BUILD A RESILIENT PLANET

Description and Rationale

Resilience is the watchword as the U.S. and the world increasingly feel the impacts of a changing climate and the need for clean, reliable, sustainable energy. Without the resilience to withstand and recover quickly from these impacts, we are at the mercy of extreme events, such as heat waves, droughts, floods, wildfires, rising oceans, and the ensuing risks of power disruptions, economic instability, food and water insecurity, and deleterious effects on human health. Often the impacts of extreme events fall disproportionately on disadvantaged communities, therefore research programs must integrate the need for environmental justice as they are being formulated. Additionally, to achieve a carbon-neutral, equitable, and sustainable economy, clean energy must constitute an increasing share of our energy sources.

NSF's Build a Resilient Planet initiative takes on the multifaceted challenges of:

- Enhancing climate observations, monitoring, and modeling, as well as addressing research gaps in predicting the response of the planet's systems to a changing climate.
- Improving climate adaptation and resilience to maximize resource utilization and sustainability within the food-energy-water system.
- Developing nature-based solutions to combat climate change.
- Innovating clean energy technologies and associated infrastructure that can adapt to a changing planet with a goal of achieving net-zero greenhouse gas emissions in the U.S. by 2050.
- Enhancing national efforts in greenhouse gas (GHG) measurement, monitoring, and verification of emissions and GHG removal from the atmosphere.

Changing climates impact the health, prosperity and welfare of people and communities and pose a significant national security threat. Accelerating the development of solutions to the interconnected challenges of resilience requires bold thinking, convergent approaches, and an overarching commitment to environmental equity, justice, and workforce development and education. NSF will invest strategically in emerging research areas on resilience to ensure U.S. leadership for an economically strong, nationally secure, sustainable, and equitable future. NSF will also leverage and enhance investments in essential research infrastructure needed to drive the discoveries that will build a more resilient planet. Innovations in artificial intelligence, high-performance computing, semiconductors, and software are also essential to advance computational approaches to modeling, simulation, analysis, prediction at the speed and scale needed to advance strategies for climate change and clean energy. NSF will take action to enhance knowledge, empower and engage communities, grow a capable and diverse scientific workforce, and generate innovative technological solutions; this includes learning with, and from, likeminded international partners at all scales. Disadvantaged and underserved communities will directly participate in, and benefit from, Build a Resilient Planet. NSF will also invest in research to accelerate the translation of new knowledge into solutions.

NSF's investments in Build a Resilient Planet will advance the priorities of the CHIPS and Science Act of 2022. Supported research will improve our understanding of climate systems and related environmental and human interactions, water quality and food-energy-water systems, and natural hazards and community resilience, including social and behavioral dimensions. Supported research will also advance sustainable chemistry, the provision of critical minerals, engineering biology,

biomanufacturing, precision agriculture, and resilient rural and urban infrastructure that will enable economic growth that protects people and the planet.

Goals of the Investment

- To advance resilience research through support for an integrated, mission-oriented approach, beyond approaches traditional for NSF, with the goal of deploying solutions within the coming decade towards a resilient planet. New investments will build on existing climate- and energy-related activities supported through the Foundation's research portfolio.
- To integrate foundational and use-inspired science and engineering research with translational approaches to climate resilience, adaptation, and mitigation and to clean energy technologies.
- To catalyze convergent research at speed and scale with an integrated systems approach focused on the causes and predictable impacts of climate change, while also developing paradigm-shifting clean energy technologies and reimagined infrastructure systems as well as non-energy related technologies aimed to improve sustainability and reduce environmental impacts. These efforts will be tailored to a local/regional scale with the ability to scale for global impact.
- To establish integrated and equitable public and private partnerships among local communities, researchers, educators, communicators, industry, international partners, tribal nations, and policy makers to advance knowledge, empower communities, and catalyze and develop resilience solutions towards a sustainable Earth.
- To democratize resilience and the ability for all communities to engage in climate resilience research regardless of socio-economic or geographical circumstances.
- To engage effectively and respectfully with communities through the incorporation of local, traditional, and indigenous knowledge in research programs co-designed with impacted stakeholders.
- To develop and enhance research infrastructure investments that are essential to advancing science and engineering that will build a more resilient Earth system.
- To develop systems-thinking capacity in the training of a skilled, globally competitive, and diverse generation of scientists and engineers while actively engaging communities and the public.

Potential for Impact, Urgency, and Readiness

The Nation has embarked on the urgent mission of building a resilient planet, as highlighted in recent reports on this priority area:

- The Fifth National Climate Assessment notes that the effects of human-caused climate change are already far-reaching and worsening across every region of the United States.[1]
- The Intergovernmental Panel on Climate Change[2] found that the world is today facing unprecedented challenges because of climate change, with impacts more severe than expected.
- The recent Engineering Research Visioning Alliance (ERVA) report "The Role of Engineering to Address Climate Change"[3] focuses on investments in critical materials, energy storage and transmission, resilient and energy-efficient infrastructure, GHG capture and elimination technologies, ecosystem sensor and sensing applications, and exploiting artificial intelligence modelling in forecasting and trend analyses.

[1] https://nca2023.globalchange.gov/downloads/NCA5_Report-In-Brief.pdf
[2] https://report.ipcc.ch/ar6/wg2/IPCC_AR6_WGII_FullReport.pdf
[3] www.ervacommunity.org/visioning-report/visioning-event-report/

- As envisioned in the National Academies of Sciences, Engineering, and Medicine (The National Academies) report on "Next-Generation Earth Systems Science at the NSF,"[4] a systems-thinking approach is needed, identifying the mechanisms and opportunities that interrelate understanding of the climate system, clean energy technologies, and society in holistic solutions to the growing climate and clean energy crisis.
- As recommended in the National Academies report on "Accelerating Decarbonization of the U.S. Energy System" (2021)[5] and (2023),[6] bold and decisive action is urgently required to address the need for clean energy. New resources are necessary to both initiate and accelerate new discoveries and insights as well as the translation of research results to technological solutions.
- The Ocean Climate Action Plan of March, 2023,[7] outlines three goals that mobilize the Federal Government and civil society to take effective and innovative ocean climate action: (1) create a carbon-neutral future, without emissions that cause climate change and harm human health, (2) accelerate solutions that tap the power of natural coastal and ocean systems to absorb and store greenhouse gases, reduce the climate threat, and protect communities and ecosystems against unavoidable changes, and (3) enhance community resilience to ocean change by developing ocean-based solutions that help communities adapt and thrive in our changing climate.
- The U.S. Global Change Research Program has fully recognized the imperative for resilience and has developed a framework in its new Strategic Plan (2022-2031)[8] to better equip the Nation and the world to respond to change and manage critical risks.

NSF's support of all fields of science and engineering make it uniquely capable of advancing the integrated, interdisciplinary research needed to enable a resilient nation and planet. Furthermore, NSF's integrated investments in education, diversity and inclusion will prepare a future workforce that understands the complex interdependencies of changing Earth systems and the built environment and that can innovate clean energy and related green industries. These investments will ensure that the U.S. continues to be a global leader in the management, mitigation, and adaptation to climate change for an economically strong and secure future.

Impacts from the Build a Resilient Planet initiative will be realized across several key areas:

<u>Advancing Climate Science</u>

Understanding climate change and the associated impacts on human and environmental systems is the central thrust to much of NSF's resilience research and is essential to identifying, developing, and ultimately implementing solutions to mitigate climate change impacts. One of the critical keys to the resilience puzzle is predicting tipping points: points at which a series of small changes or incidents reach a critical point to trigger larger, more impactful changes. Understanding and predicting tipping points underpins recognizing how changes in climate lead to drought, wildfire, thawing of permafrost, ice loss and sea-level rise, coastal flooding, and severe storms. However, scientific understanding of climate and the ability to predict impacts of climate change are not sufficient to catalyze resilience. Research results must be translated into actionable information allowing policy makers to understand regional and local threats and innovators and entrepreneurs to develop and implement mitigation

[4] https://doi.org/10.17226/26042

[5] https://nap.nationalacademies.org/catalog/25932/accelerating-decarbonization-of-the-us-energy-system

[6] https://nap.nationalacademies.org/catalog/25931/accelerating-decarbonization-in-the-united-states-technology-policy-and-societal

[7] www.whitehouse.gov/wp-content/uploads/2023/03/Ocean-Climate-Action-Plan_Final.pdf

[8] www.globalchange.gov/reports/us-global-change-research-program-2022-2031-strategic-plan

strategies. NSF brings tremendous energy and focus to the challenge of resilience through coordination with USGCRP. NSF's USGCRP-related efforts are leveraged and used as a foundational basis by other government stakeholders, thus enabling a whole-of-government effort to build a resilient future.

Climate Change Adaptation and Resilience

Build a Resilient Planet will integrate knowledge about the interconnected systems of climate, biosphere, and the built environment, along with the human behavioral, economic, and international dimensions. High-performance computing, AI, and data sharing tools will be developed to advance research on climate change, natural resource depletion, loss of biodiversity, extreme events, and sustainable energy. Such understanding will enable forecasts of the changing climate and inform and advance equitable adaptation, mitigation, and resilience strategies. This knowledge will enable capabilities to mitigate negative environmental impacts through, for example, emissions capture and reuse, energy efficiency, extreme design for a changing climate, and alternative processes for agriculture, pharmaceuticals, chemicals, fuels, materials, and manufacturing. Research in collaboration, coordination and communication with stakeholders will also be able to reimagine and develop resilient, smart, and sustainable civil infrastructure.

Nature-based Climate Solutions

Build a Resilient Planet will enhance understanding of the effectiveness of nature-based climate solutions, including terrestrial, freshwater, coastal, and ocean ecosystems that provide carbon sequestration and storage. In turn, these research outcomes will enhance ecosystem and human community resilience. Understanding how living systems respond and adapt to climate change can help us design and implement solutions that go beyond mere survival under adverse conditions to enable resilience in the face of continual change. Taking advantage of knowledge at multiple scales of biological organization—from molecules to genomes to cells to organisms to populations and ecosystems—as well as how biological systems interact in diverse environments provides foundational information to improve life on our warming planet. By sustaining and restoring valuable ecosystem services, research funded by NSF will create economic opportunities for farmers, ranchers, fishers, and foresters and will also contribute to improving national security. In addition, NSF investments in precision agriculture, biotechnology, food-energy-water systems, control of nitrogen and methane emissions from agriculture, and other research areas will mitigate climate change impacts and increase the sustainability of future U.S. agriculture.

Innovation in Clean Energy Technology and Infrastructure

The discovery, development, and deployment of clean energy solutions remains an important strategy to attenuate the impacts of climate change and to provide dependable, cost-effective, and on-demand energy sources for the world. Critical technological advances are needed to maximize access and utilization of renewable energy, enable grid security and storage, and electrify manufacturing, transportation, and chemical processing. Foundational research, translation, and collaboration on a new generation of sustainable energy technologies will accelerate the U.S. towards the goal of net-zero emissions with improved human health and equitable service to society without disparate impacts. Enabling and advancing the transformation of energy systems for the future requires a focus on secure and sustainable energy systems, including offshore wind/wave technologies, hydrogen at scale, fusion energy technologies, and energy-efficiency, storage, and transmission. The keys to achieving such goals lie in advancing the forefronts of fundamental engineering, physics, chemistry, and next-generation materials science research pertaining to energy, as well as research on the social,

cultural, and individual acceptance of energy system transitions. Advances in theoretical, computational, and experimental research on topics such as plasma science, thermoelectrics, superconductors, and device technologies provide new opportunities to reimagine clean energy systems globally and move toward Net-Zero Goals.

NSF-funded resilience research will enable innovations in clean energy generation and use, such as smart, wireless, sensor-based technologies to enhance system operation, storage, integration, and distribution of different types of clean energy. Likewise, large-scale data analytics and artificial intelligence techniques will allow for more efficient monitoring, management, and maintenance of decentralized energy grids, especially in remote locations or hazardous conditions. Computing technologies themselves require novel research that addresses the substantial environmental impacts throughout their entire lifecycle from design and manufacturing to deployment and operation, and finally into reuse, recycling, and disposal.

GHG Monitoring, Measurement, and Verification

Measurement, monitoring, reporting, and verification of GHG emissions and removal is critical to understanding and enhancing the progress and effectiveness of multiscale actions to address drivers of climate change. These strategies can serve as a foundation for assessing success of biotechnologies capable of using waste gases as substrates for sustainable synthesis of fuels and chemicals, thereby contributing to mitigation of the warming effects of such gases. Build a Resilient Planet research will result in sensors, imaging tools, and technologies for GHG detection, understanding of the impacts of proposed solutions, and the development of new technologies for capturing, converting, and sequestering GHG.

Anticipated Potential Contributors

NSF's investments in Build a Resilient Planet reflect an integrated portfolio allowing for rapid acceleration not just within each of the areas mentioned above, but also at the intersections between them. Funding will further a broad suite of programs to advance research and innovation in key areas across all NSF directorates and offices. Investments include ideas from researchers across the science and engineering spectrum to create broad new understanding and innovations that will increase energy resilience, enhance sustainability, mitigate climate change, and lead to other societal benefits.

Education and workforce development investments will prepare students, representing the diversity of the Nation, for climate and clean energy careers. Preparing a diverse future workforce that understands the complex interdependencies of the climate, human, and other earth systems and that can innovate in clean energy and related green industries is critical for the U.S. A knowledgeable workforce can contribute to sustainable economic growth, increase environmental sustainability, foster environmental justice, and a more resilient planet. Also important will be efforts to engage the public in resilience and clean energy topics through informal learning contexts such as exhibitions, giant screen films, television and radio programming, and public engagement in scientific research.

BaRP is closely aligned with the missions of other federal agencies such as the National Oceanic and Atmospheric Administration, National Aeronautics and Space Administration, Department of Energy, United States Geological Survey, and National Institutes of Health. As activities are developed under BaRP, NSF expects to develop appropriate interagency partnerships in areas of common interest.

Research infrastructure essential to advancing resilience research will be a core focus of this activity.

- Ongoing infrastructure investments include the National Ecological Observatory Network (NEON), the National Center for Atmospheric Research (NCAR), the Academic Research Fleet (ARF), infrastructure and logistics to support access to the Arctic, Antarctic continent, and Southern Ocean, the seismic and geodetic services of the National Geophysical Facility (formerly the independent Geodetic Facility for the Advancement of Geoscience (GAGE) and Seismological Facility for the Advancement of Geoscience (SAGE)).
- Upgrade of critical infrastructure in the Antarctic will continue, as will development of the design for an Antarctic Research Vessel (ARV).
- Centers, hubs, and teams for research, testing, coordination, and translation will be established to address complex challenges in adaptation and resilience, the bioeconomy, clean energy, wildfires and drought at the urban/rural interface, sustainable chemistry, connections with the environment and society, and other topics. Likewise, connectors will be funded to couple foundational advances across and within other large-scale NSF research and infrastructure investments into these new centers and hubs.
- Research infrastructure investments in more energy-efficient facilities, advanced computing, digital simulations, electric grid testbeds, *in situ* environmental observation technologies, and Natural Hazards Engineering Research Infrastructure (NHERI) will continue, and new opportunities for access to facilities and testbeds will begin.
- In FY 2025, NSF will continue its investments in the development of a National Discovery Cloud for Climate. This resource will federate advanced computer, data, software, and networking resources, democratizing access to a cyberinfrastructure ecosystem that is increasingly necessary to further climate-related science and engineering.