RESEARCH INFRASTRUCTURE

Description and Rationale

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

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

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

Modern RI for fundamental research and innovation gathers and processes vast amounts of data, makes sense of those data using data analytics, computational modeling and simulation, and AI, and supplies both raw and processed data to researchers across the U.S. and around the world. Advanced cyberinfrastructure is increasingly a key element of all successful RI. Importantly, cutting-edge RI is also integral to attracting, developing, and training the next generation of STEM talent and inspiring

those who will lead the next generation of advances in infrastructure. The skills required to design, operate, and maintain RI are critical for the future of the Nation's STEM enterprise. NSF RI both benefits from and contributes to the training of the skilled technical workforce. For example, the Marine Technology Mentoring and Internship Program on Oceanographic Research Vessels provides interns work onboard research vessels. These experiences provide them with the opportunity to develop their technical, scientific, seamanship and interpersonal skills.

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

Goal of Investment

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

Potential for Impact, Urgency, and Readiness

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

Budget Justification

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

Activities with a focus on fundamental research:

- Increasing investment in the commissioning and early science investigations of the Daniel K. Inouye Solar Telescope and the Vera C. Rubin Observatory will help the science community achieve full benefit from the telescopes sooner, since their commissioning and early science

periods were shortened by COVID-19-induced delays in construction; this will enable earlier fulfillment of the scientific promise that led to the approval to build these facilities in the last decade, and will enhance provision of data access to students nationwide.

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

[1] www.nationalacademies.org/our-work/decadal-survey-on-astronomy-and-astrophysics-2020-astro2020

[2] https://catalog.data.gov/dataset/artificial-intelligence-and-wireless-spectrum-opportunities-and-challenges

Activities that specifically enable broader access to RI:

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

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

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