STRENGTHEN RESEARCH INFRASTRUCTURE

Description and Rationale

Research infrastructure (RI), from individual instruments to major research facilities, is foundational to the scientific endeavor. Definitions of RI have evolved significantly over the years, particularly as remote access and cyberinfrastructure have become essential components of almost every tool in use by the research community. The COVID-19 pandemic further emphasized the critical nature of these components and illustrated how they contribute to ongoing efforts to expand access to RI to historically underserved groups and communities. Additionally, NSF investments in science and engineering have stimulated discovery and innovation in the design and development of novel infrastructure, giving rise to new and different forms of RI.

The National Science and Technology Council's (NSTC) *National Strategic Overview for Research and Development Infrastructure*[1] defines Research and Development Infrastructure (RDI) as "facilities or systems used by scientific and technical communities to conduct research and development (R&D) or foster innovation." The report 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 throughout.

RI is an essential enabler of science and engineering research and education. It is needed for all forms of fundamental research – from curiosity-driven, exploratory research to use-inspired, solutions-oriented research. RI is critical to the success of research across a wide array of disciplines and over a broad range of time scales. Investments in RI 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 (see the Build A Resilient Planet narrative for more details), studies of the rate at which members of underrepresented groups are engaged in science and engineering disciplines, 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 plays an important role in development of advanced wireless communications, research on new nanomaterials and design of new biomaterials, refinement of meteorological and space weather models and forecasts, creation of AI algorithms for a variety of societal uses, and the development of quantum computing and communication capabilities.

Importantly, RI expands to comprise instrumented and living laboratories and testbeds, enabling advances in Emerging Industries (see the Advance Emerging Industries for National and Economic Security narrative 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 analytics, computational modeling and simulation, and AI, and supplies both raw and processed data to researchers across the U.S. and around the world. Accordingly, advanced cyberinfrastructure is increasingly a vital aspect of all successful RI. New

[1] www.whitehouse.gov/wp-content/uploads/2021/10/NSTC-NSO-RDI-_REV_FINAL-10-2021.pdf

and new types of RI is anticipated to enable NSF's support of provisions in the CHIPS and Science Act.

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, build, operate, and maintain RI are critical for the future of the Nation's STEM enterprise, including individuals from skilled technical workers to PhDs.

In short, investments in research must be complemented by corresponding investments in RI in order for the U.S. to lead the world in science and innovation.

Goal of Investment

Strengthening Research Infrastructure promotes a stronger, U.S.-led science and engineering enterprise and STEM ecosystem. NSF's RI portfolio uniquely positions the agency to support research advances that are not enabled by other federal entities. Intentional investments in RI are pillars that buttress NSF's efforts to Create Opportunities Everywhere, Build a Resilient Planet, and Advance Emerging Industries for National and Economic Security. Overarching goals for FY 2024 include:

- Sustain state-of-the-art RI to foster 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 U.S. competitiveness, biosecurity, climate change, and socioeconomic and regional inequities. This includes expanding our knowledge of the Earth's atmosphere, ocean, land, and ice surfaces using the sensors and data made available through major and mid-scale research infrastructure, characterizing near-Earth objects and providing computational capacity to simulate biological organisms such as viruses.
- Boost access to RI to 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 RI needed for research, other equity and broadening participation efforts cannot reach their full potential.
- Sharpen RI's focus on workforce development with continued emphasis on training students and the skilled technical workforce in the design and implementation of infrastructure to ensure a technically proficient and diverse workforce.

Potential for Impact, Urgency, and Readiness

In addition to establishing a definition for RDI, the NSTC's *National Strategic Overview for Research and Development Infrastructure* laid out a strategic vision for Federal government investments that emphasized the importance of RDI in maintaining U.S. national security and economic competitiveness. The report further acknowledged the importance of integrating input from the R&D community, such as that NSF routinely receives from its advisory committees and the National Science Board, and from studies conducted by the National Academies of Sciences, Engineering and Medicine (NASEM). Recent NASEM reports[2] continue to guide NSF's investments in new and established RI.

[2] For example, National Academies of Sciences, Engineering, and Medicine. 2021. *Pathways to Discovery in Astronomy and Astrophysics for the 2020s*. Washington, DC: The National Academies Press. https://doi.org/10.17226/26141; National Academies of Sciences, Engineering, and Medicine. 2020. *A Vision for*

Continued investment in RI is critical for maintaining U.S. leadership in scientific research and innovation. RI is often the key ingredient that makes cutting-edge science and discovery possible and, consequently, demand is high. NSF's Mid-scale RI programs are many-fold oversubscribed and research communities across many STEM fields have released ambitious plans involving acquisition or construction of new infrastructure to support their science goals. Exciting and robust RI is essential to achieving equitable participation by all in careers in science and engineering. Programs associated with RI that engage and attract groups underrepresented in STEM must 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.

NSF's investments in RI span a range of activity types. For ease of reading, these examples are divided below into the separate categories of fundamental research and enabling broader access to RI, but there is considerable overlap among these categories, and many investments would benefit both focus areas.

Activities with a focus on fundamental research:

- Support for Antarctic infrastructure and logistics to enable researchers to access remote areas of the Antarctic continent (both in person and virtually).
- 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 those in which aging of the physical infrastructure now threatens the ability to deliver forefront science.
- Construction of the Leadership-Class Computing Facility (LCCF) to meet the increasing demand for large-scale computing and data analytics capabilities, while minimizing gaps in resource availability as the current system (*Frontera*) obsolesces.

Activities that specifically enable broader access to RI:

- Funding 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] At the FY 2024 Budget level, additional Mid-scale RI Track 1 ($6-20 million range) and Track 2 ($20-100 million range) awards will be possible, providing more capacity for innovative developments that expand the STEM workforce and provide cutting-edge RI to previously underserved communities.
- Investment in major research instrumentation (MRI), with a sustained commitment to invest in predominantly undergraduate institutions, historically under-resourced institutions, and geographic diversity.

NSF Earth Sciences 2020-2030: Earth in Time. Washington, DC: The National Academies Press. https://doi.org/10.17226/25761; National Academies of Sciences, Engineering, and Medicine. 2021. *Mid-Term Assessment of Progress on the 2015 Strategic Vision for Antarctic and Southern Ocean Research*. Washington, DC: The National Academies Press. https://doi.org/10.17226/26338.

[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 spectrometers that will specifically enable research at smaller universities and Minority Serving Institutions that have not previously had access to such infrastructure.

- 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, and partnerships with technical and community colleges.

Directorate Contributions to Research Infrastructure

In FY 2024, BIO will continue to invest in the National Ecological Observatory Network by expanding the biorepository capacity. CISE, through its Office of Advanced Cyberinfrastructure, will oversee the construction of LCCF and will support cyberinfrastructure and cybersecurity efforts at major facilities through an internal NSF working group. GEO and MPS will continue to provide operations and maintenance (O&M) funding to major facilities, with a focus on maintaining state-of-the-art capability and addressing deferred maintenance items and upgrades. Additional investment in logistics support for the U.S. Antarctic Program will enable OPP to advance critical climate-focused research in West Antarctica, where glacial instabilities have been recently discovered. OIA administers the MRI and Mid-scale RI Track 1 programs, in which all directorates are overseeing funded projects. The requested funding level in FY 2024 will enable more awards in each of these programs, expanding access to cutting-edge RI to a broader population of researchers and students. All directorates support research resources, smaller scale RI that nonetheless enables discovery and innovation across NSF's portfolio of awards. Finally, through SBE's National Center for Science and Engineering Statistics, further investment will be made in the America's Data Hub Consortium to expand provision of and access to data from Federal agencies.