CLIMATE AND CLEAN ENERGY TECHNOLOGY

Description and Rationale

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

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

Goals of Investments

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

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

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

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

cultural, and individual acceptance of energy system transitions.

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

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

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

Potential Impact for Urgency and Readiness

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

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

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

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

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

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

Budget Justification

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

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

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

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

In summation, FY 2023 investments will support:

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

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

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

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

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

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

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