finance, and Award Management (BFA)-Large Facility Office (LFO), BFA Division of

Acquisition and Cooperative Support (DACS), BFA Division of Institution and Award Support - Cost Analysis and Pre-Award Branch, Office of 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.

External Governance Structure
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 Cooperative Agreement. 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, comprised of 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.

Partnerships and Other Funding Sources
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 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, 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. A number 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 2020 Actual | FY 2021 Estimate | FY 2022 Request | ESTIMATES[1] FY 2023 | FY 2024 | FY 2025 | FY 2026 | FY 2027 |
|---|---|---|---|---|---|---|---|---|
| Operations & Maintenance | $65.00 | $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 February 2023.

The NEON program in BIO provides all support for operations, which are estimated at approximately $70.00 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 confirm 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. 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 $65.0 million). This operations and maintenance phase provided Battelle time 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 his intention to exercise the option for a fourth year of funding. A Dear Colleague Letter was released announcing NSF’s intention to compete the management of NEON operations and maintenance and encouraging organizations to submit requests for information. BIO anticipates 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 15 months. Thus, NSF, based on positive annual reviews of operations by panels of external experts and other data, has asked Battelle to operate NEON through February 2023, allowing the Agency time to execute a robust competition. NSF continues to consider the optimal time frame for the competition based on the status of the COVID-19 pandemic and the ability to execute all elements of a robust competition. The anticipated lifetime of the NEON project is thirty years.

## NATIONAL HIGH MAGNETIC FIELD LABORATORY (NHMFL) — $38,910,000 / +$12,930,000 / 49.8%

**National High Magnetic Field Laboratory Funding**

(Dollars in Millions)

| FY 2020 Actual[1] | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|
| $34.59 | $25.98 | $38.91 | $12.93 | 49.8% |

[1] Includes $12.0 million to fund part of FY 2021 operations costs and excludes $14.20 million obligated in FY 2019 for FY 2020 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. The 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. 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 is conducted by users of NHMFL investigating topics including quantum phenomena of 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 imperative in energy production, storage, and use.

A major scientific impact is expected from the research on quantum materials conducted by researchers using the NHMFL magnets. These magnets allow for the exhibition, identification, and visualization of new and unusual quantum effects that lead to deeper understanding of quantum materials and enable the discovery of new ones. Over the last several years, the NHMFL has contributed to major scientific accomplishments in superconductivity and the budding field of topological materials, an entirely new class of quantum materials prominently distinguished by the 2016 Nobel Prize in Physics. For example, in 2019 the 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, and its occurrence at high fields 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 the NHMFL include the first

[1] www.nationalmaglab.org/news-events/news/rare-lazarus-superconductivity

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. In April 2017, 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 opens new probing capabilities for chemists and biologists.

**Status of the Facility**

Status with respect to Scientific Community

- 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 of $8.40 million to date3 for development and conceptual 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 (DMR-1946998), 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.
- 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 field 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.

[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 a separate award, DMR-1938789 ($4.20 million in FY 2020).
[4] www.arxiv.org/ftp/arxiv/papers/2103/2103.09155.pdf

COVID-19 Status

Starting in early March 2020, the NHMFL imposed access restrictions on its facilities at all three sites (FSU, UF, and LANL) due to health concerns related to the coronavirus (COVID-19). These restrictions progressed from travel restrictions to limited access to the NHMFL sites as the COVID-19 health situation evolved and new mandates were put in place by Center for Disease Control and Prevention, as well as state and local authorities. In the spring of 2021, the NHMFL had overall about 50% of its staff working on-site while the remaining personnel were working remotely. While currently below normal activity, the NHMFL's user program remains overall operational, taking advantage of the availability of remote operations of many of the available instruments. Among the seven user programs, remote user operations vary from about 50% in the case of the DC field, to almost 100% for the FT-ICR and the Nuclear Magnetic Resonance (NMR) facilities.

**Meeting Intellectual Community Needs**

NHMFL is the largest and highest-powered magnet laboratory in the world with more than 2,000 users annually. The annual number of NHMFL users continues to grow with about 20 percent of the total users each year being new users. The users include senior investigators, postdoctoral researchers, and students listed on the user proposals. The condensed matter physics, chemistry, and biology user communities have experienced significant growth in recent years.

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 Experience for Undergraduates program, summer programs for teachers, a summer camp for middle school girls, and activities to raise the scientific awareness of the general public. 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) supports the FT-ICR Facility, which is overseen by a CHE program director. The Division of Acquisition and Cooperative Support (DACS) and the Large Facilities Office (LFO) within the Office of Budget, Finance, and Award Management (BFA), provide financial and administrative support and assist with agency oversight and assurance. 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 agreement signatory, is responsible for administrative and financial oversight and for ensuring that lab operations are consistent with the cooperative agreement. The principal investigator, the NHMFL director, reports to the FSU Vice President for Research. Four senior faculty members are co-principal investigators. The NHMFL director receives guidance primarily from the NHMFL executive committee, the NHMFL science council, and the NHMFL diversity committee together with recommendations from an external advisory committee and the users’ executive committee.

Partnerships and Other Funding Sources

The State of Florida contributes approximately $12 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 million per year to the NHMFL. Additional funding, at the level of $4 to $6 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 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 of these projects 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 2020 Actual | FY 2021 Estimate | FY 2022 Request | ESTIMATES[1] FY 2023 | FY 2024 | FY 2025 | FY 2026 | FY 2027 |
|---|---|---|---|---|---|---|---|---|
| Operations & Maintenance (DMR)[2] | $32.86 | $24.10 | $37.18 | $36.09 | $36.09 | $36.09 | $36.09 | $36.09 |
| Operations & Maintenance (CHE) | 1.73 | $1.88 | 1.73 | 1.73 | 1.73 | 1.73 | 1.73 | 1.73 |
| **Total** | **$34.59** | **$25.98** | **$38.91** | **$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] FY 2020 Actual includes $12.0 million to fund part of FY 2021 operations costs and excludes $14.20 million obligated in FY 2019 for FY 2020 operations.

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 million per year) is escalated by 3 percent annually, and CHE generally provides $1.73 million annually to support NHMFL's FT-ICR facility. The actual budget each year varies due to forward funding and supplemental funding actions.

## 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.

**Renewal/Recompetition/Termination**

The current award, in an amount not to exceed $184.05 million for the operation of the NHMFL started on January 1, 2018 and will end on December 31, 2022. MPS developed an analysis of considerations for potential renewal, recompetition, 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. Currently there are no plans for divestment of this facility.

**OCEAN OBSERVATORIES INITIATIVE (OOI)** **$48,500,000**
**+$4,500,000 / 10.2%**

**Ocean Observatories Initiative Funding**
(Dollars in Millions)

| | | | Change over FY 2021 Estimate | |
|---|---|---|---|---|
| FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Amount | Percent |
| $43.97 | $44.00 | $48.50 | $4.50 | 10.2% |

## 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 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 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.

## Status of the Facility

OOI began full operations in FY 2016 with seven arrays. In 2019-2020 the two Global Arrays in the Southern Hemisphere, in the Argentine Basin and at 55 South, were descoped following recommendations from the National Academies of Science, Engineering and Medicine's *Sea Change* report. In 2021 OOI is operating the remaining five arrays and a fleet of gliders as described above. A maintenance cruise is conducted annually at each Global Array and the Regional Cabled Array and bi-annually at each Coastal

[1] www.oceanobservatories.org
[2] www.oceanobservatories.org/data-portal/

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 on board 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 Regional Cabled Array are transmitted ashore in real-time via the underwater 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 booth and a virtual Town Hall at the Fall 2020 Virtual American Geophysical Union meeting.

NSF is currently collaborating with the science community to identify and assess possible options for relocating the Pioneer Array (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 the stakeholders are working together through a series of Innovation Labs to identify future location options. Initial experience with OOI shows that the complexity and logistical issues involved with moving an array make it likely that the typical interval before relocating an array will be longer than 5 years. The PA would be deployed in its new location and configuration in 2024.

COVID-19 has impacted the OOI team by limiting the access of team members to the laboratories to conduct required 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 the requirements to mitigate the potential spread of COVID-19. Despite the limitations, the OOI team has been able to conduct maintenance cruises for all the arrays and thereby significantly mitigated the potential for loss of valuable in-water infrastructure. There were some instances where reduced battery power required adjustments to the instrument sampling rates, resulting in reduced data flow.

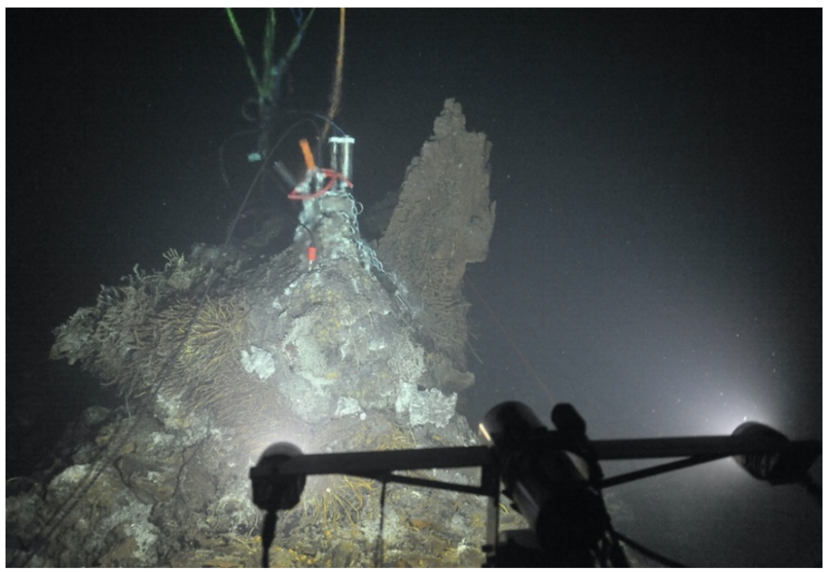
**Meeting Intellectual Community Needs**

In close collaboration with and in response to the needs expressed by the science community, the overarching scientific themes of the OOI 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 modifies the mineralogy of oceanic crust and sediments, leads to the formation of hydrothermal vents that support unique micro- and macro-biological communities can form economically-important mineral deposits, and concentrates methane to form massive methane gas and methane hydrate reservoirs. The role that transient events (e.g., earthquakes, volcanic eruptions, and slope failures) play in these fluid-rock interactions and in the dynamics of benthic and sub-seafloor microbial communities remain largely unknown.
- *Plate-Scale, Ocean Geodynamics*. Lithospheric movements and interactions at plate boundaries at or beneath the seafloor are responsible for short-term events such as earthquakes, tsunamis, and volcanic eruptions. These tectonically active regions are also host to the densest hydrothermal and biological activity in the ocean basins. The degree to which active plate boundaries influence the ocean from a physical, chemical, and biological perspective are largely unexplored.

The science community is continuing its use of the OOI data through downloads of both raw data and derived products. Feedback from users in the science community has been very positive. 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. After the new website went online, the number of users and number of new users of the site doubled, and the number of page views and number of unique page views tripled. Users of the new website also visited more pages and stayed longer on the site. The stakeholders list, which now numbers more than 2,600, has continued to grow.



The Regional Cabled Array 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*.

A summary of several statistics on the usage of OOI for the October-December 2020 period show:
- 9.9 TB of data were provided to 122 distinct users based on over 37.2 million data requests.
- OOI posted 56 times to its Instagram site and had 160 new followers.
- OOI tweeted 98 times with 2,540 likes and gained 50 new followers for a total of 1,522 followers.
- OOI posted to its Facebook account 98 times with 80 new followers and a total of 2,594 followers.

**Governance Structure and Partnerships**

NSF Governance Structure
The project is managed and overseen by a two-person OOI team in OCE that receives advice and oversight support as required from the Office of Budget, Finance, and Award Management, the Office of the General Counsel, the Office of Legislative and Public Affairs, the Directorate for Computer and Information Science and Engineering, and the NSF Large Facilities Office.

External Governance Structure
A new cooperative agreement for operations and management (O&M) of OOI started 1 October 2018 with Woods Hole Oceanographic Institution (WHOI) as the awardee. The OOI program director at WHOI is responsible for overall operations and maintenance, including data management, of the OOI and serves as the Principal Investigator on the award from NSF. WHOI has subawards with three Implementing Organizations:

- Oregon State University – Endurance Coastal Array and the OOI Cyberinfrastructure Data Systems Center
- University of Washington – Regional Cabled Array
- Rutgers University – Cyberinfrastructure Hardware

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 the OOI. The OOIFB assists in the process of communicating the community science use perspective to NSF and the project teams involved in deploying and operating the OOI. The OOIFB recently completed an update to the OOI Science Plan, available at the OOIFB website (www.ooifb.org). The Data Systems Committee is a subcommittee of the OOIFB helping ensure timely and reliable access to high-quality OOI data.

**Funding**

**Total Obligations for OOI**

(Dollars in Millions)

| | FY 2020 | FY 2021 | FY 2022 | ESTIMATES[1] | | | | |
|---|---|---|---|---|---|---|---|---|
| | Actual | Estimate | Request | FY 2023 | FY 2024 | FY 2025 | FY 2026 | FY 2027 |
| Operations & Maintenance | $43.97 | $44.00 | $48.50 | $48.50 | $48.50 | $48.50 | $48.50 | $48.50 |

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

The budget increase from $44.00 to $48.50 is planned to support recapitalization of the primary in-water infrastructure, including the glider fleet which has been in continuous operation since 2016.

**Reviews**

With the OOI facility in year three of the initial five-year award to WHOI, an OOI 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, 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 plans to conduct a tailored Business Systems Review in 2021.

**Renewal/Recompetition/Termination**

NSF completed the process of recompeting the O&M award through an open, merit-based external peer-review process resulting in a new award to WHOI as the Program Management Office, which started October 1, 2018 and runs through September 30, 2023. Program reviews are held annually, and NSF has begun the mid-award performance review process in accordance with the NSF Standard Operating Guidance for Renew, Recompete, or Divest decisions. Currently there are no plans for divestment of this facility.

**SEISMOLOGICAL FACILITY FOR THE ADVANCEMENT OF GEOSCIENCE (SAGE)** **$21,870,000**
**+$20,000 / 0.1%**

**Seismological Facility for the Advancement of Geosciences Funding**
(Dollars in Millions)

| FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|
| $21.50 | $21.85 | $21.87 | $0.02 | 0.1% |

**Brief Description**

SAGE is a distributed, multi-user facility that enables a diverse 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 three of a five-year award, and the current capabilities provided by the facility have evolved based on input from a series of community engagement activities held in 2015, including a NSF-sponsored workshop entitled "Future Seismic and Geodetic Facility Needs in the Geosciences".[1] The Division of Earth Sciences (EAR) in the Directorate for Geosciences is deliberating the path forward for evolving 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 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

[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
[3] www.nap.edu/catalog/25536/management-models-for-future-seismological-and-geodetic-facilities-and-capabilities

single facility with a single operator.[4]

To further inform its planning for the future geophysical facility, the Directorate for Geosciences commissioned from a subcommittee of its Advisory Committee a portfolio review of possible geophysical instrumentation and sensor networks that a new facility might support to address the science priorities highlighted in the decadal survey. The portfolio review highlights the capabilities that a new facility should support in order to best enable the community to address the science priorities in the 2020 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 now strategizing to define the best path forward for a future facility and undertaking efforts to expand existing federal partnerships.

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 continues "bare-bones" operations and data delivery, with removal now planned for 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 via awards from NSF, the U.S. Geological Survey (USGS), and other agencies. The Geophysics, GeoPRISMS, Tectonics, and Frontier Research in Earth Sciences in EAR; the GeoPRISMS and Marine Geology and Geophysics programs in the Division of Ocean Sciences (OCE); and the Earth Science and Glaciology programs in the Office of Polar Programs (OPP) provide most of the funds for the NSF-sponsored research making use of SAGE.

Demands remain high for data, equipment, and other resources provided via SAGE. In the first three quarters of fiscal year 2020:

- The total amount of data downloaded from the SAGE Data Management Center increased by a factor of 1/3 compared to the same period in FY 2019;
- At least 70 field experiments used equipment and support provided via 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.

[4] www.nsf.gov/pubs/2020/nsf20037/nsf20037.jsp

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 an LFO official. 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., OGC staff, OD 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 NSF's 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. One regional seismic network—ATA—continues to operate under the old SAGE award. This array will be decommissioned in 2021.

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 (NOAA) 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 2020 Actual | FY 2021 Estimate | FY 2022 Request | ESTIMATES[1] FY 2023 | FY 2024 | FY 2025 | FY 2026 | FY 2027 |
|---|---|---|---|---|---|---|---|---|
| Operations & Maintenance | $21.50 | $21.85 | $21.87 | $23.37 | $23.37 | $23.37 | $23.37 | $23.37 |

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

The Earth's interior remains a major scientific frontier holding the key to understanding the origin of the planet. Recent developments in seismic sensor design and the acquisition, transmission, and storage of data have resulted in dramatic improvements in the resolving power of seismic imaging of the interior of the Earth. To serve the research needs of the broad Earth science community, SAGE is organized under three primary service areas:

Instrumentation Services

- The GSN consists of over 150 permanently installed broadband digital seismic stations, most of which have real-time data access. GSN stations provide critical data for a range of global Earth science research and support key national security needs such as nuclear test-ban treaty verification and natural hazards warning and response. GSN is operated in partnership with the USGS.
- Portable Seismology includes a pool of over 5,200 portable seismometers that are made available to the Earth science research community for a wide range of principal investigator-driven experiments largely funded through the NSF merit review process to study a wide range of Earth processes.
- Polar Support Services supports the development of specialized seismic equipment for use in harsh environments and provides instrumentation, training, and field support for experiments in the polar regions.
- The Transportable Array (TA) was a continental-scale seismic observatory designed to provide a foundation for multi-scale integrated studies of continental lithosphere and deep Earth structure. After operating 1,700 stations in the lower 48 states between 2004 and 2015, the full 280-station TA network is now deployed in Alaska and western Canada. This regional seismic network continues to operate under the old SAGE award and NSF is in the process of transferring adopted stations to other Federal agencies for long-term operations and maintenance. Stations that are not adopted will be decommissioned in FY 2021.
- The Magnetotelluric component exploits the natural variations in Earth's magnetic and electric fields to provide information on the distribution and composition of fluids in Earth's crust and upper mantle, which gives constraints on Earth's structure that are complementary to those resulting from seismology.
- Instrumentation Services-Coordinated Activities include efforts to develop the next generation of seismic instrumentation for large-scale scientific experiments; global-scale geophysical networks; and training courses to distribute best practices to partners worldwide.

Data Services

SAGE Data Services manages an archive of over 540 terabytes of seismic, magnetotelluric, and other data from all SAGE components, the EarthScope program[5], and numerous affiliated networks; operates automated and manual systems to ensure the quality of all data stored in the archive; and provides systems to give the national and international research community timely access to these data. In FY 2020, more than 19,000 unique users downloaded data from the SAGE archive. These data are used for a wide range of applications, including research and education.

Education and Public Outreach

The SAGE Education and Public Outreach program enables audiences beyond seismologists to access and use seismological data and research, including student internships, and programs for under-resourced educational institutions.

In addition to the three services mentioned, program plans to implement 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

[5] EarthScope was an MREFC-funded experimental facility focused on understanding the structure and evolution of the North American continent and the processes that cause earthquakes and volcanic eruptions.

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 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 will conduct a full management review of the facility in FY 2021.

**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 is scheduled to be completed by the end of FY 2021. NSF personnel are working with other federal agency partners to take over operations of some of the stations.

The current SAGE award will fund the facility until the end of FY 2023. NSF is considering the recommendations contained in the *Earth in Time* decadal survey as well as the interagency context in which the facility operates in formulating a strategy for continued support of this important community research resource.

## FEDERALLY FUNDED RESEARCH AND DEVELOPMENT CENTERS (FFRDCS)

### GREEN BANK OBSERVATORY (GBO) $9,120,000

**+$220,000 / 2.5%**

**Green Bank Observatory Funding**

(Dollars in Millions)

| FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Change over FY 2021 Estimate Percent |
|---|---|---|---|---|
| $9.42 | $8.90 | $9.12 | $0.22 | 2.5% |

### Brief Description

GBO is a major NSF research facility and a Federally Funded Research and Development Center (FFRDC) located in Green Bank, West Virginia. It is operated by Associated Universities, Inc. (AUI) under a cooperative agreement with NSF. GBO enables leading ground-based research at radio wavelengths by offering access to telescopes, facilities, and advanced instrumentation to the U.S. scientific community, and it conducts an active program of education and public outreach. GBO is also the administrative site of the 13,000-square-mile National Radio Quiet Zone, where 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 emission of the kind associated with comets, molecular clouds, and distortions of the cosmic microwave background. GBT is complementary 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 focal plane is ideal for rapid, wide field imaging using multi-pixel cameras.

### Status of the Facility

The scientific direction and operations of the Observatory are being 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 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.

GBO conducts regular inspections of and maintenance on numerous components of its telescopes and site infrastructure. The last full structural inspection of GBT by an independent engineering firm was completed in 2018, with additional inspections scheduled to be completed in 2021 and 2024.

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 about 50% 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.

**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.

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.

**Governance Structure and Partnerships**

<u>NSF Governance Structure</u>

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 General Counsel, as well as the Division of Acquisition and Cooperative Support and the Large Facilities Office in Budget, Finance, and Award Management (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 (non-NSF) 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)[1] as well as 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 GBT in exchange for operations funding. Other partnership development efforts are continuing.

## Funding

**Total Obligations for GBO**

(Dollars in Millions)

| | FY 2020 Actual[1] | FY 2021 Estimate | FY 2022 Request | ESTIMATES[2] FY 2023 | FY 2024 | FY 2025 | FY 2026 | FY 2027 |
|---|---|---|---|---|---|---|---|---|
| Operations & Maintenance | $9.42 | $8.90 | $9.12 | $9.33 | $9.55 | $9.55 | $9.55 | $9.55 |

[1] Includes $1.75 million from a technical deobligation/reobligation action from a previous award.

[2] Outyear funding estimates are for planning purposes only. The current cooperative agreement ends in FY 2024.

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.[2] In 2012, that portfolio review recommended divestment of GBT in order to sustain balance in the AST program.[3] NSF subsequently undertook a full environmental review of options for the future of GBO, culminating in NSF's July 2019 Record of Decision (ROD)[4] 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 FY 2022 Request for GBO is $9.12 million and 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.

## Reviews

NSF conducts annual reviews of the program operating plan and reports, including external advice from community representatives. Recommendations from annual reviews are routinely used to inform GBO's operations planning and NSF's oversight thereof. The first review under the new cooperative agreement was held in December 2020.

[1] www.breakthroughinitiatives.org/initiative/1
[2] www.nap.edu/catalog/12951/new-worlds-new-horizons-in-astronomy-and-astrophysics
[3] www.nsf.gov/mps/ast/portfolioreview/reports/ast_portfolio_review_report.pdf
[4] www.nsf.gov/mps/ast/env_impact_reviews/greenbank/greenbank_rod.jsp

**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 at approximately the midpoint of the five-year award to assess choices regarding renewal, competition, or divestment of the facility beyond FY 2024.

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)** **$104,000,000**
**$0**

**National Center for Atmospheric Research Funding**

(Dollars in Millions)

| | | | Change over FY 2021 Estimate | |
|---|---|---|---|---|
| FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Amount | Percent |
| $99.70 | $104.00 | $104.00 | - | - |

**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 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 throughout 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, a consortium of 120 member universities in the U.S. and overseas. 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. It is hoped that these will be resumed in FY 2022, beginning with those that had been postponed in FY 2020 and FY 2021.

Several significant infrastructure improvement projects are at or close to completion, including a full overhaul of the primary heating and cooling systems at the NCAR Mesa Laboratory that will result in considerable increases in efficiency and reduced operating costs. A major renovation of the NCAR Research Aviation Facility at the Rocky Mountain Metropolitan Airport will provide new, state-of-the art laboratory, engineering, and technical space in support of the two 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 will result in a more than threefold increase in the computing speeds available to the Center's users in the Earth System Science research community. The new system, to be called 'Derecho' following a statewide naming competition among Wyoming school students, will become operational in early 2022.

**Meeting Intellectual Community Needs**

NCAR connects to its user stakeholders by providing the community with models, cyberinfrastructure, observing facilities, and collaborative opportunities, in addition to education, outreach, and training that are essential to its research community. FY20 highlights include:

- The Weather Research Forecast Model (WRF) continued to see strong user interest, with the cumulative number of WRF registrations standing at over 52,000 as of the end of the FY and new model registrations averaging about 4,000 per year for the past three years. NCAR hosted the annual weather model Users' Workshop in June 2020, with 595 registered participants. NCAR also conducted one WRF tutorial in January 2020, which attracted 49 students. (The second WRF tutorial, typically held in summer, was deferred due to COVID-19 restrictions).
- An improved version of the Community Earth System Model (CESM 2.2.0) was released in September 2020. CESM 2.2.0 provides a wider variety of configurations for users (allowing deeper insights into atmospheric processes), and updates to the ocean, land-surface, chemistry, geospace and atmospheric subcomponents. Comprehensive simulations performed with CESM 2.2.0 will shape community inputs to the next Intergovernmental Panel on Climate Change (IPCC) assessment.
- NCAR's 534-petaflop high-performance computer (Cheyenne) and its GLobally Accessible Data Environment (GLADE) were used by almost 1,800 individuals at 275 universities. During the year, utilization of the primary NCAR supercomputer increased to 97% (with 99% availability). In addition, NCAR maintains and provides simplified access to multi-terabyte datasets relevant to the atmospheric research community. The NCAR Research Data Archive delivered more than 7.3 PB of data to 14,000 unique users.
- In FY 2020, NCAR was able to provide support for only one local observational field campaign; all others were postponed due to the COVID pandemic. Looking ahead, requests were approved for 15 future observational field campaigns involving 16 individual observing platforms and systems.
- Every year, NCAR hosts a wide variety of community events including workshops, colloquia, conferences, symposia, and tutorials. In FY 2020, a total of 100 events (426 individual sessions) were hosted: 174 workshops, 224 tutorials, 22 conferences, and 6 colloquia with an average audience of 83 attendees per event and an estimated total audience of 35,609. The majority of these events were held virtually due to COVID-19-related restrictions.

- 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 take part in community workshops and strategic discussions, conduct independent research, participate in and/or oversee student, post-doctoral, and professional projects. In FY 2020, NCAR hosted 412 visitors from 169 different institutions in 37 U.S. states and 27 countries, the majority virtually.
- In FY 2020, NCAR staff served as graduate advisors or committee members for 202 graduate students. Eighteen of those are working on their M.S. degree and 184 are working on their Ph.D. Seventy-three percent of these students attend U.S. universities, whereas 27% study at schools in 24 different countries worldwide.
- Of NCAR staffs 746 peer-reviewed publications in FY 2020, 93% were published in collaboration with authors at other institutions.
- NCAR, in collaboration with the UCAR COMET program and Millersville University, published the remaining two of a total of ten online lessons that comprise the *Collaborative Research: Synergistic Environments in Graduate and Undergraduate Education in Atmospheric Instrumentation and Measurement Training (SEGUE)* course. These free, online lessons target students at the advanced undergraduate and graduate level and focus on the science involved in measuring basic atmospheric parameters. As of September 2020, more than 20,200 learners completed sessions spread across the various lessons, and 73 learners completed the entire course, which provides a total of approximately 20 hours of atmospheric instrumentation training.
- During the onset of the pandemic in spring of 2020, NCAR staff supported over 40 managers from GEO Research Experience for Undergraduates (REU) internship programs around the country to share ideas, adapt, and plan their summer programs by holding three weekly Zoom drop-in sessions. Staff also developed an eight-week Professional Development Series for 45 undergraduate interns from the NSF Ocean Sciences REU program that was created for the pandemic.

**Governance Structure and Partnerships**

<u>NSF Governance Structure</u>
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, the Office of Budget, Finance, and Award Management (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.

<u>External Governance Structure</u>
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.

Gulf Stream 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.*

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 NASEM studies or community workshops.

<u>Partnerships and Other Funding Sources</u>
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 $104.00 million planned FY 2021 investment, NCAR received approximately $44.8 million in support from other federal agencies, including 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, and $13.0 million from non-federal sources. This funding supports research collaboration that enhances and extends NCAR's NSF-supported research goals or facilities missions.

## Funding

**Total Obligations for NCAR**

(Dollars in Millions)

| | FY 2020 | FY 2021 | FY 2022 | ESTIMATES[1] | | | | |
|---|---|---|---|---|---|---|---|---|
| | Actual | Estimate | Request | FY 2023 | FY 2024 | FY 2025 | FY 2026 | FY 2027 |
| Aircraft Support | $10.28 | $10.50 | $10.50 | $10.50 | $10.50 | $10.50 | $10.50 | $10.50 |
| Computational Infrastructure | 34.28 | 34.00 | 34.00 | 34.00 | 34.00 | 34.00 | 34.00 | 34.00 |
| Other Facility Support | 23.16 | 27.50 | 27.50 | 27.50 | 27.50 | 27.50 | 27.50 | 27.50 |
| Research and Education Support | 31.98 | 32.00 | 32.00 | 32.00 | 32.00 | 32.00 | 32.00 | 32.00 |
| **TOTAL** | **$99.70** | **$104.00** | **$104.00** | **$104.00** | **$104.00** | **$104.00** | **$104.00** | **$104.00** |

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

The current five-year cooperative agreement for the management and operation of NCAR began on October 1, 2018 and may be extended for a further five-year period subject to NSF's determination of satisfactory performance by the awardee. The annual amount of the award 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 award of funding to renovate the NSF-owned NCAR Research Aviation Facility in 2018.

**Reviews**

The next comprehensive review of NCAR's science, facilities and management will involve virtual site visits by teams of experts from the scientific community and will take place in mid-2021. A Business Systems Review will be conducted during FY 2022.

**Renewal/Recompetition/Termination**

The award to manage and operate NCAR for a period of five years was made to the University Corporation for Atmospheric Research (UCAR) with a start date of October 1, 2018. This award may be extended for a further five-year term subject to satisfactory performance by the awardee. A determination of satisfactory performance will be informed primarily by the findings of a comprehensive mid-term scientific and management review, planned to take place during the third year of the award (FY 2021). If UCAR's performance is considered satisfactory, they 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)** **$91,160,000**
**+$3,030,000 / 3.4%**

**National Radio Astronomy Observatory Funding** [1]
(Dollars in Millions)

| FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|
| $89.25 | $88.13 | $91.16 | $3.03 | 3.4% |

[1] Funding includes the base operations for NRAO and ALMA.

## Brief Description

NRAO is a Federally Funded Research and Development Center (FFRDC) that conceives, designs, builds, operates, and maintains radio telescopes used by scientists from around the world 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.

Atacama Large Millimeter/submillimeter Array (ALMA)
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 $z\sim10$ (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 $z\sim3$ (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 (VLA)
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 expansion 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 cm 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 (VLBA)
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. 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 which the European Gaia spacecraft has achieved 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 (CDL)
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 enabling technologies such as 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 scientific, merit-reviewed proposals. NRAO facilities annually serve over 2,500 users worldwide; moreover, continued high demand for ALMA has resulted in the most proposals ever received for an astronomical facility in response to a single proposal call and has placed ALMA 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 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.

**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 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 General Counsel, Office of International Science and Engineering, and the Division of Acquisition and Cooperative Support and the Large Facilities Office in the Office of Budget, Finance, and Award Management. 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>
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.

<u>Partnerships and Other Funding Sources</u>
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% 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" or EA). NA and ESO are equal (37.5 percent) partners and EA contribute 25 percent. Canada contributes 7.25 percent of the 37.5 percent NA share of operations. Taiwan contributed about 4 percent of NA construction.

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 2020 Actual | FY 2021 Estimate | FY 2022 Request | ESTIMATES[1] FY 2023 | FY 2024 | FY 2025 | FY 2026 | FY 2027 |
|---|---|---|---|---|---|---|---|---|
| NRAO Operations & Maintenance[2] | $41.98 | $39.45 | $40.53 | $41.65 | $42.81 | $43.97 | $45.19 | $45.19 |
| *Telescope Operations* | *11.00* | *11.28* | *11.59* | *11.91* | *12.24* | *12.58* | *12.92* | *12.92* |
| *Development* | *7.58* | *7.77* | *7.98* | *8.21* | *8.43* | *8.66* | *8.90* | *8.90* |
| *Science Operations* | *6.19* | *6.35* | *6.52* | *6.71* | *6.90* | *7.08* | *7.28* | *7.28* |
| *Administrative Services* | *10.51* | *10.77* | *11.06* | *11.37* | *11.68* | *12.00* | *12.34* | *12.34* |
| *Directors Office* | *2.43* | *2.49* | *2.56* | *2.62* | *2.70* | *2.77* | *2.85* | *2.85* |
| *Education and Public Outreach* | *0.77* | *0.79* | *0.81* | *0.83* | *0.86* | *0.88* | *0.90* | *0.90* |
| *Special Projects*[3] | *3.50* | - | - | - | - | - | - | - |
| ALMA Operations | 47.27 | 48.68 | 50.63 | 52.66 | 54.77 | 56.96 | 59.24 | 59.24 |
| **Total** | **$89.25** | **$88.13** | **$91.16** | **$94.31** | **$97.58** | **$100.93** | **$104.43** | **$104.43** |

[1] Outyear funding estimates are for planning purposes only. 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] Reflects one-time funding for a special project associated with NSF's Spectrum Innovation Initiative.

The FY 2022 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 (next generation Very Large Array, or ngVLA).

**Reviews**

NSF conducts annual reviews of the NRAO Program Operating Plan and strategic planning documents, ALMA operations, and the AUI Management Report. Recommendations from annual reviews are routinely used to inform NRAO's operations planning and NSF's oversight of the facility. A comprehensive mid-term review will be conducted in 2021.

**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 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)** **$25,460,000**
**$3,370,000 / 15.3%**

**National Solar Observatory Funding**[1]
(Dollars in Millions)

| FY 2020 Actual | FY 2021 Estimate[2] | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|
| $21.79 | $22.09 | $25.46 | $3.37 | 15.3% |

[1] Includes operations for NSO and DKIST.

[2] Excludes $2.0 million for cultural mitigation activities as agreed to during the compliance process for 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 management of the construction of the Daniel K. Inouye Solar Telescope (DKIST; see narrative in the MREFC chapter) as well as its subsequent operation once completed in 2021. DKIST will be 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 the NISP program 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, to the outer corona and its interface with the interplanetary medium.

DKIST will enable the study of magnetic phenomena in the solar photosphere, chromosphere, and corona. Determining the role of magnetic fields in the outer regions of the Sun is crucial to understanding the solar dynamo, solar variability, and solar activity including flares and coronal mass ejections, and the impact on planets. Solar activity can affect civil 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**

NSO also provides 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. 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 of January 2019, NSO has vacated its site at the Kitt Peak National Observatory (KPNO). The remaining building there is currently operated by NSF's National Optical-Infrared Astronomy Research Laboratory (NOIRLab; see NOIRLab narrative for more information). NISP's SOLIS telescope was removed from KPNO and is being relocated to Big Bear, California. The construction related to this relocation has been delayed due to COVID-19 but is expected to begin in Q3 of FY 2021

Due to COVID-19, on March 17, 2020, all work-related travel ceased, and the observatory initiated 100% telework at all NSO sites to comply with stay-at-home orders issued by the governors of Colorado, New Mexico, and Hawaii. Since late October 2020, NSO headquarters in Boulder, Colorado has been 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. The GONG facility is operational, and DKIST construction is in a modified Phase 1, as discussed in the DKIST narrative in the MREFC chapter. 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 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.

**Governance Structure and Partnerships**

NSF Governance Structure

NSF oversight of NSO and DKIST is handled by two program officers (one for NSO operations, and one specifically for DKIST until the construction project is completed) 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 NSF's Office of Budget, Finance and Award Management, 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. Information on oversight of the DKIST Construction Project can be found in the DKIST narrative in the MREFC chapter.

[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

External Governance Structure
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 utilizes a Users' Committee for the purposes of self-evaluation and prioritization. The Users Committee, composed of scientists with considerable experience with the observatory, reviews for the NSO director all aspects of NSO that affect user experiences. Both 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.

Partnerships and Other Funding Sources
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 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 renewed NSO cooperative agreement, June 1, 2015 – Sept. 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 because of NSO's comprehensive midterm review (see Reviews section), which identified potential budget shortfalls over the remainder of the current award period.

**Total Obligations for NSO**
(Dollars in Millions)

| | FY 2020 | FY 2021 | FY 2022 | ESTIMATES[1] | | | | |
|---|---|---|---|---|---|---|---|---|
| | Actual | Estimate | Request | FY 2023 | FY 2024 | FY 2025 | FY 2026 | FY 2027 |
| NSO Operations & Maintenance[2] | $4.78 | $4.55 | $5.88 | $6.06 | $6.24 | $6.24 | $6.24 | $6.24 |
| DKIST Operations[3] | 17.01 | 17.54 | 19.58 | 20.68 | 21.30 | 21.30 | 21.30 | 21.30 |
| **Total** | **$21.79** | **$22.09** | **$25.46** | **$26.74** | **$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 funding for transition activities at Sacramento Peak Observatory in FY 2020 and FY 2021.

[3] FY 2021 Estimate excludes $2.0 million to another awardee for cultural mitigation activities as agreed to during the compliance process.

The total NSF obligations for NSO include additional funding in the form of supplements for work performed under the operations award, including an ongoing supplement (FY 2018-FY 2021) for about $300,000 per year to maintain the infrastructure at Sacramento Peak in collaboration with NMSU.

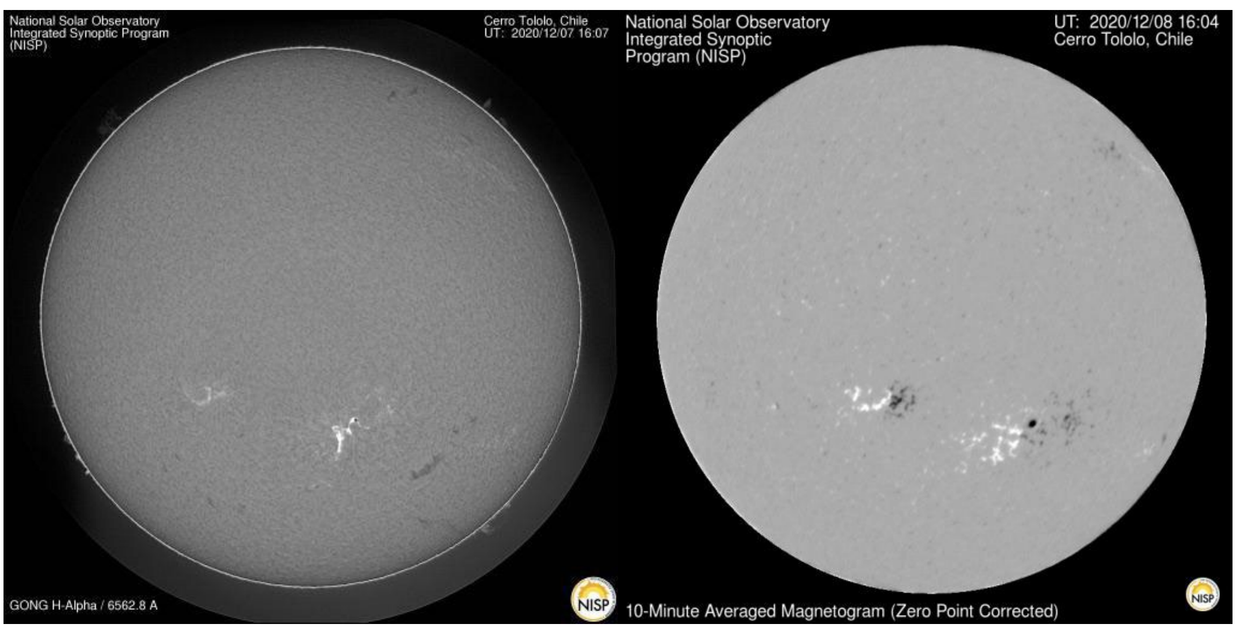
**Reviews**

- 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 review were presented to the NSB in February 2020.
- NSO participates in reviews of the DKIST construction project, as detailed in the DKIST narrative in the MREFC chapter.

**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. In order to prepare for a potential two-year re-competition process, in mid-2022, NSF will evaluate the current status of NSO operations and the performance of the managing organization, AURA. The goal will be to determine whether to begin a re-competition of the award for management and operations of the NSO in accordance with NSF policy.

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. As part of the transition of NSO infrastructure, the McMath-Pierce Solar Telescope facility on Kitt Peak is being converted to an education and outreach center by AURA under an award to NOIRLab (see NOIRLab narrative).



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)

**$54,440,000**
**-$3,490,000 / 6.0%**

**NSF's National OIR Astronomy Research Laboratory Funding[1]**
(Dollars in Millions)

| FY 2020 Actual | FY 2021 Estimate | FY 2022 Request | Change over FY 2021 Estimate Amount | Percent |
|---|---|---|---|---|
| $57.86 | $57.93 | $54.44 | -$3.49 | -6.0% |

[1]Funding includes the base operations for Gemini and Rubin

### Brief Description

Launched at the start of FY 2020, NSF's National Optical-Infrared Astronomy Research Laboratory 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—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. It will promote 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-oriented 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 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.

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

[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.

issuing alerts for changing and transient objects within 60 seconds of their discovery. For more information on the construction project, see the MREFC 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 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[2] and general PI-led astronomy, in partnership with National Aeronautics and Space Administration (NASA) | Survey science with Dark Energy Spectroscopic Instrument (DESI),[3] in partnership with DOE | General PI-led astronomy with an emphasis on PI-led survey projects with Dark Energy Camera (DECam), in partnership with DOE | General PI-led astronomy with an emphasis on time domain astronomy follow-up programs |

Community Science & Data Center (CSDC)

On behalf of the U.S. astronomy community, the CSDC in Tucson develops strategies for archival data management and is building the capacity to serve as the national center for ground based OIR data archiving and utilization. CSDC has also taken a leading role in the brokering of time-domain alerts from Rubin Observatory through its Arizona-NOAO Temporal Analysis and Response to Events System and Astronomical Event Observatory Network collaborations with the University of Arizona, the Gemini Observatory, the Las Cumbres Observatory[4], and the Zwicky Transient Facility[5].

Education and Public Outreach

NOIRLab supports U.S. educational goals by promoting the public understanding of science and by

[2] Refers to the NASA-NSF Exoplanet Observational Research (NN-EXPLORE) Exoplanet Investigations with Doppler spectroscopy (NEID) instrument, currently undergoing final testing and commissioning.
[3] DESI is currently undergoing final testing and commissioning.
[4] www.lco.global/
[5] www.ztf.caltech.edu/

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. is now in its 16th year), visitor centers at Kitt Peak and Cerro Tololo, and a web-based information portal. With supplementary support from NSF, 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 and a GeoDome Digital Planetarium, along with interactive exhibits and an astronomy classroom.

**Status of the Facility**

In 2020 and 2021, NOIRLab facilities have been 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 Hawaii. Throughout the shutdown periods, telescopes and instruments were placed in a safe state, and only a skeleton crew remained on site and at the base facilities in La Serena, Chile; Hilo, Hawaiʻi; and Tucson, Arizona. Commissioning and characterization of NEID and DESI were halted at KPNO, though work has since resumed with support from local staff. Both instruments are expected to begin their respective five-year survey programs in mid-2021. The Kitt Peak Visitor Center was closed in March 2020 and is likely to remain so through at least mid-2021. No known major technical issues resulted from the shutdown at any of the NOIRLab sites. Most operations staff were able to work effectively from home.

**Meeting Intellectual Community Needs**

Developing closer ties between 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,[6] the 2012 AST Portfolio Review,[7] and the 2015 National Academies study on the OIR system.[8] 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 sub-committee 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 AEON was used to commission queue based observing at SOAR in FY 2019.

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

[6] www.nap.edu/catalog/12951/new-worlds-new-horizons-in-astronomy-and-astrophysics
[7] www.nsf.gov/mps/ast/ast_portfolio_review.jsp
[8] www.nap.edu/catalog/21722/optimizing-the-us-ground-based-optical-and-infrared-astronomy-system

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 430 people in Arizona, Hawaii, and Chile, including engineers, technicians, support scientists, administrative support staff, postdoctoral fellows, and interns. As NSF builds towards Rubin Observatory operating at full capacity, the need for new staff at NOIRLab to support operations is expected to steadily increase in the forthcoming years as the need for staff on the Rubin Observatory construction project decreases.

**Governance Structure and Partnerships**

NSF Governance Structure
In consultation with community representatives, three 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 reports; and retrospective annual performance and management reports. A set of pre-defined Key Performance Indicators have been established to measure performance; these are defined in a Performance Evaluation and Measurement Plan. To address issues as they arise, AST also leads an Integrated Program Team (IPT) for NOIRLab, which includes representatives from other NSF offices, including the Office of General Counsel, the Division of Acquisition and Cooperative Support, Office of Budget, Finance, and Award Management, and the Large Facilities Office. The 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 agreement 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, comprised of 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 GFC.

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 is working toward renewing before the end of 2021, when the current agreement expires.

- The SOAR telescope is supported by MCTIC of Brazil, NOIRLab, the University of North Carolina Chapel Hill, and Michigan State University; a new 5-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 typically receives approximately $11 million each year from partnerships (WIYN, Mayall and SOAR), for reimbursed services provided to tenant observatories at KPNO and CTIO, from the Kitt Peak Visitors Center, and from grants from other federal agencies.
- Construction and subsequent development of 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 2020 Actual | FY 2021 Estimate | FY 2022 Request | ESTIMATES[1] FY 2023 | FY 2024 | FY 2025 | FY 2026 | FY 2027 |
|---|---|---|---|---|---|---|---|---|
| Vera C. Rubin Observatory Operations | $0.01 | $5.00 | $5.20 | $19.98 | $33.80 | $36.09 | $36.34 | $35.71 |
| Gemini Observatory O&M | 22.31 | 22.98 | 22.98 | 23.67 | 23.67 | 23.67 | 23.67 | 23.67 |
| Mid-Scale Observatories & CSDC | 33.54 | 29.95 | 26.26 | 22.55 | 21.13 | 21.13 | 21.13 | 21.13 |
| *Operations & Maintenance* | *19.91* | *20.51* | *21.13* | *21.13* | *21.13* | *21.13* | *21.13* | *21.13* |
| *Special Projects* [2] | *13.63* | *9.44* | *5.13* | *1.42* | - | - | - | - |
| NOIRLab Transition[3] | 2.00 | - | - | - | - | - | - | - |
| **Total** | **$57.86** | **$57.93** | **$54.44** | **$66.20** | **$78.60** | **$80.89** | **$81.14** | **$80.51** |

[1] Outyear funding estimates are for planning purposes only. A new NOIRLab-wide cooperative agreement is expected for the period FY 2023-FY 2027.

[2] Special projects funding supports the Windows on the Universe Center for Astronomy Outreach, ongoing activities at the WIYN telescope, as well as potential future participation in the U.S. Extremely Large Telescope program.

[3] Transition activities associated with the creation of NOIRLab were funded in FY 2019 and FY 2020.

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 narrative. The FY 2022 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 2022 Request for MSO and CSDC supports all NOIRLab Directorate-level activities, including 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 development of the Windows on the Universe Center for Astronomy Outreach, and development of next-generation OIR telescope technologies as well as planning for a potential U.S. Extremely Large Telescope Program.

**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 progress 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.

**Renewal/Recompetition/Termination**

The latest recompetition of the O&M awards for both MSO/CSDC and Gemini concluded in 2015, resulting in awards concluding at 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 the existing programmatic components of NOIRLab, which also includes Rubin Observatory pre-operations. In 2022, NSF expects to review linked five-year proposals for the renewal of all NOIRLab programs (MSO, CSDC, Gemini and

Rubin Observatory operations) for the period FY 2023-FY 2027.[9] The next opportunity to begin a competition of NOIRLab as an integrated organization would then be mid-decade. 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.

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[9] 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 the Research and Related Activities (R&RA) account.

For information on projects funded through this account, refer to the MREFC chapter of this Budget Request.

### Preconstruction Planning

Within the R&RA account, funds are provided for preconstruction studies for prospective major facility projects. This funding generally supports such activities as design, cost estimates, and other actions that prepare potential projects for oversight review, agency decision milestones, and potential implementation.

## PERFORMANCE AND MANAGEMENT

NSF Performance Framework ........ Performance and Management - 3

FY 2020 Strategic Objective Progress Updates ........ Performance and Management - 4

FY 2020 Annual Performance Report and
FY 2022 Annual Performance Plan ........ Performance and Management - 9

FY 2020 Management Challenge Progress Report ........ Performance and Management - 27

GAO-IG Act Exhibits ........ Performance and Management - 50

Program Evaluation and Monitoring Information ........ Performance and Management - 68

Other Information ........ Performance and Management - 77

**NSF PERFORMANCE FRAMEWORK**

Per the GPRA Modernization Act of 2010, this chapter, together with the Overview, contains basic information about NSF's mission and Strategic Plan, as well as NSF's FY 2022 Annual Performance Plan (APP), Major Management Challenges, FY 2020 Annual Performance Report (APR), and Strategic Objective Progress Update. Information about NSF's performance can also be found on the NSF website in the FY 2020 Performance and Financial Highlights Report.[1]

**FY 2022: A year of strategic transition**

While we present an APP for FY 2022 in this document, NSF will be releasing a new Strategic Plan in February 2022, and at that time this plan will be retired for a new APP aligned to the new Plan. The FY 2021-2023 APPR will therefore also contain targets for 2022 which will supersede those published here. While many of NSF's measures may remain the same, we anticipate that the new performance framework, with its alignment to the Learning Agenda required by the Evidence Act, will be overhauled to be maximally responsive to the priorities of the Administration and the guidance provided by NSF's Director, and the National Science Board .

**FY 2018-2022 Strategic Plan and Strategic Objectives**

In FY 2018, NSF released its Strategic Plan for FYs 2018-2022: *Building the Future: Investing in Discovery and Innovation.*[1] This Plan lays out two strategic goals that embody the dual nature of NSF's mission to advance the progress of science while benefitting the Nation: *Expand knowledge in science, engineering, and learning* and *Advance the capability of the Nation to meet current and future challenges*. A third goal, *Enhance NSF's performance of its mission*, directs NSF to hold itself accountable for achieving excellence in carrying out its mission. Each goal has two Strategic Objectives which together encompass all areas of agency activity. This goal structure enables NSF to link its investments to longer-term outcomes.

| Strategic Goal | | Strategic Objective |
|---|---|---|
| 1 | Expand knowledge in science, engineering, and learning. | **1.1 Knowledge**<br>Advance knowledge through investments in ideas, people, and infrastructure. |
| | | **1.2 Practice**<br>Advance the practice of research. |
| 2 | Advance the capability of the Nation to meet current and future challenges. | **2.1 Societal Impacts**<br>Support research and promote partnerships to accelerate innovation and to provide new capabilities to meet pressing societal needs. |
| | | **2.2 STEM Workforce**<br>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**<br>Attract, retain, and empower a talented and diverse workforce. |
| | | **3.2 Processes and Operations**<br>Continually improve agency operations. |

[1] www.nsf.gov/about/performance

## FY 2020 NSF STRATEGIC OBJECTIVE PROGRESS UPDATES

In FY 2020, the National Science Foundation conducted Strategic Reviews (SRs) of the six Strategic Objectives in its 2018-2022 Strategic Plan in response to the requirement of the GPRA Modernization Act 2010 Section 1116(f). Table 1 summarizes the outcomes to date of each SR. The table also provides NSF's determination as to whether performance towards an Objective is making noteworthy progress, should pursue focused improvement, or neither.

**Two Components to NSF SRs: 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-Foundational activity, without concentrating on 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[1] describes all annual outputs. The Committees of Visitors (COV) process[2], in which external experts assess NSF programmatic activities approximately every four years, is also comprehensive. 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 2020 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. The Objectives ranked "Noteworthy Progress" are:

- 1.1, Knowledge: Advance knowledge through investments in ideas, people, and infrastructure.
- 3.1 Human Capital: Attract, retain, and empower a talented and diverse workforce.

These rankings reflect strides made in two areas. The first is workforce management, both overall and particularly in the development of the workforce that oversees research infrastructure, including mid-scale projects and major facilities. This progress contributes to both agency objectives. The second area rated as achieving noteworthy progress is large facilities governance, another area supported by multiple objectives, and here considered as also contributing to the ranking of 1.1.

The Objective ranked "Focus Area for Improvement" is 3.2, Processes and Operations: Continually improve agency operations. This ranking reflects the need to establish and maintain an appropriate balance of funding across NSF for programmatic, operational, and support activities. A thoughtful balance is needed to ensure the agency can accommodate the additional responsibilities associated with the Administration's priorities in research and education. This will ensure that its ongoing efforts to be agile, adaptable, and able to work at speed and scale remain robust as it moves forward in the post-pandemic environment.

**2020 Process Adjustments**
NSF's FY 2020 SR process was already underway in early March when normal operations were interrupted by the COVID-19 pandemic. Despite the challenges that the pandemic presented, NSF's SR teams were able to continue their work as planned with only minor delays. Thanks in large part to the IT infrastructure and flexibilities afforded by NSF to all staff, the SR teams' work and their reports to leadership were able to proceed in a fully remote setting.

**Topical Review of "Stewardship Model" of Funding**

Strategic Objective 1.1: Knowledge: Advance knowledge through investments in ideas, people, and infrastructure.
Strategic Objective 1.2: Practice: Advance the practice of research.
Strategic Objective 2.1: Societal Impacts: Support research and promote partnerships to accelerate innovation and to provide new capabilities to meet pressing societal needs.
Strategic Objective 3.2: Processes and Operations: Continually improve agency operations.

**Background and Key Analytical Questions**

In 2019, NSF launched ten "Big Ideas" to identify and support emerging opportunities for U.S. leadership in Big Ideas that serve the Nation's future. Each initiative involved multiple NSF directorates/offices. Through and innovative pilot funding approach – the "Stewardship Model" – funds for each of the Big Ideas were held within one directorate, while management was carried out by a steering committee composed of senior managers in collaboration with working groups from all participating directorates/offices. The main idea was that, by holding the funds in one place, decisions to fund the best research would be less conflicted by the disciplinary interests of the individual directorates/offices participating in a funding research initiative.

The Review of the Stewardship Model addressed the following two hypotheses:

1. The Stewardship Model funding decisions focus on identifying the best scientific research, regardless of field/discipline. There is less focus on ensuring that the award portfolio reflects the funding contributed by different NSF directorates.
2. The Stewardship Model more effectively promotes collaboration in the funded research activities.

From these two hypotheses, three Key Analytical Questions (KAQs) where developed:

- OUTCOME: How does the Stewardship Model compare to other funding models, in terms of merit review process outcomes/outputs?
- PROCESS: Does the Stewardship Model alter the way funding decisions are made?
- BEST PRACTICES: What best practices can we identify, and what lessons have we learned, from the way the research Big Ideas implemented the Stewardship Model?

**Evidence and Conclusions**

A set of programs were selected to compare and analyze in response to the KAQs. Besides the six research Big Ideas, a comparator group of cross-directorate programs were chosen for their similarity in interdisciplinarity, partnerships, and timeframe to the Big Ideas and their manageability in scope and measurement. All the programs were evaluated via both quantitative and qualitative approaches to address the KAQs. The results from these analyses were integrated into a final set of conclusions and recommendations.

To gather perspectives from NSF staff involved in the research Big Ideas programs and other similar cross-directorate programs, a survey was designed and distributed; responses were collected from the various directorates/offices across NSF. Individual interviews were also conducted with Steering Committee and Working Group Chairs, program officers, administrative staff, and a focus group of budget officers. Everyone interviewed had direct experience with the Big Ideas programs/ stewardship model and several had experience with programs in both the Big Ideas and the comparator programs or other cross-directorate programs. Additional data was compiled and analyzed from NSF business systems, including proposal and award data, reviewer data, panel data, and management plans, to examine measures such as funding rates, panel composition, panel management, dwell time, award splits, proposal and award management, and award interdisciplinarity.

Most measures examined found no significant difference between the stewarded programs and the comparator programs and determined that existing differences were driven more by the management of the individual programs rather than the funding model used. Three major conclusions from this SR's analyses are:

1. NSF has been successful at fostering collaboration utilizing different funding models.
2. There were advantages to allowing flexibility in the management and implementation of the stewardship model of funding.
3. A range of issues were revealed during the implementation of the stewardship model (cultural, business systems, fiscal year timing, scale of effort, NSF capacity).

**Opportunities for Action or Improvement**

The team made the following three recommendations:

1. Continue to utilize multiple models for funding the best research.
2. Develop a decision tree to determine the best management model to use for a given research area and approach.
3. Ensure that each model can be effectively implemented.

**Activities after the SR**

In response to the Strategic Review findings and recommendations, NSF created a Working Group (WG) to develop a decision support tool. The WG developed a "decision tool" that frames funding options as a continuum between the most and least centralized approaches, and therefore aims to help decision-makers assess the potential fit of different funding approaches and become better aware of the trade-offs associated with the different options. The tool was tested with stakeholders and a pilot-ready draft was presented to leadership in spring 2021. In summer and fall, the tool is being piloted and further refined. After gathering feedback, NSF will determine the best ways to deploy the tool and ensure its use going forward.

**Topical Review of NSF's Major Research Infrastructure Portfolio**

Strategic Objective 1.1: Knowledge: Advance knowledge through investments in ideas, people, and infrastructure.
Strategic Objective 1.2: Practice: Advance the practice of research.
Strategic Objective 3.2: Processes and Operations: Continually improve agency operations.

**Background**
This Review focused on NSF's processes for the entry of projects into the Development and Design Stages, as defined in Sections 2.2 and 2.3 of the Major Facilities Guide (MFG). The National Science Foundation (NSF) invests in all disciplines of basic research, including the necessary supporting research infrastructure. NSF's portfolio of major facilities represents a substantial fraction of its total budget, including construction and operations of facilities at sites throughout the U.S. and around the world. Oversight of activities related to these facilities is led by Program Officers in distinct Directorates, in close collaboration with multiple Divisions within the Office of Budget, Finance, and Award Management (BFA).

Projects in the Development Stage are typically managed solely at the Program level, normally as discrete awards for prototyping or research and development to advance technologies or methods that could eventually lead to the full implementation of larger projects. As a result, entrance in and advancement through the Development Stage has been informal and therefore not always visible to NSF Leadership, including the National Science Board.

In addition, because of the lack of clear communication pathways for sharing information about projects in the Development Stage and the lack of guidelines for entrance in the Design Stage at points beyond Conceptual Design, there is the appearance of a dearth of future projects seeking funding from the Major Research Equipment and Facilities Construction (MREFC) account. Furthermore, NSF's implementation of the Mid-scale Research Infrastructure (Mid-scale RI) Track 1 and Track 2 programs (the latter being funded under the MREFC account) has created an important and growing category of NSF-supported research infrastructure. Some mid-scale activities may eventually scale to larger facility projects. In such cases, a pathway to incorporate them into the broader Development and Design Stage strategies should be considered.

**Key Analytical Questions**
- PROCESS: What are the characteristics of the many paths through development and design that have been used?
- STRATEGY AND PLANNING: What does NSF need to consider when improving the MREFC-funded research infrastructure's Development and Design Stages?

**Evidence and Conclusions**
The Review team sought evidence to understand the nature of the problem described above in three ways: analysis of two decades of records from NSF annual budget submissions, consideration of case studies describing the path through development to MREFC funding for a variety of large facility projects, and review of the outcomes of the first round of Mid-scale Research Infrastructure solicitations.

The budget information illustrated both the steady progress of some facilities from "horizon projects" through candidate MREFC status and the occasional disappearance of "horizon projects" from one year to the next (usually due to programmatic decisions, although with little or no documented explanation).

Descriptive case studies of the development of major facility projects across several of the disciplines supported by NSF revealed an array of pathways from genesis of an idea to entry into the MREFC-funded "queue." A nearly universal finding was that the Development Stage for successful projects is long, typically one to two decades from the first clear indication of the need for the infrastructure to formal entry into the Design Stage for Major Facility projects.

Another clear takeaway from the case studies was that there is no uniform pathway or process for identifying an idea, nurturing its development, and advancing it to a level of readiness for entry into the MREFC Design process. The surfacing of ideas for development of new research infrastructure (RI), and the process for prioritizing among them, varies across disciplines. This diversity of development pathways represents both a necessity and a strength, given the breadth of disciplines supported by NSF and the different cultures of the various communities.

**Opportunities for Action or Improvement**

The team made the following four recommendations:

1. Collect consistent information (at least annually) from all Divisions on projects in development.
2. Clarify, and possibly expand, mid-scale and MREFC-scale development and design funding opportunities and scope.
3. Broaden access to BFA expertise, both internally (PO training & project evaluation) and externally (community workshops and capacity building).
4. Define in the Major Facilities Guide the process for evaluating "readiness" for project entry into the MREFC Design Stages beyond Conceptual Design.

**Activities after the SR**

In response to the Strategic Review findings and recommendations, NSF has taken the following steps:

- Per recommendation 1: A list of development-stage projects is currently being developed.
- Per recommendation 2: Both MSRI solicitations have been updated to reflect the recommendation.
- Per recommendation 3: BFA has added a staff person for a new position dedicated to internal and external outreach to broaden access to BFA expertise on large facility projects.
- Per recommendation 4: The Major Facilities Guide is in the process of being updated, and the new version is expected to be available in September 2021.

**FY 2020 ANNUAL PERFORMANCE REPORT AND FY 2022 ANNUAL PERFORMANCE PLAN**

This document combines NSF's FY 2020 Annual Performance Report and FY 2022 Annual Performance Plan (APP + APR = APPR). The goals for FY 2021 and historical information on individual goals are also provided when available. Results for each performance goal are presented in strategic context, with reference to strategic goals, objectives, and targets from NSF's 2018-2022 Strategic Plan.

In FY 2020, NSF tracked progress toward its three strategic goals using eight performance goals, one of which was a 2-year Agency Priority Goal (APG) in its first year of activity. Four of the eight achieved all or some of their targets or were on track throughout the year. Three goals were not achieved. One goal changed its measurement framework midyear. These results were published online in early 2021 and are republished here in their multi-year context.

Multiple years of trend data are available for NSF's longstanding quantitative performance measures (Infrastructure Investments and Timely Proposal Decisions). Other performance goals monitor progress towards multiyear goals, such as implementation of a new process (Improve Review Quality, Culture of Inclusion), upgrades to ongoing processes (Align Job Requirements, Improve User Interactions), or strategically important investments (Key Program Investments, Expand Public and Private Partnerships).

While we present an APP for FY 2022 in this document, NSF will be releasing a new Strategic Plan in February 2022, and at that time this plan will be retired for a new APP aligned to the new Plan. The FY 2021-2023 APPR will therefore also contain targets for 2022 which will supersede those published here.

**Goal 1, Agency Priority Goal (APG): Expand Public and Private 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

| **Current and 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. | On track for 2021 achievement. |
| **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.<br><br>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<br><br>FY 2017 baseline = 57 partnerships<br><br>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 M-17-22, "Comprehensive Plan for Reforming the Federal Government." Quarterly information on this goal can also be found on performance.gov.

Private industry, foundations, and non-profits, together with other federal agencies and international funding organizations, bring additional expertise, resources, and capacity to NSF-funded research. 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 occurs at the directorate/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 2020 Results
In FY 2020, the Partnerships pillar of Renewing NSF and the APG Implementation Team merged and expanded. The group is focusing on enhancing the strategic value of the Foundation's partnerships, and is using a milestone-oriented approach to report and assess progress in three areas: improving internal and external communications, implementing process improvements, and conducting strategic outreach. Quarterly reports for FY 2020 can be found on performance.gov (https://www.performance.gov/NSF).

FY 2021 and Planned FY 2022 Changes
NSF is on track for successful closeout of this goal in FY 2021. The team has produced a number of reports and internal tools to aid in partnership formation and management, which are being made available to all staff.

**Goal 2, Ensure that Key Program Investments are on Track**
Lead Organization: Office of Budget, Finance, and Award Management

Goal Statement
Ensure that key NSF-wide program investments are implemented and on track.

Measure, Milestone, or Deliverable

| **Current and Upcoming Years** | | |
|---|---|---|
| **FY** | **Target Summary** | |
| 2022 | NSF will obligate 100 percent of designated funding targets for all identified NSF-wide priority investments. | |
| 2021 | | |
| **Reporting Year** | | |
| **FY** | **Target Summary** | **Result** |
| 2020 | NSF will obligate 100 percent of designated funding targets for all identified NSF-wide priority investments. | 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 a number of cross-agency investments in its Budget Request to Congress. Most are described in the NSF-Wide Investments chapter of the Budget Request. Although the overall impact of these investments might not be measurable for many years, tracking near-term indicators of progress can help the agency make formative changes or course corrections.

NSF selects a subset of these investments for closer quarterly tracking by agency leadership, based on internal assessments of the value that tracking is likely to add. For example, new programs, programs with recent changes, or high-profile programs may benefit from the attention of leadership, and programs that are stably operating or sunsetting have reduced need for monitoring.

Discussion of FY 2020 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.

FY 2021 and Planned FY 2022 Changes
In FY 2021, NSF continues to track the Big Ideas under this goal. NSF will include funding provided through the American Rescue Plan (ARP) under this goal, 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 will begin in FY 2021, but the 100 percent funding target will not be applied until FY 2022 since the funds are 2-year funds.

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.

| **Previous Years** | | |
|---|---|---|
| **FY** | **Target Summary** | **Result** |
| 2019 | 1. Monitor the progress of the following NSF-wide investments using a common set of milestones and indicators: Big Ideas.<br>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.<br>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.<br>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 |

By design, this goal's monitored programs change annually to match the funding priorities of the year. In addition to the annual change in the list of monitored programs, described in the narrative and the table below, the Goal Statements have changed slightly each year for this goal, as follows:

FY 2019: Ensure that key FY 2019 NSF-wide program investments are implemented and on track.
FY 2018: Ensure that key FY 2018 NSF-wide program investments are implemented and on track.
FY 2017: Ensure that key FY 2017 NSF-wide program investments are implemented and on track.
FY 2016: Ensure that key FY 2016 NSF-wide program investments are implemented and on track.
FY 2015: Meet critical targets for key program investments.

| FY | 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

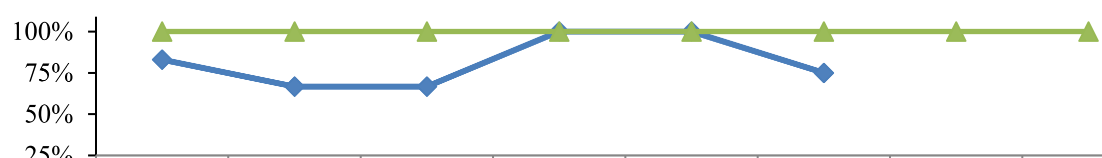
**Goal 3, Ensure that Infrastructure Investments are on Track**
Lead Organization: Large Facilities Office, Office of Budget, Finance, and Award Management

Goal Statement
Ensure program integrity and responsible stewardship of major research facilities and infrastructure.

Measure, Milestone, or Deliverable

| **Current and Upcoming Years** | | |
|---|---|---|
| **FY** | **Target** | |
| 2022<br>2021 | Construction Project Monitoring (MREFC and R&RA):<br>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.<br>2. Track cost and schedule performance for Mid-scale Research Infrastructure in the Construction Stage with a Total Project Cost (TPC) above $20.0 million that are over 10 percent complete and using Earned Value Management (EVM) principles. | |
| **Reporting Year** | | |
| **FY** | **Target** | **Result** |
| 2020 | Construction Project Monitoring: For 100 percent of MREFC facilities under construction that are over 10 percent complete, keep negative cost and schedule variance at or below 10 percent. | Not Achieved.<br>1 of 4 projects was behind schedule at the end of 2020. |
| **Measure Information for All Years** | | |

**Major Facilities Construction Project Monitoring Performance Trend, FY 2015-2020**




| | FY 2015 | FY 2016 | FY 2017 | FY 2018 | FY 2019 | FY 2020 | FY 2021 | FY 2022 |
|---|---|---|---|---|---|---|---|---|
| Result | 83% | 67% | 67% | 100% | 100% | 75% | | |
| Target | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |

The Mid-scale target was first tracked in FY 2021; no trend information available.

Strategic Alignment
Strategic Goal 1: Expand knowledge in science, engineering, and learning. Objective 1.1, Knowledge: Advance knowledge through investments in ideas, people, and infrastructure.

About This Goal
The MREFC account supports the acquisition, construction, and commissioning of major research facilities and equipment that provide unique capabilities at the frontiers of science and engineering. Performance of construction projects funded by the MREFC account is monitored using the Earned Value Management System (EVMS). EVMS is an integrated management control system for assessing, understanding, and quantifying what a contractor or field activity is achieving with program dollars. Monitoring cost and schedule is a standard measure of performance for construction projects. Projects that are under 10 percent complete are not considered eligible for this goal because EVM data is less meaningful statistically in the very early stages of a project.

While this goal added a target in FY 2020 to track mid-scale research infrastructure projects, no such projects met reporting thresholds this fiscal year, so this target is not presented.

Discussion of FY 2020 Results

Of the four projects tracked as part of this goal in FY 2020, the Antarctic Infrastructure Modernization for Science (AIMS) project fell behind schedule by 10.3 percent, very slightly outside the 10 percent goal, due to delays associated with the COVID-19 pandemic; the project's timeline will be re-baselined in FY 2021. For more information about this and all other MREFC-funded construction projects, see the MREFC chapter of this Request.

FY 2021 and Planned FY 2022 Changes

No changes planned.

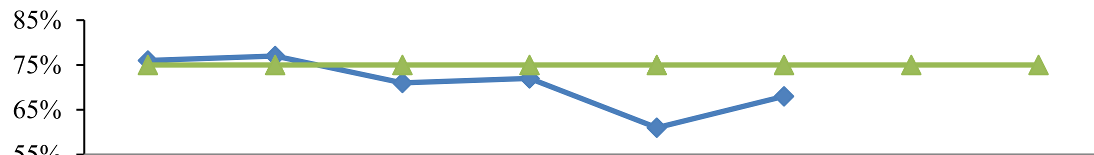
**Goal 4, Make Timely Proposal Decisions**
Lead Organization: Office of Integrative Activities

Goal Statement
Divisions and Offices will make timely proposal decisions.

Measure, Milestone, or Deliverable

| **Current and Upcoming Years** | | |
|---|---|---|
| **FY** | **Target** | |
| 2022 | For at least 75 percent of proposals, Divisions and Offices will decline a proposal or recommend it for funding within 182 days of deadline, target, or receipt date, whichever is later. | |
| 2021 | | |
| **Reporting Year** | | |
| **FY** | **Target** | **Result** |
| 2020 | 75 percent | Not Achieved. Result = 68 percent. |
| **Measure Information for All Years** | | |

**Time to Decision Performance Trend, FY 2015-2020**




| | FY 2015 | FY 2016 | FY 2017 | FY 2018 | FY 2019 | FY 2020 | FY 2021 | FY 2022 |
|---|---|---|---|---|---|---|---|---|
| Result | 76% | 77% | 71% | 72% | 61% | 68% | | |
| Target | 75% | 75% | 75% | 75% | 75% | 75% | 75% | 75% |

Strategic Alignment
Strategic Goal 3, Enhance NSF's performance of its mission. Objective 3.2, Processes and Operations: Continually improve agency operations.

About This Goal
Time to decision or "dwell time" is the amount of time that passes between receipt of a proposal and notification to the principal investigator (PI) about the funding decision. At the time of this goal's establishment in the early 2000s, one of the most significant issues raised in customer satisfaction surveys was the time it took NSF to process proposals, with only around 50 percent of proposals receiving responses within 6 months of submission or deadline. Too long a time period inhibits the progress of research as it delays the funding process, but too short a time period may inhibit review quality. The 75 percent target seeks to strike a balance between the need of the PI for timely action and the need of NSF for a credible and efficient merit review system. Since this goal was introduced, NSF's response times have improved, and over 70 percent of proposals have received responses in under 6 months for nearly two decades. More recent surveys have shown that this is now the second most common concern mentioned by PIs (see Goal 5, Improve Review Quality, for more recent survey results).

Discussion of FY 2020 Results
NSF missed this goal in FY 2020 for several reasons. One factor is the decisions NSF made to prioritize award actions after the FY 2019 shutdown, which resulted in a backlog of decline actions at the end of that year. This backlog did not appear in the FY 2019 statistics but in the year in which the decision was processed, FY 2020. Another factor is the reprioritization of agency operations in response to the COVID-19 pandemic, including providing staff with flexibilities to adjust to the changed working environment and allowing for mid-year reprioritization of workloads. 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 and Planned FY 2022 Changes
No changes planned.

Goal Change Statement
In FY 2021, the goal statement and target were reorganized to be more consistent in structure with the other goals, with a goal statement that is outcome-oriented and a target that is a full sentence describing a measurable achievement.

**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

| **Current and Upcoming Years** | | |
|---|---|---|
| **FY** | **Target** | |
| 2022 | Target to be set late 2021. | |
| 2021 | In FY 2021, assess the feasibility of and develop the strategy and plan for assessing and piloting activities to improve the quality of written reviews. | |
| **Reporting Year** | | |
| **FY** | **Target** | **Result** |
| 2020 | By September 30, 2020,<br>1. 140 NSF programs will have had reviewers view the presentation “Tips on how to write better reviews.”<br>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.<br>2. Achieved. Result = 14,434 reviewers. |
| **Previous Years** | | |
| **FY** | **Target** | **Result** |
| 2019 | By September 30, 2019,<br>1. 60 NSF programs will have had reviewers view the presentation “Tips on how to write better reviews.”<br>2. 8,000 reviewers of NSF proposals will have viewed “Tips on how to write better reviews” prior to preparing written reviews.<br>3. Improve the perceptions reported by survey respondents in a repeat survey of proposers and reviewers.<br>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.<br>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. | 1. Achieved<br>2. Achieved<br>3. Achieved |
| 2018 | By September 30, 2018,<br>1. 50 NSF programs will have held orientation sessions that include “Tips on how to write better reviews.”<br>2. 5000 reviewers of NSF proposals will have viewed “Tips on how to write better reviews” prior to preparing written reviews. | 1. Achieved<br>2. Not achieved |

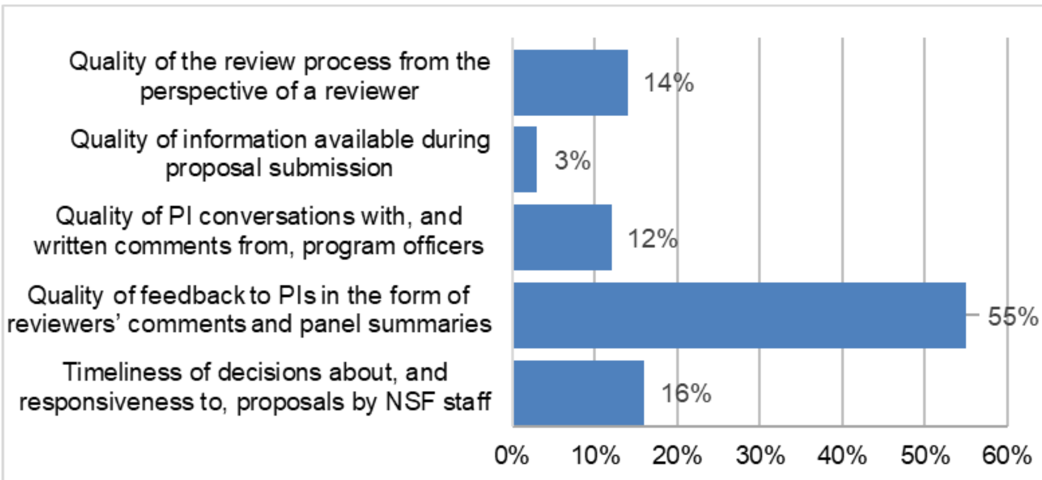
Strategic Alignment
- Strategic Goal 1: Expand knowledge in science, engineering, and learning (all Objectives)
- Strategic Goal 3: Enhance NSF’s performance of its mission. Objective 3.2, Processes and Operations: Continually improve agency operations.

About This Goal
This goal addresses and incorporates feedback NSF has received about its customer service. Committees of Visitors, program officers, and principal investigators (PIs) frequently note that the quality of individual written reviews is variable. In 2015, NSF conducted a survey of researchers who were submitting and/or reviewing proposals. Survey respondents identified the quality of reviews as the factor that would have the most significant effect on improving their proposals and fostering science (see chart below, n=22,174 respondents). A strategic review in the spring of 2015 recommended that NSF apply what was learned from the PI and reviewer survey to inform a new performance goal aimed at improving customer service. This

goal was designed in response to that recommendation.

This goal measures the implementation of a pilot program, initiated in December 2016, to improve the quality of written reviews of NSF proposals. The pilot encourages NSF programs to use the video presentation "Tips on how to write better reviews" early in the review process to orient reviewers and provide information on how to write more effective reviews. The assumption is that orienting reviewers before the reviews are written (as opposed to at the beginning of a review panel, at which time the reviews have been drafted but not finalized) helps reviewers better understand and apply the review criteria. The intention is to make written reviews more useful to both PIs and NSF program staff.

Percentage of respondents identifying each item as the most significant improvement that could be made in the merit review process.[2]




Discussion of FY 2020 Results

From the start of this goal in FY 2018 through September 30, 2020, at least 14,434 reviewers across at least 313 programs viewed the entire orientation video. Data capture issues meant that not all completed views of the video were captured, so both numbers are underestimates.

FY 2021 and Planned FY 2022 Changes

After the initial pilot period from 2018-2020, beginning in FY 2021, activities associated with this goal are focusing on assessing and piloting a wider 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.

[2] 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 Diversity and Inclusion (ODI), Office of the Director

Goal Statement
Foster a culture of inclusion through change management efforts resulting in change leadership and accountability.

Measure, Milestone, or Deliverable

| **Current and Upcoming Years** | | |
|---|---|---|
| **FY** | **Target** | |
| 2022 | Target to be set late 2021. | |
| 2021 | All NSF leaders will participate in culture change activities. | |
| **Reporting Year** | | |
| **FY** | **Target** | **Result** |
| 2020 | All NSF leaders will participate in culture change activities. | Not Achieved<br>Result = 96.2 percent. |
| **Reporting Year** | | |
| **FY** | **Target** | **Result** |
| 2019 | In FY 2019, 100 percent of NSF leaders will participate in culture change activities. | Not Achieved |
| 2018 | By September 30, 2018, ODI will conduct the new IQ process with four organizational units.<br>Improve the four NSF organizational units' New IQ Self-Survey Scores by five percent above established baseline. | Achieved<br>Achieved |
| 2017 | By September 30, 2017, ODI will conduct the new IQ process with three additional organizational units.<br>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.<br>Improve the two NSF organizational units' New IQ Self-Survey Scores by five percent above established baseline. | No targets achieved |
| 2015 | Attain six of six essential elements of a model EEO agency and perform two compliance desk reviews under antidiscrimination laws. | Not Achieved |

Strategic Alignment
Strategic Goal 3, Enhance NSF's performance of its mission. Objective 3.1, Human Capital: Attract, retain, and empower a talented and diverse workforce.

About This Goal
This goal incorporates principles from Renewing NSF, the agency operational reform plan initiated in FY 2017 in response to M-17-22, "Comprehensive Plan for Reforming the Federal Government."

Fostering inclusive work environments and realizing the full potential of the workforce's diversity requires agencies to employ effective management practices. NSF values diversity and inclusion: by engaging the talent of all our workforce, individuals are empowered to realize their full potential; by 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 Inclusion Quotient (New IQ) workshops,
- Diversity and Inclusion Dialogues,

- Workforce Inclusiveness Assessment,
- Special Emphasis observances,
- Employee Resource Groups,
- Unconscious bias awareness training, and
- Inclusion learning activities for all employees.

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 particular goal, NSF took steps in FY 2018 to help ensure that all NSF-funded research and learning environments are free from harassment by bolstering policies, guidelines, and communications so that organizations clearly understand expectations and individuals understand their rights. Internally, the agency has promoted an identical set of expectations for its staff and leaders. In relating anti-harassment efforts to the aims of this goal, NSF determined that leadership's participation in anti-harassment and anti-bullying training had the potential to contribute to culture change, since it could not only help them identify and stop harassment and bullying, but could actively promote an environment and a culture where all contributions are valued and everyone can reach their full potential.

Discussion of FY 2020 Results

NSF continued in FY 2020 to define "culture change activities" as participation in anti-harassment and anti-bullying training, and consider the target reached if all managers and executives on board more than 30 days complete the training by the end of the fiscal year[3]. NSF trained 278 of 289 managers and executives by the end of FY 2020. While not a target of the goal, NSF can also report that 1347 of 1393 (96.7 percent) of nonmanager employees received the same training. This shortfall of the 100 percent target reflects two issues that arose during the year. First, a software upgrade let to an incompatibility between NSF software and the third-party site that hosted the training videos, rendering the videos inaccessible for most of the last quarter of the year. Second, by the time the site was restored in Q4, OMB had issued M-20-34, "Training in the Federal Government." NSF therefore limited the anticipated outreach related to this goal while it took steps to ensure compliance with the OMB memo.

FY 2021 and Planned FY 2022 Changes

NSF is currently engaged in a number of high priority activities that relate directly to the diversity and inclusion activities encompassed by this goal and that will inform the development of the target for FY 2022. These activities include developing the agency's response to the *Executive Order On Advancing Racial Equity and Support for Underserved Communities Through the Federal Government*, issued on January 20, 2021, addressing the FY 2021 Management Challenge "Increasing Diversity in Science and Engineering Education and Employment" identified by the NSF Office of Inspector General, and addressing recommendations for increasing STEM talent included in the *Vision 2030* report from the National Science Board.

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"[4] status. Starting in FY 2016, this goal focused on inclusion, and New IQ workshops[5] were made available to NSF staff. The focus on leadership represents 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.

[3] For a full explanation of this approach and its rationale, see the FY 2019 Performance Report at www.nsf.gov/about/budget/fy2021/pdf/68_fy2021.pdf.
[4] www.nsf.gov/about/budget/fy2017/pdf/56_fy2017.pdf
[5] www.nsf.gov/about/budget/fy2020/pdf/67_fy2020.pdf

For more information on previous formulations of this goal, refer to the FY 2015 Annual Performance Report in the FY 2017 NSF Budget Request (Model EEO Agency[5]) or the FY 2018/FY 2020 APPR in the FY 2020 NSF Budget Request (New IQ[6]).

**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

| **Current and Upcoming Years** | | |
|---|---|---|
| **FY** | **Target** | |
| 2022 | Target to be set late 2021. | |
| 2021 | Eliminate 100 obsolete Position Descriptions in FY 2021. | |
| **Reporting 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 |
| **Previous Year** | | |
| **FY** | **Target Summary** | **Result** |
| 2019 | In FY 2019, the Division of Human Resource Management will review, modernize, or eliminate 10 percent of the existing position descriptions requiring review. | Achieved |
| 2018 | This goal was initiated in FY 2019 to replace a retired goal entitled *"Use Evidence to Guide Management Decisions,"* in which agency leaders used data-driven reviews to inform decision making. | |

Strategic Alignment
Strategic Goal 3, Enhance NSF's performance of its mission. Objective 3.1, Human Capital: Attract, retain, and empower a talented and diverse workforce.

About This Goal
This goal incorporates principles from Renewing NSF, the agency operational reform plan initiated in FY 2017 in response to M-17-22, "Comprehensive Plan for Reforming the Federal Government."

Technological improvements have automated many tasks once performed by NSF staff. Requirements for NSF's administrative staff have evolved from the more traditional competencies related to general clerical and office tasks such as categorizing, processing, and tracking paper forms to more advanced competencies related to the use of multiple automated data systems. 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 (PDs) that are outdated or do not reflect current and future work responsibilities. This PD modernization effort will enable NSF to identify the skills needed in today's work environment and will establish more relevant opportunities for training and developing NSF's existing workforce, while also enabling hiring managers to better target recruitment and outreach efforts to obtain the highest caliber of external candidates.

Discussion of FY 2020 Result

In FY 2019, NSF had identified a pool of 400 PDs that had the potential for being either updated or eliminated, based on vacancy rate or consolidation with other types of positions. The 10 percent target was measured against that denominator in FY 2019. In mid-FY 2020, related to a staff transition and pandemic-related work reprioritization, NSF revisited this limitation and determined that limiting the review to 400 predefined PDs 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.

FY 2021 and Planned FY 2022 Changes

The target of 100 position descriptions eliminated was established early in FY 2021, and a new target will be established for FY 2022 in conjunction with the development of the new strategic plan for the agency.

Goal Change History

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. As noted in the discussion of the FY 2020 result, a percentage-based target was used initially, and in FY 2020 a more straightforward numerical target was adopted.

**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

| **Current and Upcoming Years** | | |
|---|---|---|
| **FY** | **Target** | |
| 2022 | Target to be set late 2021. | |
| 2021 | By the end of FY 2021,<br>1. NSF IT systems will have been available 99.6 percent of the time, excluding 469 hours of planned downtime.<br>2. 86 percent of internal merit review functions will be accessible through a single portal.<br>3. 68 percent of external merit review functions will be accessible through a single portal. | |
| **Reporting Year** | | |
| **FY** | **Target Summary** | **Result** |
| 2020 | By the end of FY 2020,<br>1. NSF IT systems will have been available 99.6 percent of the time, excluding 469 hours of planned downtime.<br>2. 86 percent of internal merit review functions will be accessible through a single portal.<br>3. 50 percent of external merit review functions will be accessible through a single portal. | 1. Achieved<br>Result = 99.8 percent<br>2. Not Achieved<br>Result = 79 percent<br>3. Not Achieved<br>Result = 41 percent |
| **Previous Year** | | |
| **FY** | **Target** | **Result** |
| 2019 | By the end of FY 2019,<br>1. NSF IT systems will have been available 99.5 percent of the time, excluding 469 hours of planned downtime.<br>2. 72 percent of internal merit review functions will be accessible through a single portal.<br>3. 32 percent of external merit review functions will be accessible through a single portal. | 1. Achieved<br>2. Achieved<br>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 M-17-22, "Comprehensive Plan for Reforming the Federal Government."

As part of the Renewing NSF principle to make IT Work For All, NSF will focus on leveraging state-of-the-art IT solutions to develop flexible tools and improve upon current service offerings in order to streamline and simplify the interactions that staff and the research community have with NSF's IT systems. This will help ensure that their time is spent on activities where they can add the most value instead of administrative activities, thereby helping the agency more effectively carry out its mission. As part of this effort, NSF will offer single points of access to both internal and external users for the IT services that they need, ensure that IT services have close to 100 percent availability with downtime for critical maintenance and service releases carefully coordinated to minimize disruption. In addition, NSF will utilize new IT solutions for automating non-value-added steps for users, through services like robotic process automation.

Discussion of FY 2020 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 (MR) functions, and monitor software development processes. The effort began in FY 2017, and set multi-year targets for 86 percent (25 of 29) of internal MR functions and 64 percent (14 of 22) of external MR 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 2020, IT development resources were reprioritized during the year to establish capabilities needed to maintain NSF operations through the pandemic. This reprioritization resulted in fewer resources being devoted to the development of these internal and external portals, as is reflected in the missed targets for FY 2020.

FY 2021 and Planned FY 2022 Changes
An error in the FY 2021 APP published the wrong value for target 2. The correct value (86 percent) for FY 2021 was recently identified, and the correct value (86 percent) is stated above.

A new goal framework and associated targets will be established for FY 2022 in conjunction with the development of the agency's new strategic plan.

## FY 2020 MANAGEMENT CHALLENGE PROGRESS REPORT

### Background

Under the Reports Consolidation Act of 2000, NSF's Inspector General is required to summarize what it considers to be the most significant management and performance challenges facing NSF in the coming year in a memo to the NSF Director. The management challenges are identified by NSF's Inspector General and announced at the beginning of each fiscal year. In response, the Director issues a memo to acknowledge receipt of the OIG Management Challenges and to provide a report on NSF's progress and achievements made over the prior year.

The OIG's challenges, NSF's response, and NSF's progress update towards addressing previously identified challenges are included in the annual Agency Financial Report (AFR) published in November on NSF's website.[6] This section is a republication of NSF's progress report in that document. It highlights the significant actions taken as of mid-FY 2020 on the management challenges identified by NSF's Inspector General at the beginning of that fiscal year. The FY 2021 Progress Update will be published in fall of 2021.

### 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.

In response to NSF's incorporation of ERM principles in its FY 2018 report, the OIG updated its reporting format for FY 2019, and recognized NSF's progress by removing one Management Challenge cited for FY 2019, eliminating improper payments. In FY 2018, the OIG identified foreign talent plans as an emerging challenge area for FY 2019. OIG's inclusion of an emerging challenge in its FY 2019 Report enabled NSF to undertake responsive actions in FY 2019. The OIG made mitigating threats from foreign government talent recruitment programs a standalone challenge for FY 2020, and a progress report on this new challenge is included below.

FY 2020 Management Challenges

- Managing major multi-user research facilities
- Meeting Digital Accountability and Transparency Act of 2014 (DATA Act) reporting requirements
- Managing the Intergovernmental Personnel Act (IPA) Program
- Managing the Antarctic Infrastructure Modernization for Science (AIMS) Project
- Encouraging the responsible and ethical conduct of research
- Mitigating threats posed by foreign government talent recruitment programs

FY 2021 Management Challenges

- Providing Oversight of Major Multi-User Research Facilities
- Providing Oversight of Grants During a Pandemic
- Managing the Intergovernmental Personnel Act Program
- Providing Oversight of the Antarctic Infrastructure Modernization for Science (AIMS) Project
- Increasing Diversity in Science & Engineering Education and Employment
- Mitigating Threats Posed by Foreign Government Talent Recruitment Programs

[6] www.nsf.gov/about/performance

**Managing Major Multi-User Research Facilities**
Co-Leads: Chief Financial Officer and Chief Officer for Research Facilities

Summary of OIG Identified Challenge

a) Manage inherent risk associated with previously highlighted OIG concerns, including the need for strengthened controls to ensure major facilities clearly identify subrecipients, complete subrecipient risk assessments, and properly charge project expenditures to construction or operations.
b) Ensure that NSF and recipients constructing and operating major facilities maintain project management expertise.

NSF Management's Overview of the Challenge and Action Plan to Address and Monitor the Challenge
NSF understands the importance of its role in overseeing recipients' on-going management of major facilities. The agency also recognizes the importance of assessing prospective recipients' capabilities for managing major facilities prior to award. Over the past several years, NSF has greatly strengthened its oversight policies and procedures. This includes an annual Major Facilities Portfolio Risk Assessment to determine the necessary reviews and audits to be conducted by the Large Facilities Office (LFO) and Cooperative Support Branch (CSB) within the Office of Budget, Finance and Award Management (BFA). In close cooperation with NSF program offices, LFO and CSB conduct these reviews to safeguard NSF's significant, long-term investments in supporting the scientific endeavor.

NSF leadership continues to show its commitment to major facilities oversight through the active engagement of the Chief Officer for Research Facilities (CORF) and leadership's periodic review of the Office of the Director's Watch List. The governance structure currently in place, which includes the Accountable Directorate Representatives, Facilities Governance Board, Facilities Readiness Panel, and the Director's Review Board, continues to help ensure consistent implementation of NSF's expanded controls for major facilities oversight. Furthermore, NSF is ensuring adequate human capacity through implementation of the Program Management Improvement Accountability Act (PMIAA) on the major facility/acquisition portfolio for NSF staff overseeing major facility awards, and by establishing guidance on the necessary core competencies for recipient staff managing major facilities.

Since 2017, NSF has been through three Government Accountability Office (GAO) reviews related to its oversight of projects funded from the Major Research Equipment and Facilities Construction (MREFC) account. The June 2018 report entitled National Science Foundation: Revised Policies on Developing Costs and Schedules Could Improve Estimates for Large Facilities (GAO-18-370) recommended that NSF revise its policies for estimating and reviewing the costs and schedules of major facility projects to better incorporate the best practices in GAO's guides. The March 2019 report entitled National Science Foundation: Cost and Schedule Performance of Large Facilities Construction Projects and Opportunities to Improve Project Management (GAO-19-227) recommended that NSF conduct a workforce gap analysis for project management competencies, ensure recipients provide lessons learned and best practices to NSF, and establish criteria for recipient project management competencies to be incorporated into NSF's review process. The April 2020 report entitled National Science Foundation: Cost and Schedule Performance of Major Facilities Construction Projects and Progress on Prior GAO Recommendations had no new recommendations. NSF has Corrective Action Plans (CAPs) in place as described below.

The COVID-19 pandemic presents unique challenges for major facilities, including protecting the safety of personnel and property, construction delays, and unanticipated additional costs given that it is considered an "unforeseen event." The greatest risk is the inadvertent misuse of funds when re-budgeting (Operations Stage awards) and the proper use of budget contingency funds (Construction Stage awards). Following the flexibilities granted through OMB guidance under the pandemic, NSF is taking action to address these risks by developing internal and external guidance for major facility programs and recipients. These efforts have included the following: (1) developing and updating a set of frequently asked questions (FAQs) specific to major facility recipients as a complement to NSF's implementation of Office of Management and Budget (OMB) Guidance; (2) issuing guidance jointly from the Office of the Director (OD) and the Large Facilities Office (LFO) to NSF Program Offices in response to the COVID-19 pandemic to ensure recipients segregate and track related cost increases; and (3) providing guidance for addressing re-baselining of construction projects and the application of management reserve for this unforeseen event. NSF will be following its current policies and controls with only minor clarifications. No additional controls are deemed necessary.

Based on NSF's evaluation of this Management Challenge under Enterprise Risk Management (ERM), coupled with activities already completed and those planned for FY 2020, NSF has determined that the residual risk impact for fraud, waste and abuse (Risk 1) is "low" and the likelihood is "very low" and that the residual risk impact for scientific performance (Risk 2) is "moderate" and the likelihood is "very low." Risk 2 impact and likelihood assume sufficient additional funding is made available. 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.

The planned corrective actions, demonstrated progress, and monitoring activities are described below.

<u>NSF's Corrective Measures to Address the Challenge</u>

*Demonstrated Progress Through Agency Action Taken in Prior Fiscal Years*

Since 2015, NSF has implemented enhanced controls and strengthened agency governance to fully address the recommendations of the 2015 National Academy of Public Administration report; the requirements of the American Innovation and Competitiveness Act of 2017 (AICA); the FY 2018 and FY 2019 GAO Review Reports; and numerous OIG report recommendations. Examples of recent (FY 2019) agency actions include the following:

- Addition of the Chief Officer for Research Facilities (CORF) in the Office of the Director and Accountable Directorate Representatives; formation of the Major Facilities Working Group, Facilities Readiness Panel, and Facilities Governance Board; and implementation of Integrated Project Teams.
- Revised the *Major Facilities Guide* (MFG; NSF 19-68, September 2019) to include:
  - Created new Section 4.3 - *Schedule Development, Estimating, and Analysis.*
  - Requirement for Segregation of Funding Plan (as part of the Project Execution Plan) which requires recipients to describe how they allocate expenses between Construction and Operation Stage awards, particularly when awards overlap in duration.
  - Language describing the intent of the final Construction Stage review in determining whether the required project scope to meet science requirements was delivered in accordance with the Project Execution Plan and the impact on operations for any deferred work packages.
- Initiated major facilities portfolio workforce gap analysis as part of PMIAA implementation and the CAP for GAO-19-227.
- Revised Major Facilities Cooperative Agreement Supplemental Terms and Conditions (and any major facility contract terms and conditions) to require recipients to participate in NSF's Knowledge Management Program as part of the CAP for GAO-19-227.
- Drafted the new *Major Facilities Oversight Reviews* Standard Operating Guidance (SOG) to utilize external review panels more fully in addressing elements of cost and schedule and to evaluate the competencies of Recipient Key Personnel (GAO-18-370 and GAO-19-227).
- Drafted new MFG Section on *Key Personnel* as part of CAP for GAO-19-227.

*Demonstrated Progress through Agency Actions Taken in FY 2020*

- Required recipients to develop Segregation of Funding Plans for the following NSF projects: Daniel K. Inouye Solar Telescope (DKIST), Vera C. Rubin Observatory (formerly Large Synoptic Survey Telescope, or LSST), Antarctic Infrastructure Modernization for Science (AIMS), Regional Class Research Vessel (RCRV), and Large Hadron Collider Hi-Luminosity Upgrade (HL-LHC) Program (the CMS and ATLAS projects).
- Converted Director's Watch List to Office of the Director's Watch List under cognizance of the Chief Officer for Research Facilities, formalizing the process of tracking open action items on a monthly to bi-monthly interval.
- Ensured that the AIMS project has Federal Acquisition Regulations (FAR)-compliant procedures in place, including requirements for expending funds for established purposes, tracking and billing of costs incurred, and record-keeping for audit comparable to Segregation of Funding Plans under cooperative agreements.
- Revised the *Business Systems Review (BSR) Guide* to better align with the Uniform Guidance and address implementation of Segregation of Funding Plans and the allocation of expenses during the Construction and Operations Stages (if identified as a risk).
- Implemented corrective actions in response to all OIG recommendations under OIG Report 18-2-005 *Audit of NSF's Oversight of Subrecipient Monitoring,* which included updating various NSF policies and procedures to: (1) align with the Uniform Guidance; (2) provide a specific mechanism to verify that Pass-through entities (PTEs) of large and complex awards complete subrecipient risk assessments; and (3) to require that PTEs clearly identify entities that will receive a subaward.

<u>NSF's Anticipated Action Plan Milestones</u>

NSF management developed the following anticipated milestones in consideration of NSF's strategic and operational objectives and the previous actions NSF has already taken as described above:

- Revise *Obligation and Allocation of Management Reserve* SOG (NSF-LFO-FY19-02-00) to clarify the relation to the NSB delegation order and eliminate the $10 million applicability limit for use on construction projects impacted by the COVID-19 pandemic [FY 2020, Q3].
- Finalize the *BSR Guide* and post for public comment [FY 2020, Q4].
- Finalize the *Major Facilities Oversight Reviews* SOG and provide to the OIG for consideration in closing the resolved recommendation in OIG Report 19-2-006, *Audit of NSF's Controls to Prevent Misallocation of Major Facility Expenses* [FY 2020, Q4].
- Complete the major facilities portfolio workforce gap analysis as part of Program Management Improvement Accountability Act (PMIAA) implementation and the CAP for GAO-19-227 [FY 2020, Q4].
- Finalize and post interim update to the MFG for public comment [FY 2021, Q1], including:
  - Content in the new MFG Section 4.3, *Schedule Development, Estimating, and Analysis.*
  - More detailed guidance on Segregation of Funding Plans and provide to the OIG for consideration in closing resolved recommendations in OIG Report 19-2-006, *Audit of NSF's Controls to Prevent Misallocation of Major Facility Expenses.*
  - New section(s) on *Key Personnel* and *Recipient Core Competencies.*
- Monitor allocation of funds between awards as part of required cost incurred audits using Segregation of Funding Plans as reference [on-going].

**Meeting DATA Act Reporting Requirements**
Lead: Chief Financial Officer and Office Head, OIRM

Summary of OIG Identified Challenge
In OIG Fiscal Year (FY) 2019 performance audit of NSF's implementation of the Digital Accountability and Transparency Act (DATA Act), the audit report (OIG 20-2-003) noted that "[data reviewed] did not meet OMB quality requirements [and several] data elements were inaccurate, incomplete, or untimely". Most of these OIG-identified errors were related to specific award actions, notable award closeout transactions, and post-closeout upward and downward modifications, that are not captured in NSF's Awards System. The report also acknowledged that although NSF has improved its DATA Act reporting, "challenges remain in implementing a process to ensure all award actions are transparent to the public".

NSF Management's Overview of the Challenge and Action Plan to Address and Monitor the Challenge
NSF is confident in the quality of our quarterly and monthly data submissions. The data submitted includes the required linkages between the submission files, the differences are legitimate and documented, and NSF's internal controls support the reliability and validity of the agency account-level and award-level data. NSF does not agree with the OIG's finding that the NSF award and financial systems must reconcile exactly. The data that the OIG pulled and identified as errors are not designated as "errors" in the Department of Treasury's (Treasury) DATA Act Information Model Schema (DAIMS) technical requirements, but are actually broker "warnings", which are previously disclosed as explainable differences between File C and D2.

NSF stores the original award amount and the true award actions (amendments) for additional funding, no-cost extensions and other administrative amendments in its award management system (Awards). NSF maintains information regarding all financial award actions interfaced from Awards, outlays/expenditures, and accounting adjustments (resulting from award close and post-award close actions) in its financial management system (iTRAK). The policy of maintaining award close-out and post-award actions in iTRAK is in compliance with the Office of Management and Budget's (OMB) Uniform Grant Guidance (2 CFR 200). A unique Federal Award ID link exists between the two systems, providing full traceability for transactions that are interfaced from Awards to iTRAK, as required by the DATA Act guidance from OMB and Treasury (OMB M-15-12 and DAIMS specifications). The specific difference in interpretation between NSF and the OIG is whether the non-financial system should be used as an accounting ledger or sub-ledger.

NSF has communicated with OMB and Treasury requesting further guidance on this issue, and we have received several responses that support our position.

- On October 3, 2019, NSF received an email from Treasury that noted that DAIMS Policy and Procedures Guide does not provide detailed policy requirements for what should be in the award system and recommended agencies defer to FAR and 2 CFR 200 as well as OMB.
- On October 16, 2019, NSF received an email from OMB that confirmed our interpretation of 2 CFR 200, validating our approach of managing award activity between the award system and the financial management system.
- On October 24, 2019, NSF received an email from Treasury that validated NSF's opinion that the DAIMS Practices and Procedures contains no absolute requirement to have a one-to-one match between Files C and D2.
- On February 24, 2020, NSF provided OIG a walkthrough of various interactions with OMB and Treasury as well as additional clarifications on NSF data and its representation on USASpending.gov which also included a confirmation from Treasury that the "Obligation Amount" on USAspending.gov is pulled from File D2.

Since February, NSF has been in constant communication with OMB and Treasury through Leveraging Data As a Strategic Asset (LDASA) and Chief Financial Officers Council (CFOC) meetings on revising documentation to further address these explainable differences. Although we are working to resolve this issue before the next audit, Treasury has deferred documentation updates to future DAIMS releases. NSF is also currently undergoing a Government Accountability Office (GAO) audit in which we have explained the nature of the abovementioned recommendation and how it relates to our standard business processes. Since this regular business process comprises the majority of our submission warnings, we look forward to GAO's interpretation of the issue and related feedback at the conclusion of the audit.

The NSF business process that is used for recording and reporting these transactions to USASpending.gov is fully aligned with the DATA Act and applicable guidance (e.g., OMB M-17-04, and Treasury DAIMS technical guidance). Our monthly Financial Assistance Broker System (FABS) submission process ensures that reportable award actions from the Awards system are validated and reviewed by the stakeholders before publishing on USASpending.gov. NSF has also updated its Data Quality Plan (DQP) to note that the agency considers these adjustments as non-addressable, acceptable differences between Files C and D2. NSF accounts for these differences as part of its quantitative and qualitative materiality considerations, and monitors adjustments for significant increases to the risk of misstatement via its newly implemented Award Reconciliation Report. Further, NSF implemented a Quarterly Retrospective to review outstanding discrepancies and final dispositions of warnings, consider dollar materiality of issues, and document lessons learned for subsequent quarters. Through this process, NSF validates that all addressable warnings identified within monthly reporting cycles were addressed at the time of certification to provide full transparency to the public over its award actions.

<u>NSF's Corrective Measures to Address the Challenge</u>

*Demonstrated Progress Through Agency Action Taken in Prior Fiscal Years*

- Actively participated in the Chief Financial Officer Council (CFOC) DAIMS workgroup on data quality improvements, which is a cross-agency group led by Treasury for introducing potential improvements to the DAIMS specifications for improving data quality on USASpending.gov.
- Continued ongoing work, through the NSF Deputy Chief Financial Officer (DCFO) and staff, with the joint working group of the CFOC and the Council of the Inspectors General on Integrity and Efficiency (CIGIE) to provide input and recommendations around the next iteration of DATA Act policies, internal control, and audit guidance to OMB, Treasury, and CIGIE.
- Committed the NSF DCFO to leading a subgroup on internal controls, serving as primary author of a government-wide DATA Act Playbook, and actively participating in developing best practices for financial assistance data quality.
- Instituted processes to monitor and independently validate the effectiveness and sustainability of data quality measures. The NSF DATA Act Working Group worked with appropriate stakeholders from the Internal Controls and Enterprise Risk Management groups in developing and executing a data quality plan that would define NSF's FY 2019 approach to achieve reasonable assurance for internal control over quarterly DATA Act reporting. The plan was prepared in accordance with OMB M-18-16, *Appendix A to OMB Circular No. A-123*.
- Conducted a risk assessment of the 57 essential reporting elements related to procurement, financial management, and financial assistance data and submission processes and reviewed related system controls and Standard Operating Procedures (SOPs).
- Performed analysis of NSF's submission warnings to provide warning rationales, counts, and frequency of each identified warning during the execution phase of the data quality plan. This practice will continue with each quarterly submission and be reported in the annual assurance document.

- Updated documentation of DATA Act processes including, the DATA Act SOPs, Financial Assistance Broker System (FABS) Standard Operating Guidance, and NSF Acquisition Manual.
- Created a desk guide for the NSF Contracts Branch that includes step-by-step instructions intended to reduce recurring data errors.
- Implemented a SharePoint tool to assist in quarterly DATA Act submission processes by tracking Division Director assurances and the Senior Accountable Officer (SAO) certification.

*Demonstrated Progress through Agency Actions Taken in FY 2020*

- Corresponded with Treasury and OMB to get further clarity on the linkage requirements between Files C and D2 and to inform updates to Treasury DAIMS specifications that will provide more specific guidance on NSF's legitimate differences.
- Migrated reporting functionality from NSF's custom solution into iTRAK so that all reporting is now conducted directly out of NSF's financial system of record, with reconciliation reports also implemented into iTRAK directly.
- Implemented a SharePoint tool to assist in quarterly DATA Act submission process by tracking Division Director assurances and the SAO certification.
- Implemented an NSF Award Reconciliation Report to identify potential data issues across financial and award files and assign dollar impact and preliminary root causes to these issues to help report all addressable warnings.
- Incorporated lessons learned from feedback on data submissions to improve accuracy and efficiencies.
- Continued to work closely with OMB, Treasury, and intra-governmental groups to provide input into DATA Act technical guidance and policy
- Updated NSF's DQP for FY 2020 to provide an executive level summary of key and supplemental controls to ensure the completeness, accuracy, and timeliness of DATA Act submissions. This update includes new procedures developed and implemented to meet DAIMS 2.0 and OMB M-20-21 requirements.
- Updated DATA Act and FABS policies and procedures to reflect DAIMS 2.0 and OMB M-20-21 enhancements.
- Continued collaboration with NSF OIG and GAO to cooperate with and support their audit responsibilities as well as to resolve any recommendations through implementing a corrective action plan.

<u>NSF's Anticipated Action Plan Milestones</u>

NSF management developed the anticipated milestones below in consideration of NSF's strategic and operational objectives, the risks inherent to achieving these objectives, and the key actions NSF has already taken to address those risks.

- Incorporate recommendations from the GAO audit into NSF's reporting processes and controls.
- Continue to provide feedback to OMB and Treasury on recommended guidance changes that will help clarify the nature of NSF's legitimate differences, and reference to-be-published guidance in NSF policies and procedures.
- Continue to work with the OIG to achieve a common understanding and resolution of this issue.

**Managing the IPA Program**
Co-Leads: Assistant Director, BIO and Office Head, OIRM

Summary of OIG Identified Challenge
IPAs can have a heightened risk of conflicts of interest while working at NSF because most IPAs come from institutions receiving NSF grants. The IPA program remains an area with inherent risk that NSF must continue to monitor and mitigate, because:

a) IPAs serve in a temporary capacity for up to 4 years, there is frequent turnover in staff at NSF, especially in senior leadership positions filled by IPAs.
b) IPAs can spend up to 50 days each year on Independent Research/Development (IR/D).
*c)* IPAs are not subject to Federal pay and benefits limits.

NSF Management's Overview of the Challenge and Action Plan to Address and Monitor the Challenge
NSF provides the opportunity for scientists, engineers, and educators to rotate into the Foundation as temporary Program Directors, advisors, and leaders. Rotators bring fresh perspectives from across the country and across all fields of science and engineering supported by the Foundation, helping influence new directions for research in science, engineering, and education, including emerging interdisciplinary areas. Many of these rotators remain involved in their professional research and development activities while working at NSF through participation in the IR/D program, which is overseen by the NSF IR/D Council.

NSF takes a proactive approach in the management of the IPA Program to appropriately consider and mitigate inherent risks associated with its execution.

*Demonstrated Top Leadership Commitment:*
The IPA Steering Committee reports directly to the NSF Director and Chief Operating Officer (COO) and has been in place since April 2016. The IPA Steering Committee is comprised of senior-level leadership across the agency, namely a Chair and Vice-Chair who are part of the agency's Senior Executive Service (SES), the Chairs of the NSF Executive Resources Board (ERB) and IR/D Council, Head of the Office of Diversity and Inclusion, and four at-large members, including two SES and two executive-level IPAs.

The IPA Steering Committee is charged with ensuring NSF is best utilizing the IPA hiring authority. It advises the Foundation's senior leadership on matters that directly concern policy on the use of the IPA Program, and on common approaches to budgeting and implementation of the program. It also regularly reports on its oversight and stewardship of the IPA Program, including costs associated with the program, to the Director and COO, the Office of Management and Budget (OMB), and Congress, pursuant to the American Innovation and Competitiveness Act (AICA).

*Capacity:*
The IPA Steering Committee is supported in the execution of its responsibilities by various NSF units with key expertise for risk management, reporting, and accountability, including BFA, the OIRM's Division of Human Resource Management, the Office of General Counsel (OGC), the Office of Legislative and Public Affairs, and the Office of Integrative Activities.

*Demonstrated Progress:*
NSF 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 this way, NSF is ensuring the program fully supports the mission of the agency and the Nation's interests. Indeed, NSF believes that the steps taken to date as described above have reduced the inherent risk

substantially, such that the residual risk is acceptable to the agency. One example is NSF's work to resolve and close the recommendations from OIG report 17-2-008, *NSF Controls to Mitigate IPA Conflicts of Interest*. The last of the four recommendations from this report was closed by the OIG in October 2018. This result demonstrates that NSF has effectively minimized the inherent risk of IPA conflicts of interest while working at NSF (since most IPAs come from institutions receiving NSF grants). NSF is confident that these actions taken in response to prior OIG recommendations and ongoing monitoring and controls have mitigated the potential risks associated with managing IPAs' COIs.

NSF's Corrective Measures to Address the Challenge

*Demonstrated Progress Through Agency Action Taken in Prior Fiscal Years*

a) *Because individuals serve in a temporary capacity for up to 4 years, there is frequent turnover in staff at NSF, especially in senior leadership positions filled by IPAs.*
    - Ensured there is a "bench" of staff ready to fill developmental detail assignments to vacant executive positions who have been trained at the Federal Executive Institute (FEI), American University Executive Leadership Program, Harvard Business School Leadership Training, Individual Development Plans, and NSF Academy Leadership Development Program.
    - Implemented the New Executive Transition Program (NeXT) in 2009 to onboard employees and IPAs transitioning into executive-level positions to help new executives reach full performance as quickly as possible by developing executive knowledge about NSF mission, culture, organization, people, and business processes.
    - Instituted mandatory training for Program Officers, including IPAs, on NSF's Merit Review process which teaches how research proposals are evaluated and how to execute the Program Officer role.
    - Created a parallel performance management system in 2014 for IPAs to ensure clarity in setting expectations and providing feedback on performance.
    - Established a knowledge transfer process in 2015 that exiting IPA executives can use to transfer knowledge and information to incoming executives.
    - Implemented a required three-day supervisory training and development course in 2015 called Federal Supervision at NSF designed to assist new federal supervisors (including IPAs) in understanding their roles and all the requirements pertaining to federal human capital management.
    - Established a Steering Committee for Policy and Oversight of the IPA Program (IPA Steering Committee) in April 2016 to serve as the primary body for considering policy on NSF's use of IPAs, and to oversee common approaches to budgeting and implementation of the IPA program.
    - Produced IPA Program Annual Reports for the Director of NSF, beginning in 2018. This report provides annual data and trend analyses on various aspects related to the use of IPAs at NSF for use by the Director and NSF senior managers in assessing and overseeing the program.
    - Developed the Corrective Action Plan (CAP) response to the GAO report, *A Workforce Strategy and Evaluation of Results Could Improve Use of Rotating Scientists, Engineers, and Educators* (GAO-18-533).

b) *IPAs can spend up to 50 days each year on Independent Research/Development (IR/D).*
    - Established the IR/D Council in October 2011 to develop and monitor internal controls related to the IR/D Program, including tracking the time spent on IR/D activities. Data from these internal controls are disseminated to NSF senior management quarterly for use in managing the IR/D Program within each organization.
    - Developed an IR/D Guide in 2012 to clearly communicate NSF policies on the use of IR/D, including the possibility that participation in the IR/D Program could be curtailed if it compromised the completion of NSF duties.

- Designated IR/D experts in each Directorate/Office who receive annual training to ensure that NSF IR/D policies are implemented appropriately.
- Instituted a requirement that all IR/D plans provide an explanation of how the IR/D activities enhance the requestor's ability to perform NSF duties.
- Published a revised IR/D Guide in January 2017 that includes guidance limiting NSF payment of IPAs' IR/D travel to their home institutions to 12 trips per year. The guidance encourages IPAs to combine other NSF official business and/or telework with these trips to more efficiently use travel dollars.
- Delivered a "Benefits of the NSF IR/D Program" report to the NSF Deputy Assistant Directors (DADs) in March 2018 highlighting the value of IR/D in recruitment, research currency, and ethics protection.
- Monitored time spent on IR/D by both permanent and rotating staff, and provided quarterly data to NSF senior managers to ensure appropriate oversight of IR/D.
- Performed yearly data checks to assure that no IPA IR/D participant travel was paid by NSF in excess of 12 trips per year.

c) *IPAs are not subject to Federal pay and benefits limits.*
- NSF initiated a pilot requiring 10 percent cost sharing by IPAs' home institutions of their academic-year salaries and fringe benefits (per NSF Bulletin 16-11). This pilot applies to all new IPA agreements initiated in FY 2017 and beyond, including those for executive and program level staff. Additionally, NSF eliminated reimbursement for lost consulting. An assessment of the pilot indicated that the cost-share percentage increased from 7.2 percent in FY 2016 to 7.9 percent in FY 2017 to 9.2 percent in FY 2018 and to 10.4 percent in FY 2019. At the conclusion of FY 2019, NSF had realized significant cost avoidance with increased cost share dollars and participation rates each year.
- Engaged with the GAO on the salary reimbursements associated with IPAs. As noted in the GAO report, IPAs remain employees of their home institutions, with NSF reimbursing the institutions for most of their salaries and benefits. NSF does not set the salaries for rotators who are detailed to NSF using the IPA authority because their salaries are set by their home institutions.
- Submitted to Congress annual responses to the AICA (P.L. 114-329 Section 111 on Personnel Oversight) on the Justifications for Rotator Pay Exceeding the SES Pay Max.

*Demonstrated Progress through Agency Actions Taken in FY 2020*

a) *Because individuals serve in a temporary capacity for up to 4 years, there is frequent turnover in staff at NSF, especially in senior leadership positions filled by IPAs.*
- Submitted the IPA Program Annual Report covering the prior fiscal year to the Director of NSF.
- Integrated activities associated with the CAP in response to GAO-18-533 into Renewing NSF goal 1 Adapting the Workforce to the Work.
- Engaged in IPA Program Enterprise Risk Management to clearly identify IPA Program objectives and associated risks as they pertain to the mission of NSF.
- Established implementation plan to Integrate Program level and Executive level IPAs into the USA Performance Management System in FY21.

b) *IPAs can spend up to 50 days each year on Independent Research/Development (IR/D).*
- Continued the IR/D Program, which permits employees and individuals performing temporary service with NSF to maintain their involvement with their professional research and research-related activities. Prior to creating an IR/D plan, participants must receive approval from their

supervisor for the time and expense related to the submitted activities. Additionally, the plan needs to be approved by the Division Director and designated IR/D Expert from the organization. IR/D activities may not interfere with other assigned NSF duties and may be curtailed at management's or the participant's discretion.

- NSF continued to maintain robust oversight, training, and internal controls to monitor use of the IR/D program as demonstrated by these actions taken in FY 2020.
- Submitted the IR/D Annual Report to the DADs, covering program participation statistics, average days and dollars requested and used and status of IR/D training and outreach.
- Provided annual training for IR/D experts, including updates to the IR/D Guide and the online electronic IR/D plan.
- Provided quarterly data to NSF senior managers to ensure appropriate oversight of IR/D time and travel by both permanent and rotating staff.
- Continued to perform yearly data check to assure that there are no IPA IR/D participants where NSF payment of travel to their home institutions exceeds 12 trips per year.

c) *IPAs are not subject to Federal pay and benefits limits.*
   - Submitted the FY 2019 IPA Program Annual Report to OD, which demonstrated that the 10 percent cost-share pilot has reduced/eliminated the gap between IPA reimbursements and Fed salaries, and thus this is not a major risk to the agency.
   - Effective January 16, 2020, informed by the data in the IPA Program Annual Report, NSF implemented the 10 percent Cost Share Policy for Personnel on Intergovernmental Personnel Act (IPA) Assignment to NSF. Submitted to Congress the FY2019 annual response to the AICA on the Justifications for Rotator Pay Exceeding the SES Pay Max.
   - NSF is preparing a brief report to GAO that will highlight the efforts of the agency surrounding the IPA Cost Share Policy and address concerns surrounding IPA costs at the Foundation.

NSF's Anticipated Action Plan Milestones

NSF management developed the anticipated milestones and responses to the findings in the OIG Management Challenge FY 2020 Report below in consideration of NSF's strategic and operational objectives, the risks inherent to achieving these objectives, and the key actions NSF has already taken in response to those risks.

a) *Because individuals serve in a temporary capacity for up to 4 years, there is frequent turnover in staff at NSF, especially in senior leadership positions filled by IPAs.*
   - NSF conducted an analysis (January 2018) on IPA years of service and found that, on average, IPA executives serve 3.1 years at NSF and are 3 times more likely to stay for 3-4 years compared to staff-level IPAs. Non-executives serve, on average, 2.3 years at NSF. Per OPM, the average time a career SES spends in a position is 3.4 years and non-career SES is 1.7 years.[7]
   - Thus, the turnover risk for IPAs is not any greater than for other employees. NSF will continue to use the robust onboarding, training, knowledge transfer, and performance management systems that are in place, to ensure that turnover of all employees and IPAs have minimal impact on operations.
   - Migrate Program Director and Executive IPAs to the USA Performance system for managing performance plans.

[7] www.opm.gov/policy-data-oversight/senior-executive-service/facts-figures/#url=Demographics

b) *IPAs can spend up to 50 days each year on Independent Research/Development (IR/D).*
- Continue to submit the IR/D Annual Report to the DADs, covering program participation statistics, average days and dollars requested and used and status of IR/D training and outreach.
- Continue to provide annual training for IR/D experts, including updates to the IR/D Guide and the online electronic IR/D plan.
- Continue to provide quarterly data to NSF senior managers to ensure appropriate oversight of IR/D time and travel by both permanent and rotating staff.
- Continue to perform yearly data checks to assure that there are no IPA IR/D participants where NSF payment of travel to their home institutions exceeds 12 trips per year.

c) *IPAs are not subject to Federal pay and benefits limits.*
- As of FY 2020, the gap in pay between IPAs and Federal employees has been reduced/eliminated by implementing the required 10 percent cost-share as policy. Thus, this does not constitute a significant risk to the agency. NSF will continue to monitor costs of the program, and provide annual reports to the Director, COO and NSF senior management.

**Managing the Antarctic Infrastructure Modernization for Science (AIMS) Project**
Co-Leads: Assistant Director, GEO, and Office Director, Polar Programs

<u>Summary of OIG Identified Challenge</u>
a) The Antarctic Infrastructure Modernization for Science (AIMS) Project will stretch Agency resources and may present additional challenges for NSF to overcome.
b) In addition, OPP is also managing construction of the Information Technology & Communications (IT&C) primary facility – a key precursor to the success of AIMS.

<u>NSF Management's Overview of the Challenge and Action Plan to Address and Monitor the Challenge</u>
NSF—through the Office of Polar Programs (OPP) in the Directorate for Geosciences (GEO)—funds and manages the U.S. Antarctic Program (USAP). The USAP supports United States' research and national policy goals in the Antarctic. USAP has two major construction projects ongoing at McMurdo Station – the IT&C Primary Addition, which entails building onto an existing facility for the consolidation of IT&C functions, and the AIMS Project, for which 6 new facilities are being built to replace multiple outdated structures and consolidate key functions for more streamlined and efficient operations. Both projects are being implemented through NSF's Antarctic Support Contractor (ASC) under a FAR-based contract with NSF. Antarctica's remote location, extreme environment, and the short period of time during which the continent is accessible present challenges above and beyond those typically encountered for domestic construction projects.

The ASC (Leidos, Inc.) has a well-developed risk identification and mitigation process overseen by NSF as captured in the Project Execution Plan. The initial risk register for AIMS contained 120 entries to develop the project's budget contingency – key among them were delays in long-lead procurement items, inadequate quantities of fill material on-site, and work stoppages due to weather. Leidos mitigates the likelihood and impacts of these key risks through extensive pre-authorization planning and coordination to identify the key long-lead material and equipment purchases to support delivery dates meeting the logistics supply chain requirements. These procurements are captured and tracked in the project integrated master schedule and reviewed regularly by project and program leadership.

A significant challenge that remains is the risk of increased costs due to unpredictable and fluctuating market conditions. To minimize the impact of these uncertainties, each major construction package is awarded only after designs are complete, subcontractor bids are received, and costs are understood. This risk of rising costs has materialized in the first few construction packages, and mitigation steps have included evaluation of design-to-cost measures and seeking revised bids. Another significant challenge remaining is the need to align logistics chain/cargo capacities with the planned pace of construction. To mitigate this risk, NSF and Leidos held a series of workshops to clearly define execution and oversight processes for each step in the logistics pathway.

The global pandemic associated with COVID-19, which is considered an unforeseen event not addressed by budget contingency for AIMS construction, has had impacts on the entirety of USAP operations. As a result of the significant health risk to the deployed population as well as global travel restrictions, it was necessary to make significant changes to program and construction project plans. The global pandemic resulted in "excusable delays" for the contractor as well as additional government-directed delays in performance of work under the AIMS project. This included placing the construction sites in a safe and stable configuration in March 2020 and bringing home deployed construction crews earlier than anticipated. In accordance with NSF policy, the magnitude of these impacts will require re-baselining of the AIMS project and OPP is actively engaged with Leidos, BFA, and the Office of the Director for that purpose.

NSF's Corrective Measures to Address the Challenge

*Demonstrated Progress Through Agency Action Taken in Prior Fiscal Years*

- Completed design and began construction on the IT&C Primary Addition Project. As of March 2020, the facility construction was 74 percent complete and is poised to be continued as conditions warrant. Significant delays to schedule due to the COVID-19 pandemic will now require a re-baselining effort.
- AIMS received authorization for the total project cost and duration from the National Science Board in February 2019 following extensive internal reviews and Independent Cost Estimate (ICE), with the first two construction packages awarded for the Vehicle Equipment and Operations Center and the Lodging Building exterior in April 2019.
- OPP augmented internal staffing for program/project management and oversight by assigning the management of capital projects to a dedicated staff resource.
- Shortly following AIMS authorization, weekly meetings of the core Integrated Project Team – including OPP, DACS, and LFO – were initiated.

*Demonstrated Progress through Agency Actions Taken in FY 2020*

- On-site work began on AIMS with aggregate production, and demolition of facilities in the footprint of VEOC and Lodging. As of March 2020, the project was approximately 16.5 percent complete. Significant delays to schedule due to the COVID-19 pandemic will now require a re-baselining effort.
- Continued to engage the research community to ensure they remained aware of potential disruptions that construction might have on Antarctic science.
- Partnered with BFA/DACS and LFO to identify areas the contractor needed to strengthen, which resulted in the contractor hiring additional staff, restructuring the office supporting the contract, and obtaining interagency support for cost analysis from the U.S. Army Corps of Engineers (USACE).
- Augmented the AIMS Integrated Project Team by adding a Project Controls Lead, providing support to the Program Officer.
- Restructured USACE support being provided to the AIMS project by moving from cost reasonableness reviews to full independent cost estimates for proposal packages.
- Completed verification and acceptance of the AIMS Earned Value Management System (EVMS) in accordance with NSF policy.
- Enlisted formal Value Engineering sessions with NSF participation.
- Increased financial oversight of Construction in Progress reporting and construction invoicing by requiring Program Officer review of every invoice, and augmenting the accounting support to OPP.

NSF's Anticipated Action Plan Milestones

- Continue monitoring and oversight of the AIMS and IT&C Primary Addition Projects in accordance with established Internal Management and Project Execution Plans including external panel reviews and EVMS surveillance reviews for AIMS. Significant delays to schedule due to the COVID-19 pandemic will now require a re-baselining effort for both projects.
- Assess COVID-19 impacts and evaluate options for minimizing negative impacts to AIMS cost and schedule.
- Working closely with BFA, re-baseline AIMS, subject the revised cost, scope and schedule to external panel review, Facilities Readiness Panel Review, Director's Review Board Review and NSB re-authorization of the Total Project Cost.

**Encouraging the Responsible and Ethical Conduct of Research**
Lead: Chief Operating Officer

Summary of OIG Identified Challenge

a) Develop written guidelines or templates for universities to follow so that NSF can ensure the training is of sufficient quality and complies with Responsible Conduct of Research (RCR) training requirements. Strengthen the impact of RCR training by working with the National Institutes of Health to harmonize RCR expectations as much as possible.
b) Ensure that reports of sexual and other forms of harassment made pursuant to NSF's award term and condition are properly made to the NSF Office of Diversity and Inclusion and that NSF has enough staff and resources to respond to this new body of work.

NSF Management's Overview of the Challenge and Action Plan to Address and Monitor the Challenge

Research supported by NSF must be conducted responsibly and ethically to ensure that it is credible to the science and engineering community, trusted by the public, and maximizes the Nation's return on investment. NSF views the Responsible and Ethical Conduct of Research (RECR) holistically—not only as a responsibility to generate and disseminate knowledge with rigor and integrity, but also as a responsibility to conduct peer review with the highest ethical standards; diligently protect proprietary information and intellectual property from inappropriate disclosure; and treat students and colleagues fairly and with respect. This expectation is fully articulated in the June 202 update to the Proposal and Awards Policies and Procedures Guide (PAPPG)[8] and on NSF's updated RECR web page[9].

NSF does not tolerate research misconduct (falsification, fabrication, and plagiarism) in proposing or performing research funded by NSF, in reviewing research proposals submitted to NSF, or in reporting research results funded by NSF. Allegations of research misconduct (RM) are taken seriously and are investigated by NSF's OIG. The OIG refers completed investigations of RM to NSF for action. Upon determination of RM, NSF promptly takes appropriate action against individuals or organizations.

NSF is working to understand and reduce the occurrence of irresponsible and unethical research conduct through three sets of actions: 1) characterizing the problem and identifying priorities through stakeholder engagement, complemented by data collection and analysis; 2) funding basic research into the underlying causes and potential solutions, including the effectiveness of different approaches to improve RECR; and 3) implementing change through policy and public engagement. As reported by the OIG in its Fall 2019 Semiannual Report, the number of RM referrals to NSF from FY 2010 to FY 2019 has remained relatively low and has not trended upward. For example, from FY 2016 to FY 2019 NSF reviewed over 187,000 proposals, resulting in approximately 46,000 awards; *during that same four-year period, the OIG issued nearly four dozen referrals to NSF for RM (excluding other types of investigative referrals). Nearly half were allegations of research misconduct in proposals that NSF had not funded. Note that the referrals of potential RM account for just 0.02 percent of the proposals received.*

NSF is supporting research into the underlying causes, effective training practices, and how to best disseminate knowledge and best practice through community-led approaches. This approach will enhance understanding of the scope, causes, and best mitigation strategies to reduce detrimental conduct. NSF welcomes any further insight from the OIG into the scope and nature of RECR problems (including RM) brought to their attention. NSF is also involved in efforts to harmonize RECR expectations with other agencies, including the National Institutes of Health (NIH), being led by the Office of Science and Technology Policy (OSTP) through the National Science and Technology Council (NSTC) Joint Committee on Research Environment (JCORE). JCORE is co-chaired by the NSF Director, and NSF staff

[8] www.nsf.gov/pubs/policydocs/pappg20_1/pappg_9.jsp
[9] https://nsf.gov/od/recr.jsp

co-chair all four of the subcommittees: Coordinating Administrative Requirements for Research; Rigor and Integrity in Research; Research Security; and Safe and Inclusive Research Environments. Furthermore, NSF leadership has committed to ensuring that the award term and condition (T&C) associated with sexual and other forms of harassment reporting is managed effectively, dedicating professional staff and senior executives in the Office of the Director to respond to and assess the reporting processes and outcomes.

<u>NSF's Corrective Measures to Address the Challenge</u>
NSF has consistently addressed RECR by working to characterize the problem and identify priority actions; funding basic research into the underlying causes and potential solutions; and implementing change through policy and public engagement.

*Demonstrated Progress Through Agency Action Taken in Prior Fiscal Years*
<u>Characterizing the problem and identifying priority actions</u>:

- Funded the Online Ethics Center to hold a national workshop on identifying promising practices and innovative programs in RECR education and practice.
- Issued a Dear Colleague Letter welcoming proposals in Education and Human Resources (EHR) on equity, inclusion, and ethics in Science, Technology, Engineering and Mathematics (STEM).
- Issued a Dear Colleague Letter encouraging researchers in computer and information science and engineering to include fairness, ethics, accountability, and transparency in their proposals.
- Renewed and refreshed the mission of the Online Ethics Center to develop communities of practices in RECR education (continuing into FY 2020).

<u>Implementing change through policy and public engagement:</u>

- Provided intramural and extramural guidance, resources, and consultation for the inclusion of ethics considerations in citizen science, collaborative/team science, and international science by NSF program officers overseeing the Ethics and Responsible Research Program (continuing into FY 2020).
- Conducted outreach to the Principal Investigator and awardee community on promising practices in RECR training; continued to encourage STEM faculty to incorporate RECR into their mentoring, teaching, and curriculum development (continuing into FY 2020).
- Presented guidance and NSF perspectives to university research integrity officers and other research administrators at a workshop on RECR tools and methods for university leaders.
- Expanded efforts to create a harassment-free environment internally at NSF, including requiring mandatory training in harassment prevention for all personnel, which includes Federal employees; Intergovernmental Personnel Act (IPA) assignees; Visiting Scientists, Engineers and Educators; in-house fellows; experts; and others who regularly conduct business at NSF. (See Staff Memorandum OD 19-09, Required Harassment Prevention Training.
- Clarified the PAPPG requirements for anti-harassment mitigation in conference/workshop proposals.
- Funded an Online Ethics Center workshop on training STEM faculty new to teaching ethics using a "train the trainer" approach for capacity building across diverse STEM communities (continuing into FY 2020).
- Published, communicated, and implemented NSF's new harassment policy.
- Added staff in the Office of Diversity and Inclusion to manage the harassment T&C process.
- Added additional questions and answers to further explain the new harassment policy in the updated T&C FAQs.
- Drafted language on the applicability of the new T&C for awards made directly to individuals (vs. institutions); e.g., for NSF Postdoctoral Fellowships.

*Demonstrated Progress through Agency Actions Taken in FY 2020*

Characterizing the problem and identifying priority actions

- Collected stakeholder input through regular participation in the annual meetings of the Association for Practical and Professional Ethics.
- The Social, Behavioral & Economic Sciences (SBE) Directorate asked leading members from the Association for Practical and Professional Ethics to join SBE's Professional Societies Advisory Board and SBE's Committee of Visitors to provide direct stakeholder input into the Ethical and Responsible Research Program.
- OD and SBE staff members regularly discussed policy and best practices with colleagues in the HHS Office of Research Integrity.

Funding basic research into the underlying causes and potential solutions

- Repositioned the former Cultivating Cultures for Ethical STEM program to SBE's Office for Multidisciplinary Activities and renamed to Ethical and Responsible Research to fund research projects that identify factors that are effective in the formation of ethical STEM researchers and approaches to developing those factors in all STEM fields that NSF supports. Increased the budget of this program from $3.55 million to $5.55 million.
- Renewed and refreshed the mission of the Online Ethics Center to develop communities of practices in RECR education.

Implementing change through policy and public engagement:

- Provided intramural and extramural guidance, resources, and consultation for the inclusion of ethics considerations in citizen science, collaborative/team science, and international science by NSF program officers overseeing the Ethics and Responsible Research Program.
- Conducted outreach to the principal investigator and awardee community on promising practices in RECR training; continued to encourage STEM faculty to incorporate RECR into their mentoring, teaching, and curriculum development.
- Funded an Online Ethics Center workshop on training STEM faculty new to teaching ethics using a "train the trainer" approach for capacity building across diverse STEM communities.
- Provided a comprehensive definition of RECR in the 2020 PAPPG: "The responsible and ethical conduct of research involves not only a responsibility to generate and disseminate knowledge with rigor and integrity, but also a responsibility to (a) conduct peer review with the highest ethical standards, (b) diligently protect proprietary information and intellectual property from inappropriate disclosure, and (c) treat students and colleagues fairly and with respect."
- Published revisions to the PAPPG to point to promising practices in RECR training, including the encouragement of faculty training and reference material to use in designing RECR training (National Academy of Sciences, Engineering, and Medicine (NASEM) Reports: Fostering Integrity in Research; Sexual Harassment of Women: Climate, Culture, and Consequences in Academic Sciences, Engineering, and Medicine; and Reproducibility and Replicability in Science).
- Issued in the 2020 PAPPG clarification of requirements for disclosure of institutional/professional appointments to achieve full transparency.
- Created a "Speak Up" campaign to raise awareness of materials and resources available for personnel to address discrimination, bullying, harassment, stress and anxiety, physical safety, and violence in the workplace.
- ODI, in collaboration with OIA's evaluation and assessment team, developed a phased evaluation plan for the new T&C on reporting incidents of harassment, with the first stage starting in FY 2021.

NSF's Anticipated Action Plan Milestones
As NSF continues to characterize the problem and identify priority actions, fund basic research, and implement change through policy and public engagement, specific actions are planned for the coming year.

Strengthen the understanding and effectiveness of RECR training and community guidance through coordination with Federal agencies and the ethics community:

- Leverage NSF's leadership role as co-chair of the JCORE Safe and Inclusive Research Environment subcommittee and the JCORE Rigor and Integrity in Research subcommittee to promote the coordination and development of RECR among Federal agencies, including with NIH.
- Fund through the Ethical and Responsible Research program a prospective workshop that will curate relevant ethics and educational resources for NSF's RECR training requirements.
- Update NSF's RECR page periodically to ensure the newest resources and current information are available; build a more user-friendly portal for the new web site (see https://beta.nsf.gov/) that makes it easier to find available resources and makes NSF's commitment to RECR more prominent.

Assess and strengthen through action and policy efforts to reduce sexual and other forms of harassment:

- Implement Recommendation 15 from the GAO report, Sexual Harassment in STEM Research, that 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 communications mechanisms."
- Collaborate with other Federal agencies to address harassment in a coordinated manner through active participation in the JCORE Safe and Inclusive Research Environment subcommittee and its ad hoc working groups.

**Mitigating Threats Posed by Foreign Government Talent Recruitment Programs**
NSF lead: Chief of Research Security Strategy and Policy

Summary of OIG Identified Challenge
Foreign government talent recruitment programs – designed to benefit the foreign state by obtaining information and technology from abroad – have the potential to exploit the openness of American universities and threaten the integrity of U.S. research initiatives. Talent recruitment programs target individuals with expertise in cutting-edge science, including NSF-funded researchers, merit review panelists, and career Federal employees or rotators who manage NSF's scientific programs. These programs may require members to provide proprietary or export-controlled information and create conflicts of interests. Failure to disclose membership in such programs can have criminal or civil ramifications.

NSF should continue to assess and refine its controls in this area and should work to ensure that it has sufficient staff and resources to respond to this challenge.

NSF Management's Overview of the Challenge and Action Plan to Address and Monitor the Challenge
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, 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 acquire U.S. funded scientific research. These programs target scientists, engineers, and educators of all nationalities working or educated in the United States.

Over the past two years, NSF has taken steps to mitigate threats posed by foreign government talent recruitment programs. To ensure that NSF has sufficient staff and resources to continue to respond to this challenge, NSF created and filled the position of Chief of Research Security Strategy and Policy in March 2020 and is developing a new team to support the Chief. In addition, NSF coordinated with other agencies via the Joint Committee on the Research Environment (JCORE), an activity launched by the White House Office of Science and Technology Policy (OSTP) under the National Science and Technology Council in mid-2019.

Under the leadership of OSTP and through the JCORE subcommittee on research security which NSF co-chairs, U.S. science funding agencies are taking a risk-based approach to strike an appropriate balance between fostering the open and internationally collaborative environment that has contributed to the success of the U.S. research enterprise and mitigating emerging threats to the integrity of that enterprise. NSF also co-chairs a JCORE subcommittee on coordinating administrative requirements for research across the science funding agencies, including those associated with research security. We work closely with other U.S. government science agencies to share policies and practices, and regularly engage with the academic research community to educate them about the risks, hear their concerns about this emerging challenge, and clarify our positions, policies, and procedures. With an increased awareness of the risk, the U.S. research community now is better positioned to understand, evaluate, and do their part to address it.

NSF's Corrective Measures to Address the Challenge
In July 2019, NSF released a Dear Colleague Letter (DCL) on Research Protection to the research community from former Director Córdova. The DCL alerted the community to existing and emerging risks to the global research ecosystem, inspired conversations about balancing science and security, and warned of the risks of participation in foreign government talent recruitment programs. Further, it described NSF's commitment to vigilantly addressing emerging risks to the Nation's science and engineering enterprise, including concrete steps the agency is taking. To amplify the message from Director Córdova, NSF conducted outreach to multiple research community groups and sought best practices from the JASON

advisory group, the National Science Board, and NSF Advisory Committees.

At the same time, NSF issued a policy prohibiting NSF personnel and rotators such as Intergovernmental Personnel Act personnel (IPAs) detailed to NSF from participating in foreign government talent recruitment programs. This policy helps prevent inappropriate foreign influence on NSF personnel. This change built on earlier steps to protect NSF's policies, programs, and priorities, including the merit review process. For example, in 2018, NSF issued a requirement that all staff employed by NSF or detailed to NSF must be U.S. citizens or have applied for U.S. citizenship. In addition, earlier in 2019, NSF issued a note to NSF staff reminding everyone that government ethics regulations require accurate and timely financial disclosure reports and that federal ethics rules apply to both our career and rotator personnel.

NSF's actions were taken in coordination with other U.S. agencies that fund basic research, including through the White House National Science and Technology Committee's JCORE subcommittees on research security and coordinating administrative requirements for research.

*Demonstrated Progress Through Agency Actions Taken in FY 2020*

- **Improved transparency / clarification for disclosure:** In January 2020, following a public comment process that began in May 2019, NSF issued clarifications to its proposal preparation requirements specified in the PAPPG to ensure senior personnel on proposals provide information on all sources of current and pending research support, foreign and domestic. NSF has also clarified its biographical sketch preparation requirements to ensure that any titled position is identified whether or not remuneration is received. Effective June 1, 2020, all senior personnel identified on an NSF proposal are required to comply with these requirements.
- **Standardized format and streamlined processes for disclosure:** As part of its revision to the PAPPG[10], NSF announced that use of an NSF-approved format will be required to be used by senior personnel in preparation of both the biographical sketch and current and pending support sections of the proposal. To streamline the process, NSF worked with the National Institutes of Health (NIH) to use SciEncv: Science Experts Network Curriculuym Vitae[11] as an NSF-approved format for both sections of the proposal. The formats were released in April 2020, and the community will be required to use an NSF-approved format to prepare these sections of any proposal submitted or due on or after October 5, 2020.
- **Issuance of a new award term and condition regarding previously undisclosed information:** NSF's longstanding policy is that senior personnel must disclose, in any submitted proposal, all current and pending support. In July 2020, NSF released a revised set of general terms and conditions that incorporated a new term that addresses the process and content requirements to be used if an organization discovers that a Principal Investigator or co-Principal Investigator on an active NSF award failed to disclose current support or in-kind contribution information as part of the proposal submission process. This new term and condition is effective for all new awards and funding amendments on existing awards effective October 5, 2020.
- **Term and condition for foreign collaboration considerations in major facilities:** In July 2020, NSF finalized a revised term and condition on foreign collaboration considerations for major facilities. The new term and condition is effective October 5, 2020, for new awards and funding amendments on existing awards. As of October 5, 2020, awards that contain the revised term and condition must provide NSF with advance notification of potential collaboration with non-U.S. organizations or governments

[10] www.nsf.gov/pubs/policydocs/pappg20_1/index.jsp
[11] www.ncbi.nlm.nih.gov/sciencv/

in connection with its NSF-funded award and must await guidance from NSF prior to negotiating terms of any potential agreement.

- **Training for NSF staff:** In March 2020, NSF released mandatory training for all NSF personnel on science and security. It includes modules on risks from foreign governments, NSF's policies on disclosure, and NSF's policies on staff participation in foreign government talent recruitment programs.
- **Independent report on research security:** In December 2019, NSF accepted the final commissioned report from the independent JASON advisory group[12] assessing risks to fundamental research. The study included recommendations for NSF and grantee institutions to maintain balance between openness and security of science. In March 2020, NSF published its response,[13] agreeing with the report's recommendations and noting where the agency has already taken action or plans to do so. More details on NSF's actions are included elsewhere in this document, and briefly, they can be summarized in relation to the nine JASON recommendations:
  1. **Scope of disclosure:** NSF clarified its disclosure requirements in the revision to the PAPPG. NSF's new internal training reinforces these requirements. (see above)
  2. **Failures to disclose:** NSF developed a new term and condition for previously undisclosed information. (see above)
  3. **Responsibilities of all stakeholders and harmonization:**
     - NSF has conducted significant outreach with other federal agencies, Congress, the research community, and the OIG (as detailed in subsequent sections).
     - NSF has been in discussions with the NIH to examine the existing content disclosure requirements for both the biographical sketch and current and pending support by both agencies. The goal of this exercise is to harmonize, to the extent possible, the requirements imposed by both agencies.
     - Through JCORE, NSF has worked to harmonize definitions of terms such as conflicts of commitment.
  4. **Tools to evaluate risk:** Through JCORE, the U.S. government collected best practices in risk assessment and mitigation from the research community, from other agencies, and from the intelligence community. Internally, NSF has used an Enterprise Risk Management framework to identify and mitigate risks.
  5. **Expand ethics training:** NSF has reviewed its internal training modules to adapt them for potential external use.
  6. **Reaffirm the principles of NSDD-189:** NSF continues to support openness and transparency in fundamental research. In 2018, in its Statement on Security and Science (NSB-2018-42), the National Science Board "strongly reaffirm(ed) the principle behind President Reagan's National Security Decision Directive 189 (NSDD-189)."
  7. **Communicate the problem and the importance of foreign researchers and collaborations:** NSF agreed with the JASON Advisory Group on the need for an evidence-based description of the scale and scope of the problems, though as many potential conflicts are not disclosed, understanding the full scale and scope is a great challenge. NSF has and will continue to communicate to other government agencies that international collaboration and participation are essential to our continued scientific advancement.
  8. **Engage with foreign researchers in the United States:** NSF has engaged with the full community of researchers, both foreign and domestic, in the United States (see "Engagement with the Research Community" below).

[12] www.nsf.gov/news/special_reports/jasonsecurity/JSR-19-2IFundamentalResearchSecurity_12062019FINAL.pdf
[13] https://nsf.gov/news/special_reports/jasonsecurity/NSF_response_JASON.pdf

9. **Plan for maintaining competitiveness for top talent globally:** NSF's specialized focus on STEM education, with a more than $900 million budget, has programs that concentrate on maintaining the excellence of the U.S. STEM educational system.

- **Leadership in the U.S. government:** As co-chair of the JCORE subcommittee on research protection, NSF coordinated policy, practices, and guidance on science and security with the White House, other science agencies, and the intelligence and law enforcement communities. JCORE developed education and outreach materials – including a slide deck released in June 2020 called Enhancing the Security and Integrity of America's Research Enterprise – that highlight examples of risks to research and outline actions the Federal government is taking to protect America's research enterprise.
- **Engagement with Congress:** In November 2019, the Head of NSF's Office of International Science and Engineering, testified before the Permanent Subcommittee on Investigations of the Senate Committee on Homeland Security and Governmental Affairs. The briefing focused on NSF's efforts to implement all reasonable and necessary steps to ensure the integrity of federally-funded research and protect against threats from foreign government talent recruitment programs. In March 2020, a similar briefing was provided to the House Committee on Science, Space, and Technology.
- **Engagement with the research community:** To increase awareness of the risks and compliance with NSF's policies and procedures, NSF met with or presented to the research community, including to the National Science Board, Association of American Universities, Association of Public and Land-grant Universities, American Association of the Advancement of Science Board of Directors, Council on Government Relations, NSF Advisory Committees, American Physics Society, International Union of Pure and Applied Physics, American Society for Engineering Education, Federal Demonstration Partnership, and National Academies of Science, Engineering, and Medicine's Committee on Science, Engineering, Medicine, and Public Policy. NSF's outreach included an articulation of the clarified requirements for both the biographical sketch and current and pending support sections of the proposal. This outreach helped NSF to develop, issue, and update a set of Frequently Asked Questions to help ensure a consistent understanding on NSF expectations.
- **Engagement with the Office of Inspector General:** In 2020, NSF worked collaboratively with the OIG, where appropriate, to address threats posed by foreign government talent recruitment programs. In 2020, consistent with our OIG Cooperation Directive, NSF continued to support the OIG's investigations, including those involving allegations related to foreign talent programs. Our support includes taking appropriate actions such as suspending or terminating awards, based on OIG recommendations arising from, for example, investigations for failures to disclose foreign talent program affiliations.
- **Risk-benefit assessments:** Consistent with OSTP's guidance to utilize a risk-based approach to balance the need to foster an open and internationally collaborative environment while mitigating threats to the integrity of that enterprise, NSF worked with experts in Enterprise Risk Management to conduct risk assessments and analyses to guide decision-making. This includes assessing and refining NSF's controls to mitigate threats posed by foreign government talent recruitment programs. NSF also developed and implemented a formal process to assess requests for collaborative agreements with foreign entities that may involve items of value provided to or from NSF-funded major research facilities.
- **Creation of the position of Chief of Research Security Strategy and Policy:** In March 2020, NSF created and filled the position of Chief of Research Security Strategy and Policy (CRSSP) and established a Research Security Strategy and Policy Group. The CRSSP is the NSF focal point for providing science and security strategy and policy recommendations to NSF leadership and for ensuring that NSF has the information that it needs to act vigilantly to address existing and emerging risks to the Nation's science and engineering enterprise posed by foreign government talent recruitment programs.

NSF's Anticipated Action Plan Milestones

NSF management developed the anticipated milestones below in consideration of NSF's strategic and operational objectives, the risks inherent to achieving these objectives, and the key actions NSF has already taken in response to those risks.

- Continue to serve as co-chair of the JCORE subcommittees on research security and reducing administrative workload and work closely with the White House, other federal science funding agencies, and intelligence and law enforcement communities to share information, promote outreach, coordinate policy and practices, and develop guidance for federal departments and agencies, as well as for universities and other research institutions.
- Facilitate NSF's access to classified information and ability to engage in classified discussions with other U.S. government agencies more easily, including through the addition of a Sensitive Compartmented Information Facility (SCIF) in NSF's headquarters.
- Evaluate recommendations and consider implementing additional policy steps or outreach related to research security at both the agency level and the JCORE level. Additional activities could include, but are not limited to:
    1. **Scope of disclosure:** Require the use of an NSF-approved format for biographical sketches and current and pending support in proposals submitted or due on or after October 5, 2020.
    2. **Failures to disclose:** Continue to coordinate with the NSF OIG and take the appropriate action needed to address violations.
    3. **Responsibilities of all stakeholders and harmonization:** Harmonize requirements and systems with other U.S. science funding agencies, when practical; co-chair the JCORE subcommittee on coordinating administrative requirements for research.
    4. **Tools to evaluate risk:** Continue to use the Enterprise Risk Management framework to describe science and security risks and implement risk mitigation strategies; initiate the development of risk assessment tools; and carry out regular risk assessments regarding the impacts of NSF's response to the threats posed by foreign government talent recruitment programs. Develop an approach to promulgate best practices in the research community.
    5. **Expand ethics training:** Prepare and distribute communication and briefing material for the external scientific research community on science and security and research integrity.
    6. **Reaffirm the principles of NSDD-189:** Work with other U.S. government agencies to further reaffirm the National Policy on the Transfer of Scientific, Technical and Engineering Information (aka NSDD-189) and maintain the distinction between research that should continue to be made open to the scientific community and research that should be protected due to security concerns.
    7. **Communicate the problem and the importance of foreign researchers and collaborations:** Support efforts of JCORE, the intelligence community, and/or law enforcement to understand the scale and scope of the risk of inappropriate foreign influence on the U.S. science and engineering research ecosystem, recognizing that this is a great challenge.
    8. **Engage with foreign researchers in the United States:** Further engage with the full community of researchers, both foreign and domestic.
    9. **Plan for maintaining competitiveness for top talent globally:** Continue to support programs that will increase the pool of top science and engineering talent available in the United States.

## GAO-IG ACT EXHIBITS

Pursuant to P.L. 115-331, the Good Accounting in Government Act, the following three tables report on outstanding NSF OIG and GAO recommendations open for more than one year and their associated status as of May 1, 2021.

### Open OIG Recommendations – Internal Audits

| OIG Number | Title (Final Audit Report Date) | OIG Recommendation | Date | Status |
|---|---|---|---|---|
| 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 | Rec. Resolved |
| 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 | Rec. Resolved |
| 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 | Rec. Resolved |
| 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 | Rec. Resolved |
| 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 | Rec. Resolved |
| 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 | Rec. Resolved |
| 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 | Rec. Resolved |
| 20-2-002 | FISMA Audit for FY19 | 5. NSF Screening Process<br>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 | Rec. Resolved |
| 20-2-002 | FISMA Audit for FY19 | 6. Authentication and Identification<br>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 | Rec. Resolved |

## Open OIG Recommendations – Internal Audits continued

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|---|---|---|---|---|
| 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 | Rec. Resolved |
| 20-2-003 | DATA Act Audit | 1. Develop and implement a methodology to ensure that NSF systems (e.g., iTRAK and Awards) reconcile or obtain an official ruling (e.g., documentation from Treasury) to validate NSF's methodology and business process of treating File C and File D2 variance as legitimate permanent differences. | 11/8/2019 | Rec. Resolved |
| 20-2-003 | DATA Act Audit | 2. Develop and implement procedures to ensure timely review and complete reporting of the data reported to FPDS-NG, including procedures to validate the accuracy of data entered into NSF sytems that interface with FPDS-NG. | 11/8/2019 | Rec. Resolved |
| 20-2-003 | DATA Act Audit | 3. Develop monitoring procedures to ensure that the review of all SAM-derived information is complete, accurate, and timely prior to submission to USAspending.gov. Procedures may include implementation of additional steps added to the monthly validation of FABS and FPDS-NG to ensure that the review of all derived information is complete, accurate, and timely. | 11/8/2019 | Rec. Resolved |
| 20-2-003 | DATA Act Audit | 4. Develop formal procedures to periodically review the reliability and accuracy of all data submitted by awardees/recipients within SAM. | 11/8/2019 | Rec. Resolved |
| 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 | Rec. Resolved |

[1] "Resolved" status indicates where NSF and OIG have agreed upon the appropriate corrective action to address the recommendation but where implementation is ongoing or closing of the recommendation is pending OIG review to confirm responsiveness. "Unresolved" status would indicate where NSF and the OIG have not yet agreed upon the appropriate corrective action to address the recommendation.

## Open OIG Recommendations – External Audits

| OIG Number | Title (Final Audit Report Date) | OIG Recommendation | Status of Recommendation | Date Resolved | Costs Questioned | Costs Disallowed | Costs Allowed | Timeline for Final Implementation |
|---|---|---|---|---|---|---|---|---|
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |

## Open OIG Recommendations – External Audits continued

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|---|---|---|---|---|---|---|---|---|
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |

## Open OIG Recommendations – External Audits continued

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|---|---|---|---|---|---|---|---|---|
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |

## Open OIG Recommendations – External Audits continued

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|---|---|---|---|---|---|---|---|---|
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 19-1-013 | University of Pennsylvania (5/1/2019) | 1.1) Resolve $149,765 in unsupported questioned costs and direct UPenn to repay or otherwise remove the sustained questioned costs from its NSF awards. | Unresolved | TBD | $149,765 | TBD | TBD | 9/30/2021 |
| 19-1-013 | University of Pennsylvania (5/1/2019) | 1.2) Direct UPenn to strengthen the administrative and management controls and processes over obtaining and maintaining sufficient supporting documentation. | Unresolved | TBD | $0 | TBD | TBD | 9/30/2021 |
| 19-1-013 | University of Pennsylvania (5/1/2019) | 1.3) Direct UPenn to update its procurement policies to require that personnel establish a formal subaward, subcontract, or independent contractor agreement for all external services provided or invoiced to UPenn. | Unresolved | TBD | $0 | TBD | TBD | 9/30/2021 |

## Open OIG Recommendations – External Audits continued

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|---|---|---|---|---|---|---|---|---|
| 19-1-013 | University of Pennsylvania (5/1/2019) | 1.4) Direct UPenn to strengthen the administrative and management controls over the processing of invoices submitted by independent contractors. Processes should include verifying that the invoiced services were not provided by a UPenn employee. | Unresolved | TBD | $0 | TBD | TBD | 9/30/2021 |
| 19-1-013 | University of Pennsylvania (5/1/2019) | 2.1) Resolve the $56,475 in inappropriate application of indirect costs, and direct UPenn to repay or otherwise remove the sustained questioned costs from its NSF awards. | Unresolved | TBD | $56,475 | TBD | TBD | 9/30/2021 |
| 19-1-013 | University of Pennsylvania (5/1/2019) | 2.2) Direct UPenn to strengthen the administrative and management controls and processes over applying indirect costs to Federal awards. | Unresolved | TBD | $0 | TBD | TBD | 9/30/2021 |
| 19-1-013 | University of Pennsylvania (5/1/2019) | 3.1) Resolve the $50,360 in unallowable expenses and direct UPenn to repay or otherwise remove the sustained questioned costs from its NSF awards | Unresolved | TBD | $50,360 | TBD | TBD | 9/30/2021 |
| 19-1-013 | University of Pennsylvania (5/1/2019) | 3.2) Direct UPenn to strengthen the administrative and management procedures over allocating salary expenses to sponsored awards. Procedures could include reviewing salary expenses to ensure that employees are earning salary based on work performed. | Unresolved | TBD | $0 | TBD | TBD | 9/30/2021 |
| 19-1-013 | University of Pennsylvania (5/1/2019) | 3.3) Direct UPenn to strengthen the administrative and management procedures over allocating travel expenses to sponsored awards. | Unresolved | TBD | $0 | TBD | TBD | 9/30/2021 |
| 19-1-013 | University of Pennsylvania (5/1/2019) | 3.4) Direct UPenn to strengthen the administrative and management procedures over allocating relocation expenses to sponsored awards. | Unresolved | TBD | $0 | TBD | TBD | 9/30/2021 |
| 19-1-013 | University of Pennsylvania (5/1/2019) | 3.5) Direct UPenn to strengthen the administrative and management procedures over allocating food and beverage expenses to sponsored awards | Unresolved | TBD | $0 | TBD | TBD | 9/30/2021 |
| 19-1-013 | University of Pennsylvania (5/1/2019) | 4.1) Resolve the $8,853 in expenses not appropriately allocated to NSF awards and direct UPenn to repay or otherwise remove the sustained questioned costs from its NSF awards. | Unresolved | TBD | $8,853 | TBD | TBD | 9/30/2021 |

## Open OIG Recommendations – External Audits continued

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|---|---|---|---|---|---|---|---|---|---|
| 19-1-013 | University of Pennsylvania (5/1/2019) | 4.2) Direct UPenn to strengthen the administrative and management controls and processes over allocating expenses to sponsored funding sources. | Unresolved | TBD | $0 | TBD | TBD | 9/30/2021 |
| 19-1-013 | University of Pennsylvania (5/1/2019) | 5.1) Resolve the $504 in incorrect application of fringe benefits and direct UPenn to repay or otherwise remove the sustained questioned costs from its NSF awards. | Unresolved | TBD | $504 | TBD | TBD | 9/30/2021 |
| 19-1-013 | University of Pennsylvania (5/1/2019) | 5.2) Direct UPenn to update its accounting system to ensure that it correctly applies and removes fringe benefits as part of salary cost transfers. | Unresolved | TBD | $0 | TBD | TBD | 9/30/2021 |
| 19-1-013 | University of Pennsylvania (5/1/2019) | 6.1) Direct UPenn to strengthen the administrative and management procedures over the review and approval of subaward expenses charged to sponsored awards | Unresolved | TBD | $0 | TBD | TBD | 9/30/2021 |
| 19-1-013 | University of Pennsylvania (5/1/2019) | 7.1) Direct UPenn to strengthen the administrative and management controls and processes over establishing indirect cost rates for Federal awards to ensure that it applies costs at the rates in effect as of the effective date of the grant. | Unresolved | TBD | $0 | TBD | TBD | 9/30/2021 |
| 19-1-013 | University of Pennsylvania (5/1/2019) | 8.1) Direct UPenn to strengthen the administrative and management procedures over travel on sponsored awards. | Unresolved | TBD | $0 | TBD | TBD | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 19-1-016 | Ohio State University (8/8/2019) | 2.1) Resolve the $76,822 questioned subaward costs | Unresolved | TBD | $76,822 | TBD | TBD | 9/30/2021 |

## Open OIG Recommendations – External Audits continued

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|---|---|---|---|---|---|---|---|---|
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 19-1-016 | Ohio State University (8/8/2019) | 5.1) Resolve the $7,604 questioned indirect costs | Unresolved | TBD | $7,604 | TBD | TBD | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |

## Open OIG Recommendations – External Audits continued

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 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 | 9/30/2021 |
| 19-1-017 | Oregon State University (9/13/2013) | 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 | 9/30/2021 |
| 19-1-017 | Oregon State University (9/13/2013) | 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 | 9/30/2021 |
| 19-1-017 | Oregon State University (9/13/2013) | 1.3) Direct OSU to strengthen its administrative and management procedures over awarding subawards | Unresolved | TBD | $0 | TBD | TBD | 9/30/2021 |
| 19-1-017 | Oregon State University (9/13/2013) | 2.1) Resolve the $78,153 in questioned costs | Unresolved | TBD | $78,153 | TBD | TBD | 9/30/2021 |
| 19-1-017 | Oregon State University (9/13/2013) | 2.2) Direct OSU to strengthen its administrative and management procedures for obtaining NSF's approval | Unresolved | TBD | $0 | TBD | TBD | 9/30/2021 |
| 19-1-017 | Oregon State University (9/13/2013) | 2.3) Direct OSU to strengthen its administrative and management procedures for allocating salary expenses to sponsored projects. | Unresolved | TBD | $0 | TBD | TBD | 9/30/2021 |
| 19-1-017 | Oregon State University (9/13/2013) | 2.4) Direct OSU to strengthen its administrative and management procedures for allocating travel expenses to sponsored projects. | Unresolved | TBD | $0 | TBD | TBD | 9/30/2021 |
| 19-1-017 | Oregon State University (9/13/2013) | 2.5) Direct OSU to strengthen its administrative and management procedures for allocating equipment to sponsored projects. | Unresolved | TBD | $0 | TBD | TBD | 9/30/2021 |

## Open OIG Recommendations – External Audits continued

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|---|---|---|---|---|---|---|---|---|
| 19-1-017 | Oregon State University (9/13/2013) | 2.6) Direct OSU to strengthen its administrative and management procedures over use of PSC funding under NSF awards. | Unresolved | TBD | $0 | TBD | TBD | 9/30/2021 |
| 19-1-017 | Oregon State University (9/13/2013) | 3.1) Resolve the $65,153 in questioned indirect costs | Unresolved | TBD | $65,153 | TBD | TBD | 9/30/2021 |
| 19-1-017 | Oregon State University (9/13/2013) | 3.2) Direct OSU to strengthen its administrative and management procedures for applying indirect costs to Federal awards. | Unresolved | TBD | $0 | TBD | TBD | 9/30/2021 |
| 19-1-017 | Oregon State University (9/13/2013) | 4.1) Resolve $31,319 in questioned supplies, equipment, and travel costs | Unresolved | TBD | $31,319 | TBD | TBD | 9/30/2021 |
| 19-1-017 | Oregon State University (9/13/2013) | 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 | 9/30/2021 |
| 19-1-017 | Oregon State University (9/13/2013) | 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 | 9/30/2021 |
| 19-1-017 | Oregon State University (9/13/2013) | 5.1) Resolve $10,574 in Questioned Unallocable Costs | Unresolved | TBD | $10,574 | TBD | TBD | 9/30/2021 |
| 19-1-017 | Oregon State University (9/13/2013) | 5.2) Direct OSU to strengthen its administrative and management procedures for allocating expenses to sponsored projects. | Unresolved | TBD | $0 | TBD | TBD | 9/30/2021 |
| 19-1-017 | Oregon State University (9/13/2013) | 5.3) Direct OSU to encourage PIs to identify all award participants. | Unresolved | TBD | $0 | TBD | TBD | 9/30/2021 |
| 19-1-017 | Oregon State University (9/13/2013) | 6.1) Resolve the $8,820 in questioned costs. | Unresolved | TBD | $8,820 | TBD | TBD | 9/30/2021 |
| 19-1-017 | Oregon State University (9/13/2013) | 6.2) Direct OSU to strengthen its administrative and management procedures for honorarium payments. | Unresolved | TBD | $0 | TBD | TBD | 9/30/2021 |
| 19-1-017 | Oregon State University (9/13/2013) | 7.1) Resolve $5,563 in questioned lodging and M&IE costs. | Unresolved | TBD | $5,563 | TBD | TBD | 9/30/2021 |
| 19-1-017 | Oregon State University (9/13/2013) | 7.2) Direct OSU to strengthen its administrative and management procedures for reimbursing M&IE expenses. | Unresolved | TBD | $0 | TBD | TBD | 9/30/2021 |
| 19-1-017 | Oregon State University (9/13/2013) | 7.3) Direct OSU to strengthen its administrative and management procedures for reimbursing lodging expenses. | Unresolved | TBD | $0 | TBD | TBD | 9/30/2021 |
| 19-1-017 | Oregon State University (9/13/2013) | 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 | 9/30/2021 |

## Open OIG Recommendations – External Audits continued

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|---|---|---|---|---|---|---|---|---|---|
| 19-1-017 | Oregon State University (9/13/2013) | 9.1) Direct OSU to strengthen its administrative and management procedures for establishing indirect cost rates for Federal awards. | Unresolved | TBD | $0 | TBD | TBD | 9/30/2021 |
| 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 | 3/31/2022 |
| 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 | 3/31/2022 |
| 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 | 3/31/2022 |
| 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 | 3/31/2022 |
| 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 | 3/31/2022 |
| 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 | 3/31/2022 |
| 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 | 3/31/2022 |
| 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 | 3/31/2022 |
| 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 | 3/31/2022 |
| 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 | 3/31/2022 |
| 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 | 3/31/2022 |
| 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 | 3/31/2022 |

## Open OIG Recommendations – External Audits continued

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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 | 3/31/2022 |
| 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 | 3/31/2022 |
| 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 | 3/31/2022 |

## GAO Open Recommendation Over One Year as of May 1, 2021

| GAO Number | Title | GAO Recommendation | Status of Recommendation | 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 | NSF developed an initial plan to evaluate its anti-harassment policies, including sexual harassment, and communications mechanisms. This initial plan led to the development of two questions and study plans included in the NSF interim learning agenda submitted to the Office of Management and Budget in September 2020. Both studies--one focused on the term and condition and the other on the conference policy--are ongoing and expected to be completed by September 2021. Findings will be used to define the next phases in the evaluation of NSF anti-sexual harassment efforts. |
| GAO-20-59 | Information Management: Selected Agencies Need to Fully Address Federal Electronic Recordkeeping Requirements | Recommendation 18: The Director of the National Science Foundation should establish a time frame to ensure all records schedules are up-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. | Open | All schedules were updated and submitted, four were approved and two are currently pending NARA approval. NSF schedules can be located on the NSF.gov records schedule index. |
| 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. | Open | Completed EIS inventory in collaboration with the Division of Information Systems. |
| 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. | Open | NSF Bulletin No. 20-11, issued November 2020, includes controls required for electronic information systems and the required preservation mechanisms. |
| 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. | Open | NSF Bulletin No. 20-11 addresses email management requirements for staff. Email addresses of the sender, names, date of message, etc. are automatically captured in Microsoft Outlook and retained. |

## GAO Open Recommendation Over One Year as of May 1, 2021 continued

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| 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 | NSF has launched a development activity that will extend NSF-PAR to enable the system to accept these records and to make them available through the search functionality. Scheduled deployment is December 2021. |
| 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 year 2020. |
| 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 is making progress to achieve full implementation of the eight workforce planning activities identified in GAO's review. At this time, the plan is to complete all activities by December 2021. |
| 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 submitted a CAP to OMB in June 2019 and again in Oct 2020. In both instances NSF showed it met all the metrics, with one being OBE. Moreover, NSF defers to the continuing discussion between OMB and GAO regarding metrics, metrics definitions, and consistency of implementation. |

## GAO Open Recommendation Over One Year as of May 1, 2021 continued

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| 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 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, and evaluated available training options to close identified gaps. 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 2021/2022 engagement to close this recommendation. |
| 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 Major Facilities Guide (MFG) on Recipient project team competencies has been incorporated into 2021 revision which has completed the public comment period and being prepared for OMB review. Final publication is planned in September 2021. NSF also intends to incorporate review of Recipient project team competencies against these new guidelines into NSF standard internal operating guidance. Once the MFG is published and new standard internal operating guidance developed, 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. | Open | NSF has 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 determined during their 2020/2021 engagement that that action fully addressed the recommendation. This will be noted in GAO's June 2021 report. |

## GAO Open Recommendation Over One Year as of May 1, 2021 continued

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| GAO-18-656 | Science and Technology: Considerations for Maintaining U.S. Competitiveness in Quantum Computing, Synthetic Biology, and Other Potentially Transformational Research Areas | Recommendation 4: As the QIS Subcommittee moves forward, the National Science Foundation co-chair, in coordination with other co-chairs and participating agency officials, should take steps to fully implement leading practices that enhance and sustain collaboration. | Open | The QIS subcommittee is preparing a Strategic Plan that will set forth recommendations for moving the US QIS effort forward, including agency collaborations. The plan will be released following approval by the NQI-authorized Advisory Committee. The tentative date for release is late 2021. Implementation of recommendations should begin in FY 2022. |
| GAO-18-656 | Science and Technology: Considerations for Maintaining U.S. Competitiveness in Quantum Computing, Synthetic Biology, and Other Potentially Transformational Research Areas | Recommendation 5: As the Interagency Working Group on Synthetic Biology moves forward, the Director of the National Science Foundation, in coordination with participating agency officials, should take steps to fully implement leading practices that enhance and sustain collaboration. | Open | Members of the Interagency Synthetic Biology Working Group (SBWG) have been engaged in the development of a Bioeconomy Executive Order, through the Executive Office of the President. The current draft provides a formalized framework for coordination in the field of synthetic biology and other efforts in biotechnology. While the transition in administrations has temporarily delayed the issuance of a bioeconomy executive order, the SBWG continues to share information, hold retreats, identify strategic priorities, and develop opportunities to coordinate and collaborate on activities to advance the field. The SBWG website, hosted by NSF, should be made public by July 2021. These activities all demonstrate best practices for sustained collaboration. |
| GAO-18-533 | National Science Foundation: A Workforce Strategy and Evaluation of Results Could Improve Use of Rotating Scientists, Engineers, and Educators | Recommendation 1: The NSF Director of Human Resource Management should complete the development of an agency-wide workforce strategy for balancing the agency's use of IPA and VSEE rotators with permanent staff as part of NSF's current agency reform planning efforts or updates to its human capital operating plan. | Open | Anticipated completion by December 2021. |
| 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 | Evaluation underway by EAC. |

## GAO Open Recommendation Over One Year as of May 1, 2021 continued

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| GAO-18-93 | Federal Chief Officers: Critical Actions Needed to Address Shortcomings and Challenges in Implementing Responsibilities | Recommendation 22: The Director of the National Science Foundation should ensure that the agency's IT management policies address the role of the CIO for key responsibilities in the five areas we identified. | Open | NSF is implementing this recommendation by establishing new agency IT management policies and updating existing policies, specifically the CIO Authorities Policy, to address the role of the CIO in the five areas identified by GAO. NSF plans to provide the updated Policy documentation to GAO by September 2021. |
| GAO-18-370 | National Science Foundation: Revised Policies on Developing Costs and Schedules Could Improve Estimates for Large Facilities | Recommendation 2: The Director of NSF should revise the agency's policies for developing schedules for large facilities projects, and for reviewing those schedules, to better incorporate the best practices in GAO's schedule guide. | Open | Section 4.3 of the Major Facilities Guide (MFG) on schedule development, estimating and analysis has been written and incorporated into 2021 revision which has completed the public comment period and being prepared for OMB review. It is planned for final publication in September 2021. Once published, GAO will determine if this recommendation can be closed. |

## PROGRAM EVALUATION AND MONITORING INFORMATION

Evaluations at NSF are currently performed at the discretion of the individual directorate, office, or program being evaluated. A list of major external evaluations completed in FY 2020 follows, including Committees of Visitors and significant workshops. 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 2020

EHR

During FY 2020, an evaluation of the Advanced Technological Education (ATE) program was performed to document patterns of investments over time; explore the effects of program supported activities on student recruitment, retention, and completion at two-year institutions in advanced technological fields in STEM; assess the effects of program supported activities on building the capacity of faculty and institutions to address workforce needs in advanced technological fields in STEM; and explore contributions to practice and the knowledge base on technician education in STEM. The report, delivered to DUE in FY 2020, is currently under internal review.

GEO

The NASEM Decadal Survey for EAR, *Earth in Time, A Vision for NSF Earth Sciences 2020-2030*, was released in May 2020[1]. It emphasizes "the need to understand how the Earth can continue to sustain both civilization and the planet's biodiversity" because "the Earth system functions and connects in unexpected ways—from the microscopic interactions of bacteria and rocks to the macro-scale processes that build and erode mountains and regulate Earth's climate". The report identifies 12 priority research questions and provides recommendations to help NSF plan and support the next decade of Earth science research.

MPS

- CHE sponsored external evaluation of the Centers for Chemical Innovation (CCI) Program (2004-2016) was completed in FY 2020. The report and executive summary were published[2] in April 2021. The evaluation yielded substantial information about the operation and outcomes of the CCI Program.
- Several PHY sponsored decadal reports have been recently completed or are currently underway that provide important strategic advice for the division. The *Decadal Assessment and Outlook Report on Atomic, Molecular, and Optical Science AMO*[3] was published in early 2020 and the *Decadal Assessment of Plasma Science* report[4] was released in the summer of 2020.

IA

In FY 2020, the following studies and statistics reports were completed and informed decisions:

- *Research Experiences for Undergraduates Data System (REU, NSF-wide)*[5]. NSF supported the design, development, and testing of a data system for program monitoring and future research and evaluations. Results from the original pilot enabled NSF to identify the approach (from three tested) to pursue in the scale-up pilot.
- *A study of NSF's Established Program to Stimulate Competitive Research (EPSCoR)* provided findings that influenced the definition and focus of an extended effort (the Future of EPSCoR[6]) to engage stakeholders in developing a better understanding of the impact of EPSCoR's investment

[1] www.nap.edu/catalog/25761/a-vision-for-nsf-earth-sciences-2020-2030-earth-in
[2] www.nsf.gov/od/oia/eac/products.jsp
[3] www.nationalacademies.org/our-work/decadal-assessment-and-outlook-report-on-atomic-molecular-and-optical-science
[4] www.nationalacademies.org/our-work/a-decadal-assessment-of-plasma-science of-plasma-science
[5] The REU data system has now become etap and can be reviewed at www.nsfetap.org/
[6] www.futureofnsfepscor.com/

strategies and identifying opportunities to increase its effectiveness. This activity includes opportunities for the public to provide evidence-based input. An external committee will synthesize the collected input in a summary report, which will include recommendations for both NSF and its stakeholders nationwide.

- *NSF INCLUDES*. NSF supported a foundational fact-finding study of the alignment between existing evidence and current information needs (as reflected in the NSF INCLUDES learning agenda). Findings were used by the NSF INCLUDES program staff to: (1) inform the development of shared measures and (2) identify technical assistance needs for the NSF INCLUDES National Network.

OPP
The Science and Technology Policy Institute (STPI) performed its annual Survey Analysis of the United States Antarctic Program Logistical Support Services for the 2019–20 Field Season report.

**Advisory Committees and Committees of Visitors**

Each directorate and office has an external advisory committee that typically meets twice a year to review and provide advice on program management, discuss current issues, and review and provide advice on the impact of policies, programs, and activities in the disciplines and fields encompassed by the directorate or office. In addition to directorate and office advisory committees, NSF is also advised by external committees on specific topics. Recent examples include: astronomy and astrophysics; environmental research and education; equal opportunities in science and engineering; direction, development, and enhancements of innovations; polar programs; advanced cyberinfrastructure; international and integrative activities; the agency's merit review processes; and business and operations.

Committees of Visitors (COVs) are subcommittees of NSF directorate advisory committees. COV reviews provide NSF with external expert judgments in two areas: (1) assessments of the quality and integrity of program operations and program-level technical and managerial matters pertaining to proposal decisions; and (2) comments on how the outputs and outcomes generated by awardees have contributed to the attainment of NSF's mission and strategic outcome goals. COV reviews are conducted at regular intervals of approximately four years for programs and offices that recommend or award grants, cooperative agreements, and/or contracts and whose main focus is the conduct or support of NSF research and education in science and engineering. Approximately one-fourth of NSF's divisions are assessed each year.

A COV typically consists of up to 20 external experts, selected to ensure independence, programmatic coverage, and geographic balance. COV members come from academia, industry, government, and the public sector. They meet for two or three days to review and assess program priorities, program management, and award accomplishments or outcomes. Each COV prepares a report and the division or program that is being reviewed must prepare a response to the COV recommendations. These reports and responses are submitted to the parent advisory committee and to the Director of NSF. All reports and responses are public and posted on NSF's website.[7]

In FY 2020, six directorates and two offices convened 13 COVs, covering 12 divisions and one program. A table of the COVs performed in recent years and planned through FY 2022 is provided on the next page. This chapter's earlier section also contains information on these COVs, as well as information on *ad hoc* reports.

[7] www.nsf.gov/od/oia/activities/cov/covs.jsp

**Table 1 of 2, List of Committees of Visitors Meetings, FY 2016-FY 2021**

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 2016 | FY 2017 | FY 2018 | FY 2019 | FY 2020 | FY 2021 | FY 2022 |
|---|---|---|---|---|---|---|---|---|
| BIO | Biological Infrastructure | All | | | | | All | |
| | Environmental Biology | | | | All | | | |
| | Integrative Organismal Systems | | | All | | | | Proj |
| | Molecular and Cellular Biosciences | | | All | | | | Proj |
| CISE | Advanced Cyberinfrastructure | | | All | | | | |
| | Computing and Communication Foundations | | | | | All | | |
| | Computer and Network Systems | | | | | All | | |
| | Information and Intelligent Systems | | | | | All | | |
| EHR | EHR Core Research | | All | | | | | |
| | Graduate Education | | | | | | | Proj |
| | Human Resource Development | | | | | | All | |
| | Research on Learning in Formal and Informal Settings | | | | | All | | |
| | Undergraduate Education | | TUES<br>STEP<br>WIDER<br>IUSE | | | | | Proj |
| ENG | Chemical, Bioengineering, Environmental and Transport Systems | | | | All | | | |
| | Civil, Mechanical and Manufacturing Innovations | | | | All | | | |
| | Electrical, Communications and Cyber Systems | | | All | | | | Proj |
| | Emerging Frontiers and Multidisciplinary Activities | | | All | | | | Proj |
| | Engineering, Education and Centers | All | | | | All | | |
| | Industrial Innovation and Partnerships | All | | | | All | | |

**Table 2 of 2, List of Committees of Visitors Meetings, FY 2016-FY 2021**

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 2016 | FY 2017 | FY 2018 | FY 2019 | FY 2020 | FY 2021 | FY 2022 |
|---|---|---|---|---|---|---|---|---|
| **GEO** | Atmospheric and Geospace Sciences | Atmosphere Section | | Geospace Section | | All | | |
| | Earth Sciences | | All | | | | Proj | |
| | Ocean Sciences: Integrative | | | All | All | | | Proj |
| | Ocean Sciences:Research | | | | | | | |
| | Education and Diversity Programs | | All | | | | Proj | |
| **MPS** | Astronomy | | | | All | | | |
| | Chemistry | All | | | | All | | |
| | Materials Research | | | | All | All | | |
| | Mathematical Sciences | All | | | | | | |
| | Physics | | | | All | | | |
| **SBE** | Behavioral and Cognitive Sciences | | | | All | | | |
| | Office of Multidisciplinary Activities | | | | | All | | |
| | Social and Economic Sciences | All | | | | | Proj | |
| **TIP** | NSF I-Corps, PFI, SBIR, STTR | | | | | (in IIP) | | |
| **OIA** | Major Research Infrastructure | All | | | | | Proj | |
| | Established Program to Stimulate Competitive Research | | | | | All | | |
| | STC | | | | | | | Proj |
| **OISE** | | | | All (2) | | | | Proj |
| **OPP** | Antarctic Sciences (ANT) | All | | | | All | | |
| | Arctic Sciences (ARC) | All | | | | All | | |

**Committees of Visitors (COV)[8]**

BIO: In 2020, the DBI 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.

CISE: In November 2019, CISE convened a COV to examine and assess the quality of the merit review process of the FY 2014-FY 2018 programmatics within its CCF, CNS, and IIS divisions. The report from that COV was accepted by the CISE Advisory Committee at its December 2019 meeting.

EHR: An external Committee of Visitors (COV) met to review DRL in October 2019. The co-chairs of the COV presented a summary of the committee's recommendations, and the COV report was discussed and accepted, at the (virtual) EHR Advisory Committee meeting held on May 21, 2020. Overall, the COV's findings were quite positive about the quality and effectiveness of DRL's merit review processes and program management. The main area of concern was the balance of awards to new and early-career investigators. In addition, the committee encouraged DRL to consider additional opportunities for incorporating NSF's "10 Big Ideas" in solicitations; to clarify "broadening participation," "broader impacts," and "transformative" in the context of proposals for STEM education research; to continue efforts to diversify the pool of reviewers; to document the processes and the criteria that programs use to analyze and shape their award portfolios; and to consider ways to make more effective analytical use of the annual project reports submitted by investigators. DRL is addressing the recommendations as it plans future revisions of solicitations and future reviews of proposals in the programs.

ENG: In 2020, COVs reviewed IIP and EEC. The IIP COV presented its report to the ENG Advisory Committee in October 2020, and the EEC COV presented its report in April 2021.

GEO: In 2020, a COV reviewed the Division of Atmospheric and Geospace Sciences. The COV presented their report to the Advisory Committee for Geosciences at the October meeting. The COV made several recommendations including that letters of acknowledgement for reviewers be automatically generated and that a central database of reviewers with ratings\notes be created. The COV did not recommend a timeline for implementation of their recommendations.

MPS: In 2020, COVs reviewed CHE and DMS. The COVs presented their reports[9] to the DIR Advisory Committee, which convened in August and November of 2020. CHE and DMS provided responses, which are updated annually, to the COV findings.

SBE: In 2020, a COV assessed the SBE Office Of Multidisciplinary Activities (SMA) division's merit review process and presented their report to the SBE Advisory Committee (AC) in December 2020. Based on recommendations from the COV concerning additional feedback to principal investigators and reviewers; the directorate is evaluating best practices for helping researchers improve their proposals. In addition, and more broadly in response to other COV inputs, SBE is reviewing emerging areas of research, strategies for open science, and ways to optimize communication with both the research community and the general public.

TIP: The NSF I-Corps, PFI, and SBIR and STTR programs were reviewed as part of a COV convened in June 2020. The report from that COV was accepted by the ENG Advisory Committee at its October 2020 meeting.

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[8] www.nsf.gov/od/oia/activities/cov/covs.jsp, NSF Committee of Visitors (COV) Reports.
[9] www.nsf.gov/od/oia/activities/cov/mps/2020/CHE_COV_2020_Final_2020-07-13.pdf

IA: In 2020, a COV reviewed the EPSCoR Program and found no significant programmatic gaps or needs for significant improvement.[10]

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 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.

**Workshops**

BIO

BIO supported the following workshops in FY 2020 that inform planning of the directorate's research programs.

- A workshop entitled "Trans-US Government expert meeting to examine synthetic biology roadmap" was held in October 2019. The workshop, which included attendees across academia, industry, and US government agencies, was convened to examine use cases in the field of synthetic biology and the most pressing basic research, technology, infrastructure, and workforce needs to advance the field. The results of the workshop helped inform the development of the work plan for the Interagency Synthetic Biology Working group as well as agency priorities in this area. 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. This workshop has stimulated discussions that may lead to new funding opportunities. In FY 2021, a follow up retreat is being held to refresh and reprioritize the science needs that will enable the rapid advance of synthetic biology to address societal problems.
- A series of virtual and in-person workshops entitled "Reintegrating Biology Jumpstarts" were funded in 2019 and held throughout fall 2019 to engage the broader biological community in identifying: the exciting new research questions that could be addressed by combining approaches and perspectives from different sub-disciplines of biology; the key challenges and scientific gaps that must be addressed to answer these questions; and the physical infrastructure and workforce training needed. These workshops continue to inform research and training activities supported by Biology Integration Institutes.

MCB supported multiple workshops in FY 2020 that inform the planning research programs.

- A Workshop, organized by OECD, entitles "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 US voluntary contribution to OECD work in the circular bioeconomy space and helped inform future activities at OECD and across US science funding agencies regarding the role of Biofoundries in the Bioeconomy.
- A workshop entitled "Workshop: Biology, Information, Communication and Coding Theory"[2] was funded in 2019 and was held in January of 2020. The workshop and report are helping to frame a new initiative in Biological Information and the next generation solicitation of Semiconductor synthetic biology.
- A workshop on "High Pressure Small Angle X-ray scattering" was funded in FY 2020 to highlight the new capabilities of NSF funded infrastructure to address questions about biology in extreme environments. The workshop was intended to be hands on and has been delayed because of COVID-19.
- A workshop on "The Plant Cell Atlas Initiative" was held in January of 2020. The workshop aimed to

[10] www.nsf.gov/od/oia/activities/cov/oia/epscor/2020EPSCoRCOVReport_070720_final.pdf

bring together a plant cell biology community to develop an atlas of imaging resources for plant biology in much the same way as the Allen Institute has brought such resources to the field of neuroscience.

- A series of workshops were funded in FY 2020 and will be held over multiple years, “Modern Methods in Microscopy: Elucidating the physical biology of the Cell” with the aim of expanding the knowledge and access to modern microscopy tools and techniques to under-resourced institutions. This is one of many efforts in MCB to democratize access to tools associated with modern molecular and cellular biosciences.
- A workshop entitled “Broadening participation of persons with disabilities in STEM” was held in FY 2020 at the National Federation of the Blind, motivated by the need for new resources for researchers and others in academia and the private sector to increase their ability to create inclusive environments that enable the participation of persons with disabilities. The outcomes of the workshop will be widely disseminated through the NSF funded Center for Advancing Research Impacts in Society.

IOS supported multiple workshops and meetings in FY 2020 that informed planning for research programs:

- A workshop in FY 2018 “Breakthroughs 2030: A Strategy for Food and Agricultural Research”[1] led to a National Academies of Sciences, Engineering and Medicine (NASEM) Breakthroughs 2030 report and continues to help guide investments in agriculturally related plant genomics and plant biotic interactions programs. In addition, in late FY 2019 and again in late FY 2020, IOS held a community visioning workshop with the plant genomics research community to discuss future directions and new areas for high impact plant sciences research. These meetings informed the FY 2021 update of the solicitation for plant genomics research in IOS which includes the ongoing opportunities released in FY 2020 for synthetic plant biology research suggested by the community and the simplification of the submission process.
- In FY 2019, IOS commissioned a workshop from the NASEM on future directions in Functional Genomics. That workshop was held February 10-12, 2020 at the NASEM in Washington, D.C. The workshop report entitled “Next Steps for Functional Genomics”[11] will inform future investments in all IOS programs and NSF’s URoL Big Idea in FY 2022 and beyond.
- Both the “Interagency Strategic Plan for Microbiome Research FY 2018-2022”[12] released in April 2018 and the outcomes from a hybrid virtual and in person community visioning workshop entitled “Deciphering the Microbiome” held in December of 2019 guide IOS investment into microbiomes, including microbial interactions with plants and animals in the warming world, and important ecosystem services such as soil stability, fertility, and sustainability.

DEB supported multiple workshops in FY 2020 to inform planning of research programs:

- A series of cumulative workshops entitled “Revolutionizing Systematics - Revitalizing Monographs” has continued through FY 2021 with the goal of developing ideas from a wide swath of the systematics community for modernizing the practice and products of taxonomic monography. Participants are developing white papers on 5-10 topics that will be published in a special volume of a society publication.
- A virtual workshop series entitled: Workshop to Investigate an Integrated Data Architecture for Paleo genomics, Micropaleontology, and Macropaleontology” was held in the summer of 2020 to establish the current state of the science and informatics for ancient DNA, and identify the most promising short-term and next-stage opportunities for integrating ancient DNA with existing and to-be-built cyberinfrastructure for broad-scale analyses of the diversity and distribution of life over space and time.
- A virtual conference entitled: “Networking Microbiome Research: A Symposium for a Microbiome Center Consortium” was held in the winter 2020 to advance and network microbiome centers at the national level.

[11] www.nap.edu/catalog/25780/next-steps-for-functional-genomics-proceedings-of-a-workshop
[12] www.commonfund.nih.gov/sites/default/files/Interagency_Microbiome%20Strategic_Plan_Final_041918_508.pdf

- The 5th Symposium on Urbanization and Stream Ecology hosted a workshop in February 2020 to share knowledge about effective approaches for managing streams in urban landscapes. The workshop discussed four case studies as a foundation for exchanging ideas and generating actionable outcomes and draft project plans for four real-world sites in Austin, TX. This approach to sharing knowledge across natural and social science disciplines that integrated knowledge and values of the local community had clear potential benefits for achieving ecological improvements and equitable social outcomes for local communities.

DBI supported multiple workshops in FY 2020 to inform the planning of the division's promotion of open data platforms for the BIO community and to inform future program management :

- DBI supported a workshop in 2019 entitled "Developing skills for advanced careers in biology for NSF postdoctoral fellows in the PRFB Broadening Participation 2019 cohort." This was a one-day workshop held at the November 2019 Society for Advancement of Chicanos/Hispanics and Native Americans in Science (SACNAS) Diversity in STEM Conference that provided PRFB Fellows and their mentors within the Broadening Participation Area an opportunity to network and attend career talks, best-practices talks, and poster sessions focused on broadening participation in Biology. This workshop aimed to help generate long lasting partnerships and potential collaborations among PRFB fellows, mentors, and the SACNAS community.
- A 2020 workshop entitled "A Virtual Workshop to Facilitate the Use of NEON Data and Infrastructure at HBCUs" was conducted virtually (Jan 20-22, 2020) and included an overview of the NEON project goals and data provided by NEON/Battelle project staff. Twenty-two faculty and graduate students from 11 HBCUs attended. It is hoped that this workshop serves to re-ignite engagement with this community of researchers and teachers in the NEON resource.

<u>EHR</u>

- In FY 2020 the STEM Education Future of the Future Subcommittee of the EHR Advisory Committee submitted a report on its work to envision how to create STEM education that prepares and advances the U.S. for the future. *STEM Education for the Future* concludes STEM education should be student-centered, project-based, and personalized; grounded in principles of equity and inclusion; and include technology as both a tool for and a topic of learning. EHR used these insights in developing strategies for supporting STEM education during and mitigating the effects of the COVID-19.[13]
- In FY 2020 EHR/DUE/IUSE and EHR/DRL/DRK-12 supported *Workshop on Mid-scale STEM Education Research Infrastructure,*[14] a project to convene experts in STEM education offering perspectives on i) what are the key R&D questions for which no current research infrastructure exists to carry out investigations and ii) what might the characteristics of prospective research infrastructures (e.g. data aggregation and management infrastructure) look like. Insights will be used to help inform EHR deliberations about how to support such infrastructure.
- In FY 2020 NSF issued *NSF INCLUDES Special Report to the Nation II.*[15] NSF INCLUDES completed its fourth year of activities in 2019. This report provides information on the progress of the NSF INCLUDES initiative.
- In FY 2020 and FY 2021 NSF/HRD/EASE (Excellence Awards in Science and Engineering) staff, in collaboration with Booz-Allen and others, conducted multiple meetings and debrief sessions (e.g., with State Coordinators, the Presidential Awards for Excellence in Mathematics and Science Teaching [PAEMST] National Selection Committee, the Presidential Awards for Excellence in Science, Mathematics and Engineering Mentoring [PAESMEM] National Selection Committee, and the State Coordinator Leadership). Resulting insights were used to inform a variety of program decisions and plans.

[13] See www.nsf.gov/news/news_summ.jsp?cntn_id=301784&org=EHR.
[14] ww.nsf.gov/awardsearch/showAward?AWD_ID=2013314&HistoricalAwards=false.
[15] www.nsf.gov/pubs/2020/nsf20099/nsf20099.pdf

ENG

- During FY 2020, a CMMI-supported workshop and follow-on training on Increasing Reviewer Risk Tolerance Through Awareness (IRRTTA) explored the use of reviewer training on cognitive biases to increase one's tolerance toward (i.e., make them more accepting of) high-risk research. Based on the results of that pilot, CMMI funded the development of training resources and in FY 2021 began training CMMI reviewers to recognize and appropriately evaluate high-risk, high-reward proposals.
- In February 2020, a CBET-supported workshop, "Exuberance of Machine Learning in Transport Phenomena," was held in Dallas, Texas. Experts at the workshop highlighted future directions for AI in transport phenomena research. The forthcoming workshop report will inform the division's programmatic efforts.
- In February 2020, ECCS supported the "NSF SpecEES PI Meeting and Workshop on Future Wireless Research Challenges" in Newport Beach, CA, which was attended by participants from academia, industry and government. Attendees identified advanced wireless research challenges, including spectrum efficiency, latency, spectrum sharing and usage co-existence, spectrum sensing and monitoring, wireless quality of services, mm-wave and terahertz microelectronics, low-power wireless for internet of things (IoT), and wireless security.
- From July to September 2020, CMMI supported four FW-HTF stakeholder workshops, organized by SRI-International. Each of the virtual workshops focused on a different aspect of FW-HTF: restructuring the physical and virtual workspace; exploring the human-technology partnership; fostering reskilling, upskilling and lifelong learning; and ethical questions and the implications for policy. Workshop participants represented industry, other government agencies, non-profit organizations, and academia. The workshops helped identify emerging areas of FW-HTF research and ways to support larger scale collaboration between stakeholders and the FW-HTF research community.

MPS

- In FY 2020, CHE, DOE Office of Fossil Energy, DOE Office of Science, National Institute of Standards and Technology, and the American Chemical Society initiated a consensus study through the National Academies' Board on Chemical Sciences and Technologies on *Enhancing the U.S. Chemical Economy through Investments in Fundamental Research in the Chemical Sciences*. Results from the study, planned for FY 2022, are expected to inform the scope of core funding activities in the chemical sciences.

## OTHER INFORMATION

### Management Reviews

Each quarter, NSF senior leadership reviews progress towards all performance goals of the agency in a data-driven review meeting led by the Chief Operating Officer and Performance Improvement Officer. The quarterly progress of the Agency Priority Goals (APGs) and performance goals are reviewed.

### Alignment of Human Capital Efforts with Organizational Performance

In order to drive individual and organizational performance, NSF requires that the performance plans of all employees, executives, and the general workforce contain individual goals aligned with the agency's mission and strategic goals. NSF provides training and makes tools and templates available for all supervisors and employees on linking performance plans to agency mission, as well as providing assistance and training on the policies, processes, requirements, and timeframes for the development of performance plans and appraisals.

NSF also directly aligns its strategic human capital and accountability efforts to the agency goals identified in the NSF Strategic Plan. Agency performance goals currently outline specific human capital goals, and NSF uses HRStat as the agency reporting mechanism to articulate the nexus between NSF's strategic goals/objectives, including agency performance goals, and human capital initiatives at the agency. Senior leaders are briefed quarterly regarding the status of agency performance goals and the human capital initiatives aligned to those goals.

### Strategies and Collaborations

No one standard strategy is used across NSF for achievement of goals. Goal leaders at NSF choose strategies tailored to their stakeholders' needs and their institutional capabilities. NSF goals often involve testing the impacts of new activities or new approaches to existing activities, so feedback mechanisms are built in. Use of analysis, evidence, and evaluation findings is also at the discretion of each individual goal leader, as is the decision to collaborate with other agencies or external entities or to invest in contract support for their activities. Performance at NSF is reviewed quarterly by NSF's Performance Improvement Officer, who reports on goal progress to NSF senior management.

### Data Verification and Validation

It is NSF's practice to follow Government Accountability Office (GAO) guidance and engage external contractors to conduct an independent validation and verification (V&V) review of its annual performance information, data, and processes. The guidance from GAO indicates that agencies should "…describe the means the agency will use to verify its performance data…" and "…provide confidence that [their] performance information will be credible."[1] In FY 2020, 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 2020 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 V&V assessment, the Nexight Team has confidence in the systems, policies, and procedures used by NSF to calculate results for its performance

[1] 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.

measures[2]."

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.

[2] Nexight Group with Energetics Incorporated, *National Science Foundation Performance Measurement Verification and Validation Report, Fiscal Year 2020 Report*. December 2020.

# TECHNICAL INFORMATION


FY 2022 NSF Appropriations Language ........................................................ Technical Info - 3

Summary of FY 2022 NSF Budgetary Resources by Account .................................... Technical Info - 5

NSF FY 2022 Funding by Program ................................................................ Technical Info - 8

NSF by Object Classification ....................................................................... Technical Info - 12

NSF Reimbursable Activity ........................................................................... Technical Info - 13

Explanation of FY 2020 Carryover into FY 2021 by Account ................................. Technical Info - 14

# FY 2022 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; $8,139,710,000, to remain available until September 30, 2023, of which not to exceed $544,000,000 shall remain available until expended for polar research and operations support, and for reimbursement to other Federal agencies for operational and science support and logistical and other related activities for the United States Antarctic program: *Provided*, That receipts for scientific support services and materials furnished by the National Research Centers and other National Science Foundation supported research facilities may be credited to this appropriation.

## EDUCATION AND HUMAN RESOURCES

For necessary expenses in carrying out science, mathematics and engineering education and human resources programs and activities pursuant to the National Science Foundation Act of 1950 (42 U.S.C. 1861 et seq.), including services as authorized by section 3109 of title 5, United States Code, authorized travel, and rental of conference rooms in the District of Columbia, $1,287,270,000, to remain available until September 30, 2023.

## 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, $249,000,000, to remain available until expended.

## AGENCY OPERATIONS AND AWARD MANAGEMENT

For agency operations and award management necessary in carrying out the National Science Foundation Act of 1950 (42 U.S.C. 1861 et seq.); services authorized by section 3109 of title 5, United States Code; hire of passenger motor vehicles; uniforms or allowances therefor, as authorized by sections 5901 and 5902 of title 5, United States Code; rental of conference rooms in the District of Columbia; and reimbursement of the Department of Homeland Security for security guard services; $468,300,000: *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 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, $20,420,000, of which $400,000 shall remain available until September 30, 2023.

## OFFICE OF THE NATIONAL SCIENCE BOARD

For necessary expenses (including payment of salaries, authorized travel, hire of passenger motor vehicles, the rental of conference rooms in the District of Columbia, and the employment of experts and consultants under section 3109 of title 5, United States Code) involved in carrying out section 4 of the National Science Foundation Act of 1950 (42 U.S.C. 1863) and Public Law 86–209 (42 U.S.C. 1880 et seq.), $4,600,000: *Provided*, That not to exceed $2,500 shall be available for official reception and representation expenses.

## ADMINISTRATIVE PROVISION
## (INCLUDING TRANSFER OF FUNDS)

Not to exceed 5 percent of any appropriation made available for the current fiscal year for the National Science Foundation in this Act may be transferred between such appropriations, but no such appropriation shall be increased by more than 10 percent by any such transfers. Any transfer pursuant to this paragraph shall be treated as a reprogramming of funds under section 505 of this Act and shall not be available for obligation except in compliance with the procedures set forth in that section.

The Director of the National Science Foundation (NSF) shall notify the Committees on Appropriations of the House of Representatives and the Senate at least 30 days in advance of any planned divestment through transfer, decommissioning, termination, or deconstruction of any NSF-owned facilities or any NSF capital assets (including land, structures, and equipment) valued greater than $2,500,000.

## SUMMARY OF FY 2022 BUDGETARY RESOURCES BY ACCOUNT

(Dollars in Millions)

| Discretionary Accounts | FY 2020 Actual | FY 2021 Enacted | FY 2022 Request | Change over FY 2021 Enacted Amount | Change over FY 2021 Enacted Percent |
|---|---|---|---|---|---|
| ***RESEARCH AND RELATED ACTIVITIES*** | | | | | |
| Appropriation | $6,812.20 | $6,909.77 | $8,139.71 | $1,229.94 | 17.8% |
| Unobligated Balance Available Start of Year | 16.21 | 10.27 | | -10.27 | |
| Unobligated Balance Available End of Year | -10.27 | | | | |
| Adjustments to Prior Year Accounts[1] | 19.22 | | | | |
| **Subtotal, R&RA** | **6,837.36** | **6,920.04** | **8,139.71** | | |
| Transfer to/from other funds | -22.40 | -29.29 | | | |
| **Total Budgetary Resources** | **$6,814.96** | **$6,890.75** | **$8,139.71** | **$1,248.96** | **18.1%** |
| ***EDUCATION AND HUMAN RESOURCES*** | | | | | |
| Appropriation | $940.00 | $968.00 | $1,287.27 | $319.27 | 33.0% |
| Unobligated Balance Available Start of Year | 5.66 | 4.25 | | -4.25 | |
| Unobligated Balance Available End of Year | -4.25 | | | | |
| Adjustments to Prior Year Accounts[1] | 3.02 | | | | |
| **Subtotal, EHR** | **944.43** | **972.25** | **1,287.27** | | |
| Transfer to/from other funds | 2.55 | | | | |
| **Total Budgetary Resources** | **$946.98** | **$972.25** | **$1,287.27** | **$315.02** | **32.4%** |
| ***MAJOR RESEARCH EQUIPMENT & FACILITIES CONSTRUCTION*** | | | | | |
| Appropriation | $243.23 | $241.00 | $249.00 | $8.00 | 3.3% |
| Unobligated Balance Available Start of Year | 38.95 | 129.35 | | -129.35 | |
| Unobligated Balance Available End of Year | -129.35 | | | | |
| Adjustments to Prior Year Accounts[1] | 2.01 | | | | |
| **Subtotal, MREFC** | **154.84** | **370.35** | **249.00** | | |
| Transfer to/from other funds | - | | | | |
| **Total Budgetary Resources** | **$154.84** | **$370.35** | **$249.00** | **-$121.35** | **-32.8%** |

## SUMMARY OF FY 2022 BUDGETARY RESOURCES BY ACCOUNT

(Dollars in Millions)

| Discretionary Accounts | FY 2020 Actual | FY 2021 Enacted | FY 2022 Request | Change over FY 2021 Enacted Amount | Change over FY 2021 Enacted Percent |
|---|---|---|---|---|---|
| ***AGENCY OPERATIONS AND AWARD MANAGEMENT*** | | | | | |
| Appropriation | $337.90 | $345.64 | $468.30 | $122.66 | 35.5% |
| Unobligated Balance Available Start of Year | 0.15 | 9.20 | | -9.20 | |
| Unobligated Balance Available End of Year | -9.20 | | | | |
| Adjustments to Prior Year Accounts[1] | -0.12 | | | | |
| **Subtotal, AOAM** | **328.73** | **354.84** | **468.30** | | |
| Transfer to/from other funds | 19.85 | 29.29 | | | |
| **Total Budgetary Resources** | **$348.58** | **$384.13** | **$468.30** | **$84.17** | **21.9%** |
| ***NATIONAL SCIENCE BOARD*** | | | | | |
| Appropriation | $4.50 | $4.50 | $4.60 | $0.10 | 2.2% |
| Unobligated Balance - Expired | -0.07 | | | | |
| **Total Budgetary Resources** | **$4.43** | **$4.50** | **$4.60** | **$0.10** | **2.2%** |
| ***OFFICE OF INSPECTOR GENERAL*** | | | | | |
| Appropriation | $16.50 | $17.85 | $20.42 | $2.57 | 14.4% |
| Unobligated Balance Available Start of Year | 0.40 | 0.40 | | -0.40 | |
| Unobligated Balance Available End of Year | -0.40 | | | | |
| Adjustments to Prior Year Accounts[1] | -0.20 | | | | |
| **Total Budgetary Resources** | **$16.30** | **$18.25** | **$20.42** | **$2.17** | **11.9%** |
| ***TOTAL DISCRETIONARY, NATIONAL SCIENCE FOUNDATION*** | **$8,286.09** | **$8,640.23** | **$10,169.30** | **$1,529.07** | **17.7%** |

Totals exclude reimbursable amounts.

[1]Adjustments include upward and downward adjustments to prior year obligations in unexpired accounts.

**SUMMARY OF FY 2022 BUDGETARY RESOURCES BY ACCOUNT**
(Dollars in Millions)

| Mandatory Accounts | FY 2020 Actual | FY 2021 Enacted | FY 2022 Request | Change over FY 2021 Enacted Amount | Change over FY 2021 Enacted Percent |
|---|---|---|---|---|---|
| ***EDUCATION AND HUMAN RESOURCES, H-1B*** | | | | | |
| Appropriation, Mandatory (H1-B Non-Immigrant Petitioner Fees) | $153.03 | $157.00 | $162.47 | $5.47 | 3.5% |
| Unobligated Balance Available Start of Year | 77.47 | 124.67 | | -124.67 | |
| Sequestration Previously Unavailable | 9.72 | 9.03 | 8.95 | -0.08 | |
| Sequestration Pursuant OMB M-13-06 | -9.03 | -8.95 | -10.17 | | |
| Unobligated Balance Available End of Year | -124.67 | | | | |
| Adjustments to Prior Year Accounts[1] | 8.26 | | | | |
| **Total Budgetary Resources** | **$114.78** | **$281.75** | **$161.25** | **-$120.50** | **-42.8%** |
| ***DONATIONS*** | | | | | |
| Mandatory Programs (Special or Trust Fund)[2] | $27.26 | $40.00 | $10.00 | -$30.00 | -75.0% |
| Unobligated Balance Available Start of Year | 25.12 | 31.50 | | -31.50 | |
| Sequestration Previously Unavailable | - | - | - | - | |
| Sequestration Pursuant OMB M-13-06 | - | - | | | |
| Unobligated Balance Available End of Year | -31.50 | | | | |
| Adjustments to Prior Year Accounts[1] | 0.18 | | | | |
| **Total Budgetary Resources** | **$21.06** | **$71.50** | **$10.00** | **-$61.50** | **-86.0%** |
| ***TOTAL MANDATORY, NATIONAL SCIENCE FOUNDATION*** | **$135.84** | **$353.25** | **$171.25** | **-$182.00** | **-51.5%** |

Totals exclude reimbursable amounts.
[1]Adjustments include upward and downward adjustments to prior year obligations in unexpired accounts.
[2]Starting in FY 2022 the Donations account will no longer hold foreign funds. These funds will be held in NSF's Deposit Fund.

**NSF FY 2022 REQUEST FUNDING BY PROGRAM**
(Dollars in Millions)

| | FY 2020 Actual | FY 2020 CARES Act Actual | FY 2020 Total | FY 2021 Estimate[1] | FY 2022 Request | FY 2022 Request change over FY 2020 Actual: Amount | Percent |
|---|---|---|---|---|---|---|---|
| **BIOLOGICAL SCIENCES (BIO)** | | | | | | | |
| BIOLOGICAL INFRASTRUCTURE | $181.85 | - | $181.85 | $167.08 | $204.89 | $23.04 | 12.7% |
| EMERGING FRONTIERS | 98.56 | 19.00 | 117.56 | 109.58 | 149.59 | 51.03 | 51.8% |
| ENVIRONMENTAL BIOLOGY | 171.31 | - | 171.31 | 178.86 | 196.22 | 24.91 | 14.5% |
| INTEGRATIVE ORGANISMAL SYSTEMS | 204.05 | - | 204.05 | 206.98 | 227.07 | 23.02 | 11.3% |
| MOLECULAR & CELLULAR BIOSCIENCES | 153.54 | - | 153.54 | 155.64 | 170.74 | 17.20 | 11.2% |
| **TOTAL, BIO** | **$809.31** | **$19.00** | **$828.31** | **$818.14** | **$948.51** | **$139.20** | **17.2%** |
| **COMPUTER & INFORMATION SCIENCE & ENGINEERING (CISE)** | | | | | | | |
| ADVANCED CYBERINFRASTRUCTURE | $228.65 | $0.90 | $229.55 | $230.54 | $252.19 | $23.54 | 10.3% |
| COMPUTING & COMMUNICATION FOUNDATIONS | 199.34 | 1.40 | 200.74 | 201.00 | 218.50 | 19.16 | 9.6% |
| COMPUTER & NETWORK SYSTEMS | 236.14 | 6.20 | 242.34 | 238.12 | 259.87 | 23.73 | 10.1% |
| INFORMATION & INTELLIGENT SYSTEMS | 216.02 | 6.00 | 222.02 | 217.87 | 238.59 | 22.57 | 10.4% |
| INFORMATION TECHNOLOGY RESEARCH | 116.24 | 0.50 | 116.74 | 117.96 | 146.91 | 30.67 | 26.4% |
| **TOTAL, CISE** | **$996.40** | **$15.00** | **$1,011.40** | **$1,005.49** | **$1,116.06** | **$119.66** | **12.0%** |
| **ENGINEERING (ENG)[2,3]** | | | | | | | |
| CHEMICAL, BIOENGINEERING, ENVIRONMENTAL, & TRANSPORT SYSTEMS | $197.92 | $7.70 | $205.62 | $199.96 | $241.05 | $43.13 | 21.8% |
| CIVIL, MECHANICAL, & MANUFACTURING INNOVATION | 238.58 | 3.75 | 242.33 | 241.13 | 290.50 | 51.92 | 21.8% |
| ELECTRICAL, COMMUNICATIONS, & CYBER SYSTEMS | 122.86 | 1.50 | 124.36 | 124.05 | 149.52 | 26.66 | 21.7% |
| ENGINEERING EDUCATION & CENTERS | 124.06 | 1.30 | 125.36 | 125.02 | 149.30 | 25.24 | 20.3% |
| EMERGING FRONTIERS AND MULTIDISCIPLINARY ACTIVITIES | 70.88 | 0.75 | 71.63 | 71.69 | 86.42 | 15.54 | 21.9% |
| **TOTAL, ENG** | **$754.31** | **$15.00** | **$769.31** | **$761.85** | **$916.79** | **$162.48** | **21.5%** |

**NSF FY 2022 REQUEST FUNDING BY PROGRAM**
(Dollars in Millions)

| | FY 2020 Actual | FY 2020 CARES Act Actual | FY 2020 Total | FY 2021 Estimate[1] | FY 2022 Request | FY 2022 Request change over FY 2020 Actual: Amount | FY 2022 Request change over FY 2020 Actual: Percent |
|---|---|---|---|---|---|---|---|
| **GEOSCIENCES (GEO)** | | | | | | | |
| ATMOSPHERIC & GEOSPACE SCIENCES | $280.08 | - | $280.08 | $283.47 | $341.71 | $61.63 | 22.0% |
| EARTH SCIENCES | 199.21 | - | 199.21 | 201.36 | 240.04 | 40.83 | 20.5% |
| INTEGRATIVE & COLLABORATIVE EDUCATION AND RESEARCH | 113.07 | - | 113.07 | 116.30 | 137.03 | 23.96 | 21.2% |
| OCEAN SCIENCES | 401.36 | - | 401.36 | 403.05 | 476.14 | 74.78 | 18.6% |
| **TOTAL, GEO** | **$993.72** | **-** | **$993.72** | **$1,004.18** | **$1,194.92** | **$201.20** | **20.2%** |
| **MATHEMATICAL & PHYSICAL SCIENCES (MPS)** | | | | | | | |
| ASTRONOMICAL SCIENCES | $279.10 | - | $279.10 | $277.05 | $294.05 | $14.95 | 5.4% |
| CHEMISTRY | 260.37 | - | 260.37 | 259.71 | 284.14 | 23.77 | 9.1% |
| MATERIALS RESEARCH | 330.15 | - | 330.15 | 329.78 | 349.92 | 19.77 | 6.0% |
| MATHEMATICAL SCIENCES | 244.09 | - | 244.09 | 243.54 | 259.47 | 15.38 | 6.3% |
| PHYSICS | 304.39 | - | 304.39 | 303.90 | 316.59 | 12.20 | 4.0% |
| MULTIDISCIPLINARY ACTIVITIES | 112.01 | 6.00 | 118.01 | 166.50 | 186.57 | 74.56 | 66.6% |
| **TOTAL, MPS** | **$1,530.12** | **$6.00** | **$1,536.12** | **$1,580.48** | **$1,690.74** | **$160.62** | **10.5%** |
| **SOCIAL, BEHAVIORAL & ECONOMIC SCIENCES (SBE)** | | | | | | | |
| BEHAVIORAL AND COGNITIVE SCIENCES | $98.64 | $4.00 | $102.64 | $99.41 | $113.16 | $14.52 | 14.7% |
| SOCIAL AND ECONOMIC SCIENCES | 99.87 | 5.50 | 105.37 | 102.83 | 117.08 | 17.21 | 17.2% |
| MULTIDISCIPLINARY ACTIVITIES | 26.64 | - | 26.64 | 24.34 | 27.94 | 1.30 | 4.9% |
| NATIONAL CENTER FOR SCIENCE & ENGINEERING STATISTICS | 55.20 | - | 55.20 | 55.48 | 61.48 | 6.28 | 11.4% |
| **TOTAL, SBE** | **$280.35** | **$9.50** | **$289.85** | **$282.06** | **$319.66** | **$39.31** | **14.0%** |

**NSF FY 2022 REQUEST FUNDING BY PROGRAM**
(Dollars in Millions)

| | FY 2020 Actual | FY 2020 CARES Act Actual | FY 2020 Total | FY 2021 Estimate[1] | FY 2022 Request | FY 2022 Request change over FY 2020 Actual Amount | FY 2022 Request change over FY 2020 Actual Percent |
|---|---|---|---|---|---|---|---|
| **TECHNOLOGY, INNOVATION & PARTNERSHIPS (TIP)** | | | | | | | |
| TRANSLATIONAL IMPACT (TI)[3] | $254.13 | $2.75 | $256.88 | $254.87 | $329.87 | $75.74 | 29.8% |
| *[SBIR/STTR, including operations]* | *[232.06]* | *[2.75]* | *[234.81]* | *[232.06]* | *[274.64]* | *[42.58]* | *[18.3%]* |
| INNOVATION ECOSYSTEMS[3] | 98.18 | 0.80 | 98.98 | 110.00 | 335.00 | 236.82 | 241.2% |
| TECHNOLOGY FRONTIERS | - | - | - | - | 150.00 | 150.00 | N/A |
| PARTNERSHIPS OFFICE | - | - | - | - | 50.00 | 50.00 | N/A |
| **TOTAL, TIP** | **$352.31** | **$3.55** | **$355.86** | **$364.87** | **$864.87** | **$512.56** | **145.5%** |
| **OFFICE OF INTERNATIONAL SCIENCE AND ENGINEERING (OISE)** | **$51.04** | **-** | **$51.04** | **$51.32** | **$75.32** | **$24.28** | **47.6%** |
| **OFFICE OF POLAR PROGRAMS (OPP)** | | | | | | | |
| OFFICE OF POLAR PROGRAMS | $480.59 | - | $480.59 | $483.35 | $506.29 | $25.70 | 5.3% |
| *[US Antarctic Logistical Support Activities]* | *[77.00]* | *[-]* | *[77.00]* | *[77.00]* | *[77.10]* | *[0.10]* | *[0.13%]* |
| **Total, OPP** | **$480.59** | **-** | **$480.59** | **$483.35** | **$506.29** | **$25.70** | **5.3%** |
| **INTEGRATIVE ACTIVITIES (IA)** | | | | | | | |
| ESTABLISHED PROGRAM TO STIMULATE COMPETITIVE RESEARCH (EPSCoR) | 190.32 | 1.25 | 191.57 | 200.00 | 239.64 | 49.32 | 25.9% |
| INTEGRATIVE ACTIVITIES[4] | 162.65 | 0.70 | 163.35 | 184.88 | 265.26 | 102.61 | 63.1% |
| **TOTAL, IA** | **$352.97** | **$1.95** | **$354.92** | **$384.88** | **$504.90** | **$151.93** | **43.0%** |
| **UNITED STATES ARCTIC RESEARCH COMMISSION** | **$1.60** | **-** | **$1.60** | **$1.60** | **$1.65** | **$0.05** | **3.1%** |
| **TOTAL, RESEARCH AND RELATED ACTIVITIES** | **$6,602.70** | **$70.00** | **$6,672.70** | **$6,738.22** | **$8,139.71** | **$1,537.01** | **23.3%** |

**NSF FY 2022 REQUEST FUNDING BY PROGRAM**
(Dollars in Millions)

| | FY 2020 Actual | FY 2020 CARES Act Actual | FY 2020 Total | FY 2021 Estimate[1] | FY 2022 Request | FY 2022 Request change over FY 2020 Actual: Amount | FY 2022 Request change over FY 2020 Actual: Percent |
|---|---|---|---|---|---|---|---|
| **EDUCATION & HUMAN RESOURCES (EHR)** | | | | | | | |
| GRADUATE EDUCATION[4] | $405.48 | $0.66 | $406.14 | $420.64 | $466.63 | $61.15 | 15.1% |
| HUMAN RESOURCE DEVELOPMENT | 210.77 | 0.80 | $211.57 | 215.36 | 307.88 | 97.11 | 46.1% |
| RESEARCH ON LEARNING IN FORMAL AND INFORMAL SETTINGS | 198.62 | 2.16 | $200.78 | 204.16 | 229.66 | 31.04 | 15.6% |
| UNDERGRADUATE EDUCATION | 269.37 | 1.38 | $270.74 | 270.10 | 283.10 | 13.73 | 5.1% |
| **TOTAL, EDUCATION & HUMAN RESOURCES** | **$1,084.24** | **$5.00** | **$1,089.24** | **$1,110.26** | **$1,287.27** | **$203.03** | **18.7%** |
| **MAJOR RESEARCH EQUIPMENT & FACILITIES CONSTRUCTION** | **$154.84** | **-** | **$154.84** | **$241.00** | **$249.00** | **$94.16** | **60.8%** |
| **AGENCY OPERATIONS AND AWARD MANAGEMENT** | **$347.58** | **$1.00** | **$348.58** | **$374.93** | **$468.30** | **$120.72** | **34.7%** |
| **OFFICE OF INSPECTOR GENERAL** | **$16.30** | **-** | **$16.30** | **$17.85** | **$20.42** | **$4.12** | **25.2%** |
| **OFFICE OF THE NATIONAL SCIENCE BOARD** | **$4.43** | **-** | **$4.43** | **$4.50** | **$4.60** | **$0.17** | **3.9%** |
| **TOTAL, NATIONAL SCIENCE FOUNDATION** | **$8,210.08** | **$76.00** | **$8,286.08** | **$8,486.76** | **$10,169.30** | **$1,959.22** | **23.9%** |

[1] Not included in the FY 2021 Estimate is $600.0 million in American Rescue Plan Act of 2021 (ARP) (P.L. 117-2) supplemental mandatory 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.

[2] The ENG Division of Industrial Innovation and Partnerships (IIP) is being dissolved in FY 2022. Most programs are moving to TIP, while the remainder are moving to the ENG Division of Engineering Education and Centers. Funding for FY 2020 Actuals and FY 2021 Estimate are restated for comparability.

[3] The Directorate for Technology, Innovation, and Partnerships is created in FY 2022. Funding for FY 2020 Actuals and FY 2021 Estimate is restated for programs moving to TIP for comparability.

[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.

**OBJECT CLASSIFICATION**
**NSF Consolidated Obligations**
(Dollars in Millions)

| Object Class Code | Standard Title | FY 2020 Actual | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|---|
| **11.1** | Full-time permanent | $184 | $197 | $222 |
| **11.3** | Other than full-time permanent | 13 | 15 | 18 |
| **11.5** | Other personnel compensation | 4 | 7 | 7 |
| **11.8** | Special personal service payment | 46 | 46 | 52 |
| | Total personnel compensation | 247 | 265 | 299 |
| **12.1** | Civilian personnel benefits | 65 | 72 | 85 |
| **21.0** | Travel and transportation of persons | 10 | 13 | 26 |
| **22.0** | Transportation of things | 1 | - | - |
| **23.1** | Rental payments | 24 | 24 | 26 |
| **23.3** | Communications, utilities, and miscellaneous charges | 1 | 1 | 3 |
| **23.1** | Printing and reproduction | - | 1 | - |
| **25.1** | Advisory and assistance services | 197 | 221 | 227 |
| **25.2** | Other services | 39 | 39 | 53 |
| **25.3** | Purchases of goods and services from Government accounts | 250 | 244 | 248 |
| **25.4** | Operation and maintenance of facilities | 134 | 140 | 150 |
| **25.5** | Research and development contracts | 6 | 6 | 6 |
| **26.0** | Supplies and materials | 1 | 1 | 1 |
| **31.0** | Equipment | 10 | 2 | 5 |
| **32.0** | Land and Structures | 50 | 90 | 90 |
| **41.0** | Grants, subsidies, and contributions | 7,252 | 8,127 | 8,950 |
| | **Total, Direct obligations[1]** | **$8,287** | **$9,246** | **$10,169** |

[1] Excludes obligations for mandatory and reimbursable accounts.

**REIMBURSABLE ACTIVITY**

Reimbursements for the Research and Related Activities Appropriation and the Education and Human Resources Appropriation are realized from other federal agencies that have entered into interagency agreements with the Foundation. NSF enters into agreements (including Memoranda of Understanding) with other U.S. government agencies, as authorized by the NSF Act, 42 U.S.C. 1870 (c), and the Economy Act, 31 U.S.C. 1535, under which NSF assumes some responsibility for activities supported by these agencies. These activities can include jointly funded projects and programs, support of research operations and logistics, and access to NSF supported research facilities.

**NSF Reimbursements by Agency**

(Dollars in Millions)

| DEPARTMENT/AGENCY | FY 2020 Actual |
|---|---|
| DEFENSE | |
| *Air Force* | $5.91 |
| *Navy* | 4.70 |
| *Army* | 4.60 |
| *Other DoD (DARPA, NSA & Intelligence)* | 12.78 |
| Subtotal, DoD | $27.99 |
| Congressional Budget Office | 1.38 |
| Agriculture | 0.83 |
| Commerce (Including Census, NOAA, & NIST) | 11.14 |
| Interior | 1.26 |
| State | 0.90 |
| Energy | 7.80 |
| Equal Employment Opportunity Commission | 1.30 |
| Health & Human Services | 37.17 |
| Homeland Security | 3.78 |
| NASA | 3.86 |
| Corps of Engineers, Civil | 1.35 |
| Transportation | 0.60 |
| OTHER (less than $500,000) | 1.04 |
| **TOTAL REIMBURSEMENTS** | **$100.42** |

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 2020 CARRYOVER INTO FY 2021 BY ACCOUNT

The National Science Foundation's total unobligated balance of $309.63 million ($153.46 million from Discretionary accounts, and $156.17 million from Mandatory accounts) is described below.

**Discretionary and Mandatory Accounts:**
**Distribution of NSF FY 2020 Carryover into FY 2021**
(Dollars in Millions)

| **Discretionary Accounts** | **Amount** |
|---|---|
| Research and Related Activities | $10.27 |
| Education and Human Resources | 4.25 |
| Major Research Equipment and Facilities Construction | 129.34 |
| Agency Operations and Award Management | 9.20 |
| Office of Inspector General | 0.40 |
| **Total, Discretionary** | **$153.46** |

| **Mandatory Accounts** | |
|---|---|
| H-1B Non-Immigrant Petitioner | 124.67 |
| Donations | 31.50 |
| **Total, Mandatory** | **$156.17** |
| **TOTAL, NSF** | **$309.63** |

## DISCRETIONARY

Research and Related Activities (R&RA)
Within the R&RA account, $10.27 million (including $3.27 million in no-year recoveries) was carried over into FY 2021.

Integrative Activities Research Investment Communications
- Amount: $1.93 million
- Purpose: Funding will be used on four procurement actions in process that will be completed in time for award this fiscal year.
- Obligation: FY 2021 Quarter 2

Integrative Activities for Convergence Accelerator–Future of Work at the Human Technology Frontier (CA-FW-HTF)
- Amount: $2.30 million
- Purpose: Grantee failed the Division of Institution and Award Support (DIAS) pre-award administrative/financial review. Cost Analysis and Pre-award Branch (CAP) delayed any re-evaluations until FY 2021; thus, funding is delayed until FY 2021.
- Obligation: FY 2021 Quarter 2 and Anticipated FY 2021 Quarter 3

Integrative Activities for Convergence Accelerator Research
- Amount: $553,198
- Purpose: Funds will be used to pay for curriculum development and delivery for both the 2019 Cohort Phase II and the 2020 Cohort Phase I.
- Obligation: FY 2021 Quarter 2 and Anticipated FY 2021 Quarter 3

Integrative Activities for Program Planning and Policy Development

- Amount: $441,580
- Purpose: These funds will be used to support IA's stewardship of merit review process.
- Obligation: FY 2021 Quarter 2 and Anticipated FY 2021 Quarter 3

National Coordination Office for Networking and Information Technology Research and Development

- Amount: $67,409
- Purpose: Funding to continue government procurements and operational expenses (i.e., credit card purchases, government travel, mailroom operations, etc.).
- Obligation: Anticipated FY 2021 Quarter 4

National Nanotechnology Coordination Office

- Amount: $2,982
- Purpose: Funding for the National Nanotechnology Coordination Office (NNCO) for NNCO operational expenses.
- Obligation: Anticipated FY 2021 Quarter 4

The remaining $1.71 million within R&RA consists of funds from throughout the Foundation for projects not funded in FY 2020.

<u>Education and Human Resources (EHR)</u>
Within the EHR account, $4.25 million was carried over into FY 2021, including $2.18 million in anticipated no-year recoveries.

Advanced Technological Education (ATE)

- Amount: $1.45 million
- Purpose: Funds became available late in FY 2020 after decommitment of an incremental grant commitment. Funds will be used on new ATE projects recommended for award.
- Obligation: FY 2021 Quarter 2 and Anticipated FY 2021 Quarter 3

Robert Noyce Teacher Scholarship Program (Noyce)

- Amount: $564,832
- Purpose: These funds will be used to invest in teacher preparation and/or support Noyce fellows during completion of a teaching obligation.
- Obligation: FY 2021 Quarter 2

The remaining $55,000 consists of funds from EHR for projects not funded in FY 2020.

<u>Major Research Equipment and Facilities Construction (MREFC)</u>
Within the MREFC account, $129.35 million (including $3.42 million in no-year recoveries) was carried over into FY 2021.

Mid-scale Research Infrastructure Track 2 (Mid-scale RI-2)

- Amount: $65.0 million
- Purpose: Funding for Mid-scale Track 2 awards. Awards pending independent cost estimates required by Congress in the American Innovation and Competitiveness Act (AICA), and then to complete the NSF cost analysis on the new projects prior to award.
- Obligation: FY 2021 Quarter 1 and Anticipated FY 2021 Quarter 3

Antarctic Infrastructure Modernization for Science (AIMS)
- Amount: $29.71 million
- Purpose: Baseline and budget contingency funding not obligated in FY 2020.
- Obligation: Anticipated FY 2021 Quarter 3 to support FY 2022 fabrications and FY 2023 construction

Regional Class Research Vessel (RCRV)
- Amount: $10.97 million
- Purpose: Budget contingency funding not obligated in FY 2020.
- Obligation: Anticipated FY 2021 Quarter 3

Vera C. Rubin Observatory
- Amount: $10.07 million
- Purpose: Management reserve funding not obligated in FY 2020.
- Obligation: Anticipated FY 2021 Quarter 4 as the cost impacts of COVID-19 become better known

Daniel K. Inouye Solar Telescope (DKIST)
- Amount: $9.40 million
- Purpose: Management reserve funding not obligated in FY 2020.
- Obligation: Awarded towards mitigating impact of COVID-19 final construction in FY 2021 Quarter 1.

Dedicated Construction Oversight
- Amount: $780,000
- Purpose: Support for major facility construction oversight required under AICA and NSF policy, National Ecological Observatory Network construction close-out, and additional management reserve for DKIST, if needed.
- Obligation: Anticipated FY 2021 Quarter 4

<u>Agency Operations and Award Management (AOAM)</u>
Within the AOAM account, $9.20 million ($9.06 million in two-year funds and $146,425 in recovered no-year funds) is estimated for carryover into FY 2021.

- Amount: $9.06 million
- Purpose: To complete procurement actions in process that were not able to be completed in FY 2020 and other balances due to actual expenses coming in lower than anticipated due to operational limitations related to COVID-19 including limited travel in FY 2020.
- Obligation: FY 2021 Quarter 1-2 and Anticipated FY 2021 Quarter 3-4

<u>NSF Headquarters Relocation</u>
- Amount: $146,245
- Purpose: Budget contingency funding not obligated in FY 2020. Funds will be used towards the cost of the SCIF project.
- Obligation: FY 2021 Quarter 1-2 and Anticipated FY 2021 Quarter 3-4

<u>Office of Inspector General (OIG)</u>
Within the OIG two-year account, $400,000 was carried over into FY 2021.

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 2021 Quarter 3

**MANDATORY**

Within the H-1B account, $124.67 million was carried over into FY 2021.

Innovation Technology Experiences for Students
- Amount: $33.42 million
- Purpose: Since NSF receives the largest payments of H-1B visa fees in August and September, there was insufficient time to obligate the receipts on awards before the end of the fiscal year.
- Obligation: FY 2021 Quarter 1-2 and Anticipated FY 2021 Quarter 3-4

Scholarships in Science, Technology, Engineering, and Mathematics
- Amount: $89.88 million
- Purpose: Since NSF receives the largest payments of H-1B visa fees in August and September, there was insufficient time to obligate the receipts on awards before the end of the fiscal year.
- Obligation: FY 2021 Quarter 1-2 and Anticipated FY 2021 Quarter 3-4

The remaining $1.37 million remains available for H1B account adjustments.

Within the Donations account, $31.50 million was carried over into FY 2021. Donations are received from foreign governments, organizations, and individuals to fund various cooperative efforts in science, research, and education.

## QUANTITATIVE DATA TABLE

## NATIONAL SCIENCE FOUNDATION

**Research and Development Special Analysis**

(Dollars in Millions)

| | FY 2020 Actual | FY 2020 Actual CARES Act | FY 2020 Total | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|---|---|
| Investment Activities | | | | | |
| Conduct of Research and Development | | | | | |
| Basic Research | $5,390.46 | $66.16 | $5,456.62 | $5,500.05 | $6,532.25 |
| Applied Research | 829.30 | 8.42 | 837.72 | 848.10 | 1,046.10 |
| Subtotal, Conduct of R&D | 6,219.77 | 74.58 | 6,294.34 | 6,348.15 | 7,578.35 |
| Physical Assets | | | | | |
| Research and Development Facilities | 157.64 | - | 157.64 | 243.86 | 252.39 |
| Research and Development Major Equipment | 283.87 | - | 283.87 | 289.57 | 342.57 |
| Subtotal, R&D Facilities & Major Equipment | 441.51 | - | 441.51 | 533.43 | 594.96 |
| Total, Research and Development | 6,661.28 | 74.58 | 6,735.85 | 6,881.58 | 8,173.31 |
| Conduct of Education and Training | 728.45 | 0.20 | 728.64 | 746.43 | 949.98 |
| Non-Investment Activities | 820.36 | 1.23 | 821.59 | 858.75 | 1,046.01 |
| **TOTAL** | **$8,210.09** | **$76.00** | **$8,286.09** | **$8,486.76** | **$10,169.30** |

## QUANTITATIVE DATA TABLE

### RESEARCH AND RELATED ACTIVITIES

**Research and Development Special Analysis**

(Dollars in Millions)

| | FY 2020 Actual | FY 2020 Actual CARES Act | FY 2020 Total | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|---|---|
| Investment Activities | | | | | |
| Conduct of Research and Development | | | | | |
| Basic Research | $5,220.77 | $64.33 | $5,285.11 | $5,325.67 | $6,300.35 |
| Applied Research | 545.68 | 5.40 | 551.07 | 556.64 | 658.51 |
| Subtotal, Conduct of R&D | 5,766.45 | 69.73 | 5,836.18 | 5,882.31 | 6,958.86 |
| Physical Assets | | | | | |
| Research and Development Facilities | 2.81 | - | 2.81 | 2.86 | 3.39 |
| Research and Development Major Equipment | 283.79 | - | 283.79 | 289.49 | 342.47 |
| Subtotal, R&D Facilities & Major Equipment | 286.60 | - | 286.60 | 292.36 | 345.86 |
| Total, Research and Development | 6,053.05 | 69.73 | 6,122.78 | 6,174.66 | 7,304.72 |
| Conduct of Education and Training | 284.71 | 0.07 | 284.78 | 290.43 | 343.58 |
| Non-Investment Activities | 407.21 | 0.20 | 407.41 | 415.39 | 491.41 |
| **TOTAL** | **$6,744.96** | **$70.00** | **$6,814.96** | **$6,880.48** | **$8,139.71** |

## QUANTITATIVE DATA TABLE

### EDUCATION AND HUMAN RESOURCES

**Research and Development Special Analysis**

(Dollars in Millions)

| | FY 2020 Actual | FY 2020 Actual CARES Act | FY 2020 Total | FY 2021 Estimate | FY 2022 Request |
|---|---|---|---|---|---|
| Investment Activities | | | | | |
| Conduct of Research and Development | | | | | |
| Basic Research | $169.69 | $1.83 | $171.52 | $174.38 | $231.90 |
| Applied Research | 283.63 | 3.02 | 286.65 | 291.46 | 387.59 |
| Subtotal, Conduct of R&D | 453.32 | 4.85 | 458.17 | 465.84 | 619.49 |
| Physical Assets | | | | | |
| Research and Development Facilities | - | - | - | - | - |
| Research and Development Major Equipment | 0.08 | - | 0.08 | 0.08 | 0.10 |
| Subtotal, R&D Facilities & Major Equipment | 0.08 | - | 0.08 | 0.08 | 0.10 |
| Total, Research and Development | 453.39 | 4.85 | 458.24 | 465.92 | 619.59 |
| Conduct of Education and Training | 443.74 | 0.13 | 443.87 | 456.00 | 606.40 |
| Non-Investment Activities | 44.84 | 0.03 | 44.87 | 46.08 | 61.28 |
| **TOTAL** | **$941.98** | **$5.00** | **$946.98** | **$968.00** | **$1,287.27** |

## QUANTITATIVE DATA TABLE

### MAJOR RESEARCH EQUIPMENT AND FACILITIES CONSTRUCTION

**Research and Development Special Analysis**

(Dollars in Millions)

| | **FY 2020 Actual** | **FY 2020 Actual CARES Act** | **FY 2020 Total** | **FY 2021 Estimate** | **FY 2022 Request** |
|---|---|---|---|---|---|
| Investment Activities | | | | | |
| Conduct of Research and Development | | | | | |
| Basic Research | - | - | - | - | - |
| Applied Research | - | - | - | - | - |
| Subtotal, Conduct of R&D | - | - | - | - | - |
| Physical Assets | | | | | |
| Research and Development Facilities | $154.84 | - | $154.84 | $241.00 | $249.00 |
| Research and Development Major Equipment | - | - | - | - | - |
| Subtotal, R&D Facilities & Major Equipment | 154.84 | - | 154.84 | 241.00 | 249.00 |
| Total, Research and Development | 154.84 | - | 154.84 | 241.00 | 249.00 |
| Conduct of Education and Training | - | - | - | - | - |
| Non-Investment Activities | - | - | - | - | - |
| **TOTAL** | **$154.84** | **-** | **$154.84** | **$241.00** | **$249.00** |

## QUANTITATIVE DATA TABLE

### AGENCY OPERATIONS AND AWARD MANAGEMENT

**Research and Development Special Analysis**

(Dollars in Millions)

| | FY 2020 Actual | FY 2020 Actual CARES Act | FY 2020 Total | FY 2021 Estimate | FY 2022 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 | $347.58 | $1.00 | $348.58 | $374.93 | $468.30 |
| **TOTAL** | **$347.58** | **$1.00** | **$348.58** | **$374.93** | **$468.30** |

## QUANTITATIVE DATA TABLE

### OFFICE OF INSPECTOR GENERAL

**Research and Development Special Analysis**

(Dollars in Millions)

| | FY 2020 Actual | FY 2020 Actual CARES Act | FY 2020 Total | FY 2021 Estimate | FY 2022 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 | $16.30 | - | $16.30 | $17.85 | $20.42 |
| **TOTAL** | **$16.30** | **-** | **$16.30** | **$17.85** | **$20.42** |

## QUANTITATIVE DATA TABLE

### OFFICE OF THE NATIONAL SCIENCE BOARD

**Research and Development Special Analysis**

(Dollars in Millions)

| | FY 2020 Actual | FY 2020 Actual CARES Act | FY 2020 Total | FY 2021 Estimate | FY 2022 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 | $4.50 | $4.60 |
| **TOTAL** | **$4.43** | **-** | **$4.43** | **$4.50** | **$4.60** |