Emerging Frontiers in Research and Innovation (EFRI-2022/23)

1. Engineered Living Systems (ELiS) 2. Brain-Inspired Dynamics for Engineering Energy-Efficient Circuits and Artificial Intelligence (BRAID)

PROGRAM SOLICITATION
NSF 21-615

REPLACES DOCUMENT(S):
NSF 20-614

National Science Foundation

Directorate for Engineering

Directorate for Biological Sciences

Directorate for Computer and Information Science and Engineering

Directorate for Geosciences

Directorate for Mathematical and Physical Sciences

Directorate for Social, Behavioral and Economic Sciences

Air Force Office of Scientific Research

Department of Defense

National Aeronautics and Space Administration

Letter of Intent Due Date(s) ***(required)*** (due by 5 p.m. submitter's local time):

November 10, 2021

September 12, 2022

Preliminary Proposal Due Date(s) ***(required)*** (due by 5 p.m. submitter's local time):

December 16, 2021

October 13, 2022

Full Proposal Deadline(s) (due by 5 p.m. submitter's local time):

March 10, 2022

February 07, 2023

IMPORTANT INFORMATION AND REVISION NOTES

Proposals may optionally include requests for cloud computing resources through an external cloud access entity, https://CloudBank.org, supported by NSF's Enabling Access to Cloud Computing Resources for CISE Research and Education (Cloud Access) Program.

Access to hardware is available through NSF's National Nanotechnology Coordinated Infrastructure (NNCI) https://nnci.net/.

Any proposal submitted in response to this solicitation should be submitted in accordance with the revised *NSF Proposal & Award Policies & Procedures Guide*

(PAPPG) (NSF 22-1), which is effective for proposals submitted, or due, on or after October 4, 2021.

SUMMARY OF PROGRAM REQUIREMENTS

General Information

Program Title:

EMERGING FRONTIERS IN RESEARCH AND INNOVATION (EFRI): Engineered Living Systems (ELiS) and Brain-Inspired Dynamics for Engineering Energy-Efficient Circuits and Artificial Intelligence (BRAID)

Synopsis of Program:

The Emerging Frontiers in Research and Innovation (EFRI) program of the NSF Directorate for Engineering (ENG) serves a critical role in helping ENG focus on important emerging areas in a timely manner. This solicitation is a funding opportunity for interdisciplinary teams of researchers to embark on rapidly advancing frontiers of fundamental engineering research. For this solicitation, we will consider proposals that aim to investigate emerging frontiers in one of the following two research areas:

- **Engineered Living Systems (ELiS)**
- **Brain-Inspired Dynamics for Engineering Energy-Efficient Circuits and Artificial Intelligence (BRAID)**

This solicitation will be coordinated with the Directorate for Biological Sciences (BIO), the Directorate for Computer and Information Science and Engineering (CISE), the Directorate for Mathematical and Physical Sciences (MPS), the Directorate for Geosciences (GEO), and the Directorate for Social, Behavioral and Economic Sciences (SBE), along with Air Force Office of Scientific Research (AFOSR), Department of Defense - Defense Threat Reduction Agency (DTRA), and National Aeronautics and Space Administration (NASA).

EFRI seeks proposals with potentially transformative ideas that represent an opportunity for a significant shift in fundamental engineering knowledge with a strong potential for long term impact on national needs or a grand challenge. The proposals must also meet the detailed requirements delineated in this solicitation.

INFORMATIONAL WEBINAR: The Emerging Frontiers and Multidisciplinary Activities (EFMA) Office will host an informational webinar in October 2021 to discuss the EFRI program and answer questions about the FY 2022/23 solicitation. Details on how to join this webinar will be posted on the EFMA Website.

Cognizant Program Officer(s):

Please note that the following information is current at the time of publishing. See program website for any updates to the points of contact.

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- Sridhar Raghavachari, BIO/IOS, telephone: (703) 292-4845, email: sraghava@nsf.gov

Applicable Catalog of Federal Domestic Assistance (CFDA) Number(s):

- 12.800 --- Air Force Office of Scientific Research
- 43.001 --- National Aeronautics and Space Administration (Science)
- 47.041 --- Engineering
- 47.049 --- Mathematical and Physical Sciences
- 47.050 --- Geosciences
- 47.070 --- Computer and Information Science and Engineering

- 47.074 --- Biological Sciences
- 47.075 --- Social Behavioral and Economic Sciences

Award Information

Anticipated Type of Award:

Standard Grant or Continuing Grant

Estimated Number of Awards:

30

(15 each in FY22 and FY23; 4-year awards)

Anticipated Funding Amount:

$60,000,000

$30,000,000 per fiscal year; Pending the availability of funds

Eligibility Information

Who May Submit Proposals:

Proposals may only be submitted by the following:

- Institutions of Higher Education (IHEs) - Two- and four-year IHEs (including community colleges) accredited in, and having a campus located in the US, acting on behalf of their faculty members.Special Instructions for International Branch Campuses of US IHEs: If the proposal includes funding to be provided to an international branch campus of a US institution of higher education (including through use of subawards and consultant arrangements), the proposer must explain the benefit(s) to the project of performance at the international branch campus, and justify why the project activities cannot be performed at the US campus.
- Non-profit, non-academic organizations: Independent museums, observatories, research labs, professional societies and similar organizations in the U.S. associated with educational or research activities.

Who May Serve as PI:

For proposals submitted by Institutions of Higher Education, the lead Principal Investigator (PI) must be full-time, tenured or tenure-track faculty. For proposals submitted by Non-Profit, Non-Academic Organizations, the lead PI must meet all of the following requirements: (1) the PI has a continuing appointment that is expected to last the four years of an EFRI grant; (2) the appointment has substantial research responsibilities; and (3) the proposed project relates to the PI's job responsibilities as well as to the mission of the department or organization.

A minimum of one PI and two co-PIs must participate in each proposal. Either the PI or one of the co-PIs must have a full-time, tenured or tenure-track faculty appointment within a College/Department of Engineering.

Limit on Number of Proposals per Organization:

There are no restrictions or limits.

Limit on Number of Proposals per PI or co-PI: 1

Individuals may participate as either PI or co-PI in only one proposal submitted to this solicitation in a single fiscal year. It is the responsibility of the submitting organization to ensure that the PI and all co-PIs are participating only in one proposal as either PI or co-PI and not in any others submitted in response to this solicitation in a single fiscal year.

If an individual is listed as PI or co-PI on more than one proposal in response to this solicitation in a single fiscal year, all proposals in excess of the limit for any person will be returned without review in the reverse order received, based on the proposal submission time stamp on the Cover Sheet.

Proposal Preparation and Submission Instructions

A. Proposal Preparation Instructions

- **Letters of Intent:** Submission of Letters of Intent is required. Please see the full text of this solicitation for further information.
- **Preliminary Proposals:** Submission of Preliminary Proposals is required. Please see the full text of this solicitation for further information.
- **Full Proposals:**
  - Full Proposals submitted via Research.gov: *NSF Proposal and Award Policies and Procedures Guide* (PAPPG) guidelines apply. The complete text of the PAPPG is available electronically on the NSF website at: https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg.
  - Full Proposals submitted via Grants.gov: *NSF Grants.gov Application Guide: A Guide for the Preparation and Submission of NSF Applications via Grants.gov* guidelines apply (Note: The *NSF Grants.gov Application Guide* is available on the Grants.gov website and on the NSF website at: https://www.nsf.gov/publications/pub_summ.jsp?ods_key=grantsgovguide).

B. Budgetary Information

- **Cost Sharing Requirements:**

  Inclusion of voluntary committed cost sharing is prohibited.

- **Indirect Cost (F&A) Limitations:**

  Not Applicable

- **Other Budgetary Limitations:**

  Not Applicable

C. Due Dates

- **Letter of Intent Due Date(s)** ***(required)*** (due by 5 p.m. submitter's local time):

  November 10, 2021

  September 12, 2022

- **Preliminary Proposal Due Date(s)** ***(required)*** (due by 5 p.m. submitter's local time):

  December 16, 2021

  October 13, 2022

- **Full Proposal Deadline(s)** (due by 5 p.m. submitter's local time):

  March 10, 2022

  February 07, 2023

Proposal Review Information Criteria

Merit Review Criteria:

National Science Board approved criteria. Additional merit review criteria apply. Please see the full text of this solicitation for further information.

Award Administration Information

Award Conditions:

Additional award conditions apply. Please see the full text of this solicitation for further information.

Reporting Requirements:

Additional reporting requirements apply. Please see the full text of this solicitation for further information.

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I. INTRODUCTION

The Office of Emerging Frontiers and Multidisciplinary Activities (EFMA) in the Directorate for Engineering provides funding opportunities for interdisciplinary teams of researchers to embark on rapidly advancing frontiers of fundamental engineering research. The Emerging Frontiers in Research and Innovation program (EFRI), the signature program of the EFMA Office, seeks proposals with potentially transformative ideas that represent an opportunity for a significant shift in fundamental engineering knowledge with strong potential for long-term impact on national needs or a grand challenge. For this solicitation, EFRI will consider proposals that aim to investigate emerging frontiers in one of the following two specific research areas: 1) Engineered Living Systems (ELiS) and 2) Brain-inspired Dynamics for Engineering Energy-Efficient Circuits and Artificial Intelligence (BRAID). Proposals must meet the detailed requirements delineated in this solicitation.

1. **Engineered Living Systems (ELiS)**

The EFRI topic Engineered Living Systems (ELiS) supports foundational and potentially transformative research to advance the design, modeling, fabrication, and manufacturing of engineered living systems to address societal needs as well as the associated ethical, legal, and social implications of using living systems as building blocks and components for next-generation sustainable engineering. The Engineered Living Systems topic has a focus on three emerging application areas: 1) a sustainable built environment, 2) a safe built environment, and 3) the sustainable recovery and supply of critical minerals, metals and elements. ELiS research projects have the potential to revolutionize sustainable engineering through the integration of living cells, organisms, plants and nanobiohybrids into systems capable of performing tasks that are not accessible to existing engineered systems, such as self-replication, self-regulation, self-healing and environmental responsiveness. Realizing the vision and goals of ELiS will require a convergence research approach that engages engineers and scientists with complementary expertise to tackle challenging problems relevant to sustainable engineering with a focus on three national/societal needs: Thread 1) a sustainable built environment, Thread 2) monitoring and surveillance for a safe built environment, and Thread 3) biomining for sustainable metal extraction and resource recovery. Engaging social scientists in the interdisciplinary teams will be critical to addressing the associated ethical, legal, and social implications of using living systems as building blocks and components for next-generation sustainable engineering. ELiS projects are also envisioned as ideal platforms for innovative educational and workforce development programs, such as curriculum development and outreach activities to broaden participation of underrepresented groups in STEM.

2. **Brain-inspired Dynamics for Engineering Energy-Efficient Circuits and Artificial Intelligence (BRAID)**

The EFRI topic Brain-Inspired Dynamics for Engineering Energy-Efficient Circuits and Artificial Intelligence (BRAID) supports interdisciplinary research to create a new engineering science of brain-inspired engineered learning systems. Neuroscience research is in a period of explosive growth, producing new understanding of biological learning processes and their efficiency that remains largely untapped by engineers, computer scientists, and society. This revolution in our understanding of the brain has revealed, for example, the critical interplay of temporal dynamics across time scales from milliseconds to lifetimes, and neural structures across spatial scales from nanometers to entire brains. BRAID seeks to exploit these emerging advances for the design of engineered learning systems that would emulate the flexibility, robustness, and efficiency of biological intelligence, exemplified respectively by the continual and causal learning needed for adaptive autonomy, the abstraction and generalization needed to learn from few examples and to identify relevant strategies from previously learned concepts and contexts, and the energy efficiency needed to extend the benefits of learning and autonomy throughout the built environment, while considering the energy costs of information processing.

The working hypothesis of BRAID is that the characteristic capabilities of biological learning far exceed mainstream machine learning hardware and algorithms and can inspire innovations to meet the urgent needs of mission-critical engineering applications. BRAID projects will transform innovative findings from neuroscience into new frameworks that distill and apply biological learning principles to the design of engineered learning systems, in particular, new classes of algorithms, circuits, networks, and devices. BRAID also seeks insights into the co-design of theory, algorithms, and devices that arise from the integration of principles for information storage, processing, and learning from neurons, neural circuits, neural ensembles, and neuroanatomical structures observed in biological organisms.

BRAID invites proposals from diverse teams of engineering-led researchers that may include participants from multiple engineering disciplines, computer and information sciences, the life sciences, the social and behavioral sciences, and the mathematical and physical sciences. The inclusion of theoretical neuroscience expertise on each team is mandatory. Together, interdisciplinary BRAID teams will enable the broad yet ethical deployment of novel engineered learning systems with new classes of energy-efficient learning capabilities. The anticipated capabilities arising from this program will include features of intelligence associated with humans and other complex living systems not available in current artificial intelligence and/or machine learning approaches.

ENHANCING DIVERSITY IN ENGINEERING - THE BROADENING PARTICIPATION PLAN

The Directorate for Engineering (ENG) promotes diversity in all aspects of its programs. In keeping with ENG's priority to broaden the participation of underrepresented groups in Engineering (see detailed definition below), the Office of Emerging Frontiers and Multidisciplinary Activities is addressing the need to enhance diversity in all fields of Engineering by **requiring all EFRI projects to include a "Broadening Participation Plan"** as part of the EFRI 2022/23 Solicitation. One goal is to increase the participation of members of underrepresented groups in the field of engineering and in engineering research, such as women, persons with disabilities, and underrepresented minorities in science, technology, engineering, and mathematics (STEM). This requirement will not only promote diversity in the human resources engaged in these EFRI projects but will also expand diversity of thought, ideas, and approaches brought together by EFRI in defining and solving important research questions.

The Broadening Participation Plan must be described as part of Broader Impacts of the proposal both in the Project Summary and in the Project Description. Proposers should include a preliminary version of the Broadening Participation Plan in their preliminary proposal and a detailed version in their full proposal (if invited to submit). The Plan may include, but is not limited to, any of the following menu of activities as appropriate for your project and the circumstances of your organization(s):

- PI, Co-PI, or other SENIOR PERSONNEL - Inclusion of persons from underrepresented groups as PI, co-PI, and/or other senior personnel, as appropriate for the project;
- STUDENTS AND POST-DOCTORAL RESEARCHERS - Inclusion of persons from underrepresented groups as undergraduate student(s), graduate student(s), and post-doctoral researcher(s);
- RESEARCH EXPERIENCES FOR UNDERGRADUATES (REU) - A plan to apply for supplement(s) to engage undergraduate researchers, using REU supplement(s);
- RESEARCH EXPERIENCE AND MENTORING (EFRI-REM) - A plan to apply for post-award supplement(s) to enhance research goals through diversification of the EFRI research teams;
- MINORITY-SERVING INSTITUTIONS - Inclusion of faculty at minority-serving institutions (MSIs) as PI, co_PI, or senior personnel, and/or student

researchers from MSIs in the research project;
- COMMUNITY COLLEGES - Engaging faculty and/or student researchers at community colleges in the research project;
- RESEARCH EXPERIENCES FOR TEACHERS (RET) - A plan to apply for post-award supplement(s) to engage teachers and/or Community College Faculty through the RET program;
- RESEARCH EXPERIENCES FOR HIGH SCHOOL STUDENTS - Provide research opportunities for members of underrepresented groups at the high school level;
- RESEARCH EXPERIENCES FOR VETERANS - A plan to apply for post-award supplement(s) to engage veterans through the Research Experience and Mentoring (REM) or Veterans Research Supplement (VRS) programs;
- EXISTING INSTITUTIONAL PROGRAMS - Enhance/collaborate with existing diversity programs at your home organization and/or nearby organizations;
- MENTORING - Senior Personnel serve as role models and mentors for an underrepresented student population;
- TUTORING OPPORTUNITIES - Provide tutoring opportunities for underrepresented middle school, high school, and undergraduate students;
- K-12 OUTREACH - Outreach activities that will interest and attract underrepresented K-12 students to engineering undergraduate programs.

The EFMA Office encourages proposers to be creative in the planning of activities to attract and retain members of underrepresented groups to the fields of engineering and engineering research when developing their Broadening Participation Plans.

Ethical, Legal, and Social Implication (ELSI) - Developments in engineered living systems, brain-inspired engineered energy-efficient circuits, and brain-inspired artificial intelligence all have ethical, legal, and social implications. Proposals are required to integrate ethical considerations and implications of their research including: research integrity, diversity of the research team, and societal impacts. This could include consideration of issues such as: transparency, inclusivity, social responsibility, impartiality, reliability, security and privacy. Related issues are openness and fairness of societal access to new technologies, responsible development of safe, secure, and robust operations in expected or foreseeable social and/or engineering contexts. Investigators are encouraged to consider the ethical implications of both intended and possible unintended consequences of new technologies and how best to mitigate risk to society. It is strongly recommended that the research team includes appropriate expertise from the SBE sciences to address these issues. For additional resources on ethical research, refer to the following potential resources:

https://www.nsf.gov/bfa/dias/policy/rcr.jsp

https://onlineethics.org

https://braininitiative.nih.gov/brain-programs/neuroethics

II. PROGRAM DESCRIPTION

The required elements listed below for each topic (Research Threads, Programmatic Considerations) are expected to be addressed in both preliminary proposals and full proposals.

1. **Engineered Living Systems (ELiS)**

The convergence of engineering, biology and materials science is providing unprecedented opportunities to integrate unicellular and multicellular organisms, such as natural/engineered cells, multicellular modules, microbial consortia, nanobiohybrids, plants, and protists, into next generation engineered systems capable of performing tasks associated with living systems such as self-replication, self-regulation, self-healing, and environmental responsiveness. The purpose of ELiS is to support foundational, transformative, and convergence research with the goal of creating living systems for sustainable engineering. ELiS aims to revolutionize sustainable engineering by seeding and catalyzing research that leverages the utilization of natural and/or engineered organisms as building blocks and components for next-generation sustainable processes, products, and technologies. ELiS will lay the foundation and provide a path for the introduction of a broad range of new processes, products and technologies that will advance the US bioeconomy while addressing critical national and societal needs, including a sustainable built environment, integrated networks of living sensors to monitor the presence and movement of pollutants and pathogens in built environments, and the sustainable supply of critical minerals, metals, and elements. ELiS will also contribute to the development of the basic science and engineering knowledge needed to advance the respective missions of our Federal Partner Agencies including 1) NASA's goals for sustainable space exploration and 2) DTRA's goals for the development and deployment of enabling capabilities to understand the built environment, threats, and vulnerabilities.

Research Threads

Each proposal submitted in response to this topic of the EFRI solicitation must address one of the three research threads and each of the foundational research components listed below including a) design and/or modeling, b) fabrication and/or manufacturing, and c) ethical, legal, and social implications.

Foundational Research

The foundational research component will be structured around three core research activities: 1) design and/or modeling, 2) fabrication and/or manufacturing, and 3) ethical, legal, and social implications.

Design and/or Modeling

Design and/or modeling approaches and tools of relevance to this solicitation may include but are not limited to, 1) mechanistic mathematical models, computational biology, bioinformatics, artificial intelligence (AI), and machine learning (ML) to support the design-build-test-learn cycles that are often required to develop components and building blocks for the living systems of relevance to this solicitation, including novel engineered cells, microbial consortia, and plants, 2) multiscale computational chemistry and computational materials modeling to guide the design, selection, processing, fabrication and/or manufacturing of the material scaffolds (organic, inorganic, and polymeric) and building blocks of engineered living systems, and 3) multi-scale and multi-physics process modeling to guide the fabrication, manufacturing and deployment of living systems to advance the goals of this EFRI topic.

Fabrication and Manufacturing

Since plants are immobile and anchored to their environments, they require little or no fabrication and/or manufacturing to serve as autonomous engineered living systems. Conversely, fabrication and/or manufacturing will be required to integrate multicellular modules, microorganisms (e.g., bacteria

and fungi), and microbial consortia into robust and viable engineered living systems. Methods and processes for the fabrication and manufacturing of the components and building blocks of the living systems of relevance to ELiS may include but are not limited to 1) seeding and inoculation of abiotic media (e.g., foundational soils and geomaterials) with microorganisms followed by processing to produce living building materials, 2) seeding and inoculation of geomaterials (e.g., ores, minerals, and lunar/Martian regolith simulants) and solid wastes (e.g., e-wastes) followed by processing to enable biomining and resource recovery, 3) seeding of a suspension of precursors (organic, inorganic, and/or polymeric) with microorganisms followed by processing to produce living porous and nonporous composites, 4) electrospinning of suspensions of microorganisms and polymers to produce living fibers, and 5) 3D printing of bioinks, including suspensions of microorganisms, onto substrates (e.g., organic, inorganic and/or polymeric) to produce biofilms and living surfaces. For the fabrication and manufacturing of artificial microbial niches, including 1D, 2D and 3D habitats for engineered microbiomes, various methods and processes may be utilized, including, but not limited to, droplet microfluidics, microfluidics, soft lithography, sol-gel chemistry, fiber drawing/spinning, inkjet printing, spin-coating, 3D printing, gel casting, templating, and self-assembly to enable the confinement, spatiotemporal control, manipulation, and exploitation of microorganisms and microbial consortia of relevance to the goals of this solicitation. For microbial-based living systems, proposals with natural/engineered organisms that maintain their viability when exposed to harsh environmental conditions including but not limited to heat, pH extremes, UV inactivation, and desiccation are highly encouraged.

Ethical, Legal and Social Implications (ELSI)

ELiS projects will be required to address the ethical, legal, and social implications of using living systems as building blocks and components for next-generation sustainable processes, products, and technologies. ELiS teams are expected to identify ethical, social, economic, health, legal, safety, and environmental considerations that are relevant to proposed projects. Submitted proposals must discuss how challenges resulting from these considerations will be addressed, within the context and scope of the project description. Collaboration with ethicists, social scientists, and economists is strongly encouraged, as appropriate.

Research Thread 1: Sustainable Built Environment

The built environment encompasses all structures that are built by humans to provide people with living, working, and recreational spaces. It includes residential/commercial buildings, streets, roads/pavements, communal spaces such as parks, and the infrastructure that supports our modern daily life such as transportation and utilities (electricity, water, and wastewater), and telecommunications. The construction and maintenance of the built environment requires large amounts of materials and energy. In the United States, billions of tons of materials (concrete, steel, and wallboard) will be required to construct, maintain, and operate the Nation's built environment in the foreseeable future. Residential and commercial buildings account for about 40% of CO_2 emissions and 39% of the total energy consumption in the United States. The decarbonizations of cement and steel production are predicted to proceed more slowly than improvements in energy efficiency, increasing the construction industry's share of global CO_2 emissions, which currently accounts for 10% of global greenhouse gas (GHG) emissions. Importantly, climate change will also adversely impact the resilience and viability of buildings and critical infrastructure in coastal communities as sea-level rise accelerates erosion and flooding in coastal areas.

The objective of this thread is to support and catalyze high-risk and high-reward research that will leverage the unique properties of living materials and systems to advance a sustainable built environment. NASA is interested in supporting high-risk and high-reward research to advance the development of durable low-mass surface habitats on the Moon and Mars using living systems and lunar/Martian regolith as building blocks and components. DTRA's interests are primarily directed toward projects that address the development of living surfaces to capture, sequester, and deactivate airborne/waterborne pollutants and pathogens. Potential and relevant projects for this thread include but are not limited to, 1) residential/commercial buildings with living walls/roofs that capture and store CO_2, 2) buildings/structures with living foundations that can grow under loadings to strengthen their soil supports, 3) living modules that can be applied to existing infrastructure that will continuously repair damage, prolonging useful life, 4) buildings with living walls and living surfaces/pavements that can capture, immobilize and/or deactivate airborne/waterborne pollutants and pathogens, and 5) engineered reef-like structures that can serve as building blocks and components for next generation living shorelines to attenuate wave action, erosion, and flooding to protect coastal areas from sea-level rise due to climate change. Proposals which integrate living building materials/systems that can perform multiple functions (e.g., CO_2 capture with building/infrastructure repair or the simultaneous capture and deactivation of airborne and waterborne pollutants/pathogens) are highly encouraged.

Research Thread 2: Monitoring and Surveillance for a Safe Built Environment

In today's modern world, residential homes/buildings, offices/schools, and commercial, entertainment, and recreational facilities are equipped with a broad range of sensors that monitor various physical parameters including temperature, humidity, CO_2 concentration, occupancy, light, and air flow. Monitoring these parameters provides valuable data needed to maximize building occupant comfort and minimize energy consumption. However, existing building sensor networks are not designed for the continuous monitoring and early detection of hazardous indoor air pollutants such as carbon monoxide and volatile organic compounds (e.g., formaldehyde). The recent COVID-19 pandemic suggests that the continuous monitoring of aerosolized airborne pathogens (e.g., viruses and bacteria) in residential/commercial buildings and facilities may be critical in the early detection and mitigation of future pandemics. Of note, wastewater surveillance (including wastewater-based epidemiology) has emerged as a versatile and complementary platform to existing clinical tools for monitoring and tracking the spread and transmission of pathogens. In addition to pathogens, wastewater surveillance can also provide information that reflects chemical exposure in the built environment and within communities. Since living organisms (e.g., bacteria and fungi) continuously monitor their environments with detection abilities that exceed the capabilities of existing sensor systems, they have great potential as building blocks and components for next generation environmental monitoring and surveillance systems.

The objectives of this thread include the creation of 1) integrated and multimodal sensor systems based on engineered sentinel cells/organisms and microbial consortia to monitor the presence and movement of indoor air pollutants and airborne pathogens in residential/commercial buildings and facilities, 2) multimodal and scalable biosensor devices and systems based on engineered sentinel cells and closely integrated with data analytics to enable distributed wastewater surveillance in residential/commercial buildings and facilities, and 3) plant-based biosensor systems that continuously monitor the presence of pathogens and hazardous compounds in the open spaces of the built environment including outdoor gardens, streets/pavements, and urban green spaces such as parks and playgrounds. Emerging designs in biosensors, based on the integration of living materials/systems with nanomaterials and nanotechnology for enhancement of sensitivity and accuracy, miniaturization and multiplexing are highly encouraged. Proposals which integrate multiple transduction mechanisms, such as bioluminescence for the detection of specific target pollutants and/or pathogens on a continuous basis are also encouraged. DTRA's interests are largely captured in the description provided above, although the list of analytes may be expanded to include precursors, process chemicals, and impurities indicative of processes designed to produce chemical, biological, and nuclear weapons. Wastewater surveillance that allows identification of the source of these materials is of particular interest to DTRA. In all cases, proposals that advance the design of microbial-based and plant-based living systems for autonomous monitoring/surveillance of the built environment while addressing the critical issues of system durability, stability, longevity along with a limited need for human intervention to power or service the resultant monitoring/surveillance systems are highly encouraged.

Research Thread 3: Biomining for Sustainable Metal Extraction and Resource Recovery

Critical minerals, metals and elements are the building blocks and pillars of a sustainable society and global economy. There is growing awareness that the development and large-scale implementation of the clean and renewable energy technologies needed to address global climate change will require sizeable amounts of critical minerals, metals, and elements. In addition to rare earth elements (REEs) and platinum group metals (PGMs), significant amounts of copper, silver, cobalt and nickel will also be needed to build (i) solar cells, (ii) wind turbines, (iii) electric vehicles, and (iv) energy-efficient lighting devices. The U.S. Department of Interior (DOI) has recently published a list of 35 metals of critical importance to the Nation's security and economic prosperity including REEs, PGMs and metals such as lithium, nickel, cobalt, and vanadium. Most of the critical metals listed by DOI are produced through the mining, extraction, and processing of virgin ores. Because there is a significant lag time between the discovery of new virgin ores and the commissioning of new mines, current and future shortages of critical minerals, metals, and elements cannot be addressed simply by opening new mines and mineral/metal extraction and processing facilities. Moreover, mining has a heavy environmental footprint; it requires significant amounts of land, energy, and water and generates substantial waste. Thus, the U.S. needs a multipronged strategy to ensure a robust and sustainable supply of critical minerals, metals, and elements. To support its goal of sustainable space exploration, NASA is also interested in new and innovative processes and technologies that leverage engineered living systems to catalyze and accelerate soil formation and nutrient release from lunar/Martian regolith using appropriate and relevant geomaterial simulants. Biomining has emerged as a promising technology for the sustainable extraction of critical minerals, metals, and elements from geomaterials and solid wastes including Earth's materials/wastes and lunar/Martian regolith simulants.

The objectives of this thread focus on microbial biomining as it provides the most promising and industrially scalable pathway for advancing next generation biomining for sustainable metal extraction and resource recovery. NSF, NASA and DTRA invite convergent research proposals to advance and accelerate two critical unit operations of biomining: 1) bioweathering and 2) biohydrometallurgy. For bioweathering, we invite innovative and convergent research proposals aimed at designing and engineering microbial consortia (i.e., microbiomes with functional diversity and distributed metabolism) that could accelerate natural biological weathering processes to break down geomaterials (rocks, ores, and minerals), solid wastes (e.g., electronic wastes including spent silicon chips), and lunar/Martian regolith simulants in order to facilitate the liberation and release of valuable minerals, metals, and elements without using energy-intensive comminution processes such as crushing, grinding, and milling. For biohydrometallurgy, we invite convergent research proposals aimed at designing and engineering microbiomes with functional diversity and distributed metabolism that can 1) selectively extract and concentrate critical/valuable ions that are released from processed ores, minerals, solid wastes, and lunar/Martian regolith simulants (i.e., crushed geomaterials from accelerated bioweathering and/or comminution); and 2) convert the released metal ions to metallic particles (e.g., oxides, zero valent and others) that could be recovered using low-energy separation technologies including but not limited to, particle separations based on size, density, electrical and magnetic properties. Biomining proposals which integrate accelerated bioweathering and biohydrometallurgy are highly encouraged.

EFRI-ELiS Programmatic Considerations

Interdisciplinary Research

EFRI-ELiS will provide an opportunity for convergent research conducted by interdisciplinary teams of engineers and scientists from diverse fields, including bioengineering, geotechnical engineering, chemical/environmental process engineering, hydrometallurgy, molecular separations, materials science, synthetic biology, systems biology, plant synthetic biology, microbiology, geomicrobiology, sensor networks, multiscale computational chemistry, multi-scale and multi-physics process modeling, computational biology, bioinformatics, and data science (AI and ML). Engaging social scientists in the interdisciplinary research team will be critical to addressing the associated ethical, legal, and social implications of designing, manufacturing, and deploying living systems to advance next-generation sustainable engineering.

Proposed projects must address one of the three research threads and all the foundational research components.

Responsible Innovation

The proposed research activities are expected to create socially responsible innovations for solving complex problems with positive societal and environmental impact. EFRI-ELiS projects are expected to yield economic benefits, addresses critical national/societal needs, and advance environmental sustainability. EFRI-ELiS teams are expected to identify ethical, social, economic, health, legal, safety, and environmental considerations that are relevant to proposed projects. Submitted proposals must discuss how challenges resulting from these considerations will be addressed, within the context and scope of the project description. Collaboration with ethicists, social scientists, and economists is encouraged, as appropriate.

2. **Brain-inspired Dynamics for Engineering Energy-Efficient Circuits and Artificial Intelligence (BRAID)**

Brain-inspired engineering efforts have focused on highly simplified concepts from neuroscience. In AI, artificial neural network (ANN) models assume point-like neurons, passive linear synapses without dendritic structures, and dense feedforward connectivity. ANNs are typically trained in sequenced epochs of discrete batches of data from extremely large datasets. This learning scheme has enabled the scale of the current state-of-the-art of machine learning, but at the cost of ignoring neurobiological details that may be central to the complex dynamics of learning in the brain. In contrast to ANNs, biological learning adapts the behavior of an organism over its lifetime based on sparse examples through experience. Biological learning depends on many features of neurons, such as spatial morphology, dendritic tree structure, and different types of ion channels, and the influence of chemical neuromodulators and non-neuronal tissue, such as glial cells and perineuronal nets. Temporal dynamics arising from complex interactions also influence how the brain integrates external inputs and internally-generated activity. These complex temporal dynamics include phenomena such as synchrony, oscillatory coupling, sequences, metastability, and chaotic or quasi-periodic signals that are thought to support the adaptive flexibility and energy- and data-efficient learning that is observed in the intelligent behavior of humans and other animals.

Given the obstacles to the transfer of knowledge across disciplines, it is understandable that these biological complexities, in particular, the brain's spatiotemporal dynamics and subcellular nonlinearities, have not yet been translated into the design of engineered learning systems. These and other features subserve neurocognitive functions, such as causal inference, deliberative decision-making in novel situations, continual learning, and lifelong memory, that would be of tremendous benefit to society if implemented in engineered learning systems. BRAID posits that engineered learning systems designed from principled theoretical frameworks of the brain's structural/dynamical complexity will be more controllable, interpretable, and auditable, while simultaneously enhancing resilience, autonomy, data and energy efficiencies, and the intuitiveness of human-machine interactions.

For the purposes of this program, intelligence is what enables animals to adapt their actions over time to survive, including the drives to explore, exploit, and interact. Intelligence can include seamlessly interacting processes of long-term memory, imagination, prediction, evaluation, planning, decision-making, introspection, reflection, and metacognition. All of these capabilities require a deeper capacity for continual learning than demonstrated by any previous AI models. While all aspects of intelligence are of interest, the focus of BRAID is on learning and memory, encompassing mechanisms by which a system learns in real time and uses its cumulative experience for creative and successful adaptation to the challenges of its environment.

BRAID proposals should strive to demonstrate how principles of biological intelligence can be translated to engineered learning systems in the context of situated relationships between **brain body**, and **environment** by drawing from models and knowledge of theoretical neuroscience. Close interaction is expected between theory and algorithm, between theory and hardware, or across all three research threads, as further described below.

Biological organisms demonstrate remarkably **energy-efficient** implementations of learning and memory. The human brain with over 100-1000 trillion synapses has a 12-20 W power budget, while its cortical layer alone operates at only 0.2W. In contrast, the equivalent number of components in a conventional von Neumann CMOS architecture would require 10 MW of power. Thus, the realization of equivalent energy efficiency by brain-inspired engineered learning systems is of particular interest to this program topic.

Although neuroscience provides a rich source of instructive examples for engineered learning systems, and collaborations with experimental neuroscientists under this topic are encouraged, PIs should only propose experimental neuroscience research which has explicit engineered learning system goals. Although it is a desired impact of the BRAID program that new insights into biological learning result from successful multidisciplinary collaborations, basic research in neuroscience is not a main goal of this topic. Any proposed experiments involving model organisms, *in vitro, in vivo, ex vivo,* or brain organoids or materials with similar properties, will be evaluated on the extent to which they advance the basic research understanding necessary for the development of engineered learning systems.

Research Threads

Each proposal submitted in response to this topic of the EFRI solicitation must address at least two out of the three threads. While responses to all three threads are encouraged, response to Thread 1 is mandatory.

Thread 1: Theoretical Neuroscience

The objective of this thread is to explore and integrate spatiotemporal mechanisms of biological learning based on experimental neuroscience, neurotechnologies, theories, and computational models of multi-scale interactions that explain complex observations in neural data: from the microscale (subcellular dendrites, synapses, axons, somata) to the mesoscale (interacting networks of neural circuits) and the macroscale (brain-wide circuits). These recent advances suggest that the complex dynamics of synapses, dendrites, and neurons give rise to the richness and flexibility of information flow over many spatial and temporal scales in the brain. These theories and models also reflect the variety of neuronal and non-neuronal cell types in the brain, and suggest that flexible arrangements among them lead to complex, adaptable, efficient, and robust circuits, networks, and architectures. Additionally, behavioral and cognitive studies have revealed how complex dynamics of behavior build on and emerge from dynamic synaptic, neuromodulatory, and circuit activity within and across neural architectures, enabling organisms to learn and adapt over many spatial and temporal scales of experience. Thus, incorporation of concepts and insights from modern neuroscience via the creation of new theories may lead to the development of a new generation of engineered energy-efficient circuits and engineered learning systems. Investigators should seek to distill neuroscience principles to inform the design of energy-efficient brain-informed hardware (Thread 2) and/or create new theories for translation to algorithms and learning rules for brain-inspired engineering applications for efficient continual, causal, and/or out-of-distribution learning (Thread 3).

Thread 2: Brain-informed Hardware Design

The objective of this thread is to create new classes of hardware that can support learning with the extreme energy and data efficiency characteristic of biological systems as elucidated in Thread 1. The goal of this thread is not to perform a one-to-one translation of dendrites, synapses, neurons, neural circuits, or neuroanatomy to an engineering setting, and neither is it to imitate the input/output functionality of the brain. Rather, the goal is to extract the principles by which biological learning occurs through dynamic processes arising in neuroanatomical structures, and then to create engineering analogs of those processes and structures. The incorporation of innovative sensor, circuitry and actuation technologies with new learning hardware is also within scope for this thread, as biological systems are distinguished by the integration of sensing, processing, and actuation functions. Similarly, the exploration of novel material systems and multifunctional devices is also in scope, although there must be convincing pathways to successful proof-of-concept demonstrations of learning. Co-design of novel learning circuits with innovative models of learning based on theoretical neuroscience is required. Discovery and fabrication of emerging multiscale, ultra-low power, dynamic, reconfigurable, and brain-inspired devices will form the foundation to theory, algorithm development and system level investigations. The use of software simulators in lieu of hardware fabrication is permissible.

Thread 3: Algorithmic Learning for Resilient Adaptive Technologies

The objective of this thread is to engineer learning algorithms based on theories and models of biological learning guided by ideas and findings as elucidated in Thread 1. The focus will be on engineered learning systems with innovative algorithms to achieve extreme data efficiency and adaptive resilience in dynamic environments, characteristic of biological organisms. These systems should demonstrate real-time sensing, learning, and data-driven decision making and prediction. The algorithms should respond to novel, uncertain, and rapidly changing conditions in real-time, and enable appropriate decisions based on small amounts of data over short time horizons. Algorithmic development should include uncertainty quantification for data of high sparsity, large size, mixed modalities, and diverse distributions, pushing the bounds on out-of-distribution generalization. Frameworks for bounding system response or for incorporating context-dependent constraints, along with desired outcomes, are sought. Responses to this thread must incorporate improvements to autonomy and resiliency in changing environments, which could lead to a new class of brain-inspired robotics and sensor systems with broad societal applications.

Metrics of Performance

All BRAID projects must formulate quantitative metrics to evaluate the new engineered learning systems with respect to alternative learning approaches. These metrics should be used over the course of the project to understand the advantages and disadvantages of the proposed brain-inspired approaches for different objectives, and under a variety of conditions. Engineered learning systems that achieve the extreme energy or data efficiency of biological learning are a high priority for the BRAID program. Careful consideration should be given to defining metrics that capture the energy cost of various learning strategies. However, energy metrics alone are insufficient. For all threads, proposals should develop appropriate notions of performance, formulate corresponding quantitative measures, and describe clear plans to validate the research results of the project against those measures. The dissemination plan should include explicit sharing of these performance metrics for the broader community.

Experimental Validation

All BRAID projects must involve experiments that demonstrate realistic continual, causal, or other forms of learning in data-sparse environments for each project's resilient adaptive learning algorithms and/or hardware platforms. Experimental validation should apply the metrics of performance developed for the project. The BRAID program recognizes that experimental research of this type may require resources beyond the capabilities of some institutions; in those cases, BRAID proposals may describe simpler proof-of-concept demonstrations, or validation using numerical or computational simulations. Experimental demonstrations are encouraged that exemplify the societal benefits of engineered learning systems, e.g., in the domain of autonomous systems, rehabilitation, manufacturing, and technologies that boost U.S. competitiveness.

EFRI-BRAID Programmatic Considerations

Interdisciplinary Research

Proposed research on this topic should involve strong collaborations between engineers and other disciplines. The inclusion of theoretical neuroscience expertise is mandatory and should be well aligned with the proposed project. Projects should define and address quantitative performance metrics and a rigorous experimental/analytical/simulation validation plan. Projects should include scientific or engineering analysis of ethical and societal implications as part of the research plan and broader impacts.

Proposed projects should convincingly show the potential to advance fundamental understanding in two or more disciplines and should relate these advances to a problem that meaningfully incorporates at least two out of the three research threads. Interactions with neuroscientists must be lasting throughout the period of performance culminating in a transdisciplinary demonstration by the end of the project.

BRAID investigators will be encouraged to work with other teams to demonstrate synergies across the portfolio of projects in creating fundamental breakthroughs in brain-inspired engineered learning systems.

Brain Inspiration

Proposals must clearly identify which principles of biological **learning** from neuroscience are the basis of their proposed engineered learning system, including algorithm and/or hardware design. Proposals should clearly articulate the innovative translation to engineered learning systems and describe plans for experimental and/or computational verification of these neuroscience principles. Reciprocity, in the sense of applying the new engineered learning systems to increase insight in experimental and/or theoretical neuroscience research, is not required but is encouraged.

Proposed projects must address at least two of the three threads. Thread 1 is mandatory.

Responsible Innovation

Proposals are required to integrate ethical considerations and implications of their research including research integrity, diversity of the research team, and societal impacts. This could include consideration of issues such as: transparency, inclusivity, social responsibility, impartiality, reliability, security and privacy. Related issues are openness and fairness of societal access to new technologies, and responsible development of safe, secure, and robust operations in expected or foreseeable social and/or engineering contexts. Investigators are encouraged to consider the ethical implications of both intended and possible unintended consequences of new technologies and how best to mitigate risk to society. It is strongly recommended that the research team includes appropriate expertise from the SBE sciences to address these issues.

Cloud Computing Resources

Proposals may request cloud computing resources to use public clouds such as Amazon Web Services (AWS), Google Cloud Platform (GCP), Microsoft Azure, and IBM Cloud. Cloud computing resources described in proposals may be obtained through CloudBank (CloudBank.org), an external cloud access entity supported by NSF's Enabling Access to Cloud Computing Resources for CISE Research and Education (Cloud Access) Program.

Proposers requesting cloud computing resources through CloudBank should describe the request in a Supplementary Document no longer than two pages with (a) anticipated annual and total costs for accessing the desired cloud computing resources, based on pricing currently available from the public cloud computing providers; and (b) a technical description of, and justification for, the requested cloud computing resources. The NSF Budget should not include these costs for accessing public cloud computing resources via CloudBank.org. Proposers should include "CloudAccess" (one word without space) at the end of the Overview section as a key word (before the section on Intellectual Merit) of the Project Summary page if incorporating such a request into the proposal. Proposers may contact CloudBank.org (see https://www.cloudbank.org/faq) for consultation on determining the budget estimate for using cloud computing resources.

Neural Datasets

Teams are encouraged to use available datasets such as those provided by the US BRAIN Initiative. Refer to the following potential resources:

http://brain-map.org/

http://crcns.org/

https://neuinfo.org/rin/suggested-data-repositories?p1=SCR_006770

https://nda.nih.gov/about/about-us.html

https://www.microns-explorer.org/cortical-mm3

https://www.nwb.org/

Hardware

Hardware cost sharing is permissible through NSF's National Nanotechnology Coordinated Infrastructure (https://www.nnci.net).

III. AWARD INFORMATION

The anticipated budget for this program solicitation is $30,000,000 in FY 2022 and $30,000,000 in FY23, pending the availability of funds. Each award will be funded as a Standard Grant or Continuing Grant. The anticipated number of awards for in each fiscal year is up to 15 awards. Each project team may receive support of up to a total of $2,000,000 spread over four years. It is not expected that all awards will receive the maximum amount; the size of awards will depend upon the type of research program proposed.

If a proposal involves multiple organizations, it must be submitted as a single proposal with subawards: separately submitted collaborative proposals are not permitted.

IV. ELIGIBILITY INFORMATION

Who May Submit Proposals:

Proposals may only be submitted by the following:

- Institutions of Higher Education (IHEs) - Two- and four-year IHEs (including community colleges) accredited in, and having a campus located in the US, acting on behalf of their faculty members.Special Instructions for International Branch Campuses of US IHEs: If th February 07, 2023e proposal includes funding to be provided to an international branch campus of a US institution of higher education (including through use of subawards and consultant arrangements), the proposer must explain the benefit(s) to the project of performance at the international branch campus, and justify why the project activities cannot be performed at the US campus.
- Non-profit, non-academic organizations: Independent museums, observatories, research labs, professional societies and similar organizations in the U.S. associated with educational or research activities.

Who May Serve as PI:

For proposals submitted by Institutions of Higher Education, the lead Principal Investigator (PI) must be full-time, tenured or tenure-track faculty. For proposals submitted by Non-Profit, Non-Academic Organizations, the lead PI must meet all of the following requirements: (1) the PI has a continuing appointment that is expected to last the four years of an EFRI grant; (2) the appointment has substantial research responsibilities; and (3) the proposed project relates to the PI's job responsibilities as well as to the mission of the department or organization.

A minimum of one PI and two co-PIs must participate in each proposal. Either the PI or one of the co-PIs must have a full-time, tenured or tenure-track faculty appointment within a College/Department of Engineering.

Limit on Number of Proposals per Organization:

There are no restrictions or limits.

Limit on Number of Proposals per PI or co-PI: 1

Individuals may participate as either PI or co-PI in only one proposal submitted to this solicitation in a single fiscal year. It is the responsibility of the submitting organization to ensure that the PI and all co-PIs are participating only in one proposal as either PI or co-PI and not in any others submitted in response to this solicitation in a single fiscal year.

If an individual is listed as PI or co-PI on more than one proposal in response to this solicitation in a single fiscal year, all proposals in excess of the limit for any person will be returned without review in the reverse order received, based on the proposal submission time stamp on the Cover Sheet.

Additional Eligibility Info:

As part of NSF's interest in broadening participation, we encourage proposals from Minority-Serving Institutions (e.g., Historically Black Colleges and Universities (HBCUs), Hispanic-Serving Institutions (HSIs), and Tribal Colleges and Universities (TCUs).

V. PROPOSAL PREPARATION AND SUBMISSION INSTRUCTIONS

A. Proposal Preparation Instructions

Letters of Intent *(required)*:

A one-page Letter of Intent is required. The letter should be submitted via FastLane no later than the date specified in this solicitation. The subject heading of the letter should include a brief title of the proposal and the name of the lead organization. Each letter must include the following:

1. THE TITLE - Title of the EFRI proposal, preceded by the words "**EFRI ELiS**:" or "**EFRI BRAID**:".
2. THE TEAM - Names, departmental and organizational affiliation, and expertise of the Principal Investigator and at least two co-Principal Investigators.
3. THE SYNOPSIS (GOALS) - Brief description of the specific goals of the proposal (maximum of 250 words).

These letters of intent are not used as pre-approval mechanisms for the submission of preliminary proposals and no feedback is provided to the submitters, *however letters of intent are required for all submitted preliminary proposals to this solicitation.* The letters of intent are not reviewed but are used to assess the overall response to the solicitation. They help NSF anticipate review requirements for preliminary proposals. For more information on letters of intent, please review the PAPPG.

Letter of Intent Preparation Instructions:

When submitting a Letter of Intent through FastLane in response to this Program Solicitation please note the conditions outlined below:

- Submission by an Authorized Organizational Representative (AOR) is required when submitting Letters of Intent.
- A Minimum of 2 and Maximum of 4 Other Senior Project Personnel are permitted
- A Minimum of 0 and Maximum of 4 Other Participating Organizations are permitted
- Submission of multiple Letters of Intent is not permitted

Preliminary Proposals *(required)*: Preliminary proposals are required and must be submitted via the NSF FastLane system, even if full proposals will be submitted via Grants.gov.

Preliminary proposals should provide a brief overview of the project focusing on its transformative aspect. They should include sufficient information to allow assessment of the main ideas and approaches and how proposed projects are appropriate for the EFRI program as opposed to other NSF programs. Review of the preliminary proposals will include particular emphasis on the potentially transformative nature and impact of the proposed idea.

Preliminary Proposal Preparation Instructions:

Preliminary proposals must be submitted via FastLane in accordance with the instructions below. Preliminary proposals that are not compliant with this solicitation will be returned without review. It is the submitting organization's responsibility to ensure that the proposal is compliant with all applicable requirements. If there are multiple organizations involved in a preliminary proposal, it must be submitted as a single proposal with subawards and not as separately submitted collaborative proposals. Preliminary proposals should not include separate subaward budgets, but should include planned levels for subawards on the budget justification page. Preliminary proposals must contain the items listed below and must strictly adhere to the specified page limitations. No additional information may be provided as an appendix or by links to web pages. Figures and tables must be included within the applicable page limit. All elements of the proposal, including legends and tables, must meet all formatting requirements for font size and characters per inch as specified in the PAPPG.

Preliminary proposals must include the following items:

Cover Sheet: Select the EFRI program solicitation number from the pull-down list. Check the box indicated for preliminary proposal. Entries on the Cover Sheet are limited to the principal investigator and a maximum of four co-principal investigators. A minimum of two co-principal investigators must be identified. Additional project leaders or senior personnel should be listed on the project summary page and entered into FastLane as senior personnel.

Title of Proposed Project: The title for the proposed EFRI project must begin, as appropriate, with either "**EFRI ELiS Preliminary Proposal:"** or "**EFRI BRAID Preliminary Proposal:"**. The title must state clearly and succinctly the major emerging frontier in research and innovation that is the focus for the project.

Project Summary: The project summary may not exceed one page in length and must consist of three parts:

1. In the Overview section, include the title of the project, the name of the PI, the lead organization, and a list of co-PIs and senior personnel together with their organizations. Proposers requesting cloud resources through CloudBank.org should include “CloudAccess” (one word without a space) at the end of the Overview section (before the section on Intellectual Merit) of the Project Summary page if incorporating this request into the proposal;
2. Provide a succinct summary of the ***intellectual merit*** of the proposed project. This should include the transformative nature of the proposed research and the significant leap or paradigm shift in fundamental engineering knowledge it will provide; and
3. Describe the ***broader impacts*** of the proposed work, including the potential long-term impact on national needs or a grand challenge.

Proposals that do not separately address in the project summary both intellectual merit and broader impacts will be returned without review.

Project Description: The project description of the preliminary proposal is limited to five pages and should include the following three sections:

1. **Vision and Goals -** Describe the vision and specific goals of the proposed research in approximately one page;
2. **Approach and Methodology** - Describe the approach and methodology, including the ethical, legal, and social implications of the project, that will be used to achieve the vision and goals in approximately three pages; and
3. **Transformative Impact** - In approximately one page, describe the transformative aspects of the project, including how the synergy of experts from different disciplines will achieve a significant advancement of fundamental engineering knowledge and will have strong potential for long-term impact on a national need or grand challenge. Include a succinct statement of your preliminary Broadening Participation Plan.

References Cited: Indicate with an asterisk any cited publications that resulted from prior research funded by NSF for the PI or co-PI (s).

Biographical sketches: The standard NSF biographical sketch, according to the PAPPG, must be provided for the PI, co-PIs and other senior personnel listed on the project summary page.

Budget: The preliminary proposal must include a budget for each of the four years proposed. FastLane will automatically provide a cumulative budget. Preliminary proposals should not include separate subaward budgets. However, the budget justification should include planned levels for subawards to any partner organization. Enter the anticipated total level of subaward support on line G5, Subawards.

Current and Pending Support for the PI, co-PIs, and senior personnel must be included.

In the **Supplementary Documentation** section, include the following:

List of **key personnel involved** (maximum one page), with a succinct description of what each person uniquely brings to the project and how their expertise will be integrated to foster synergy.

A **PowerPoint Slide** summarizing the vision of the EFRI proposal. This slide will be used during review panel discussions.

In the **Single Copy Documents** section, include the following:

Collaborators and Other Affiliations Information: Proposers should follow the guidance specified in the PAPPG. Grants.gov Users: The COA information must be provided through use of the COA template and uploaded as a PDF attachment.

Preliminary proposals will be reviewed by panels of outside experts. Based on the reviews, a limited number of PIs will be invited to submit full proposals. By mid-February 2022 for fiscal year 2022 and end of December 2022 for fiscal year 2023, invited proposers should expect to receive an invitation from the EFRI program to submit a full proposal.

Full Proposal Preparation Instructions: Proposers may opt to submit proposals in response to this Program Solicitation via FastLane or Grants.gov.

- Full proposals submitted via FastLane: Proposals submitted in response to this program solicitation should be prepared and submitted in accordance with the general guidelines contained in the *NSF Proposal & Award Policies & Procedures Guide* (PAPPG). The complete text of the PAPPG is available electronically on the NSF website at: https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg. Paper copies of the PAPPG may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-8134 or by e-mail from nsfpubs@nsf.gov. Proposers are reminded to identify this program solicitation number in the program solicitation block on the NSF Cover Sheet For Proposal to the National Science Foundation. Compliance with this requirement is critical to determining the relevant proposal processing guidelines. Failure to submit this information may delay processing.
- Full proposals submitted via Grants.gov: Proposals submitted in response to this program solicitation via Grants.gov should be prepared and submitted

in accordance with the *NSF Grants.gov Application Guide: A Guide for the Preparation and Submission of NSF Applications via Grants.gov*. The complete text of the *NSF Grants.gov Application Guide* is available on the Grants.gov website and on the NSF website at: (https://www.nsf.gov/publications/pub_summ.jsp?ods_key=grantsgovguide). To obtain copies of the Application Guide and Application Forms Package, click on the Apply tab on the Grants.gov site, then click on the Apply Step 1: Download a Grant Application Package and Application Instructions link and enter the funding opportunity number, (the program solicitation number without the NSF prefix) and press the Download Package button. Paper copies of the Grants.gov Application Guide also may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-8134 or by e-mail from nsfpubs@nsf.gov.

See PAPPG Chapter II.C.2 for guidance on the required sections of a full research proposal submitted to NSF. Please note that the proposal preparation instructions provided in this program solicitation may deviate from the PAPPG instructions.

Based on the review of preliminary proposals, a limited number of PIs will be invited to submit a full proposal. If multiple organizations are involved in an invited full proposal, it must be submitted as a single full proposal with subawards, and not as separately submitted collaborative proposals.

The review of invited full proposals will include *ad hoc* and/or panel reviews. The following exceptions and additions to the *NSF Proposal & Award Policies & Procedures Guide* or NSF Grants.gov Application Guide apply to full proposals submitted to this Program:

Full proposals will be accepted only from PIs who have submitted preliminary proposals in the current review cycle and who were invited to submit a full proposal. Submission of full proposals by PIs whose preliminary proposals received a review recommendation of 'Not Invited' will be returned without review.

Cover Sheet: Select the EFRI program solicitation number from the pull-down list. Entries on the Cover Sheet are limited to the principal investigator and a maximum of four co-principal investigators. Additional project leaders or senior personnel should be listed on the project summary page and be included in the proposal as senior personnel. When preparing the Cover Sheet for full proposals, please list the related preliminary proposal number.

Title of Proposed Project: The title for the proposed EFRI project must begin with "**EFRI ELiS:"** or "**EFRI BRAID:"**. The title must state clearly and succinctly the major emerging frontier in research and innovation that is the focus for the project.

Project Summary (one-page limit): The Project Summary consists of an overview, a statement on the intellectual merit of the proposed activity, and a statement on the broader impacts of the proposed activity. Provide the following information:

1. In the Overview section provide the title of the project, the name of the PI, the lead organization, and a list of co-PIs and senior personnel together with their organizations. Proposers requesting cloud resources through CloudBank.org should include “CloudAccess” (one word without space) at the end of the Overview section (before the section on Intellectual Merit) of the Project Summary page if incorporating this request into the proposal;
2. A succinct summary of the **intellectual merit** of the proposed project. This should include the potentially transformative nature of the proposed research, and the significant leap or paradigm shift in fundamental engineering knowledge; and
3. The **broader impacts** of the proposed work, including the potential long-term impact on a national need, a grand challenge, or both. Include a summary of your Broadening Participation Plan.

Proposals that do not contain the Project Summary, including an overview and separate statements on intellectual merit and broader impacts will not be accepted or will be returned without review.

Project Description (maximum 15 pages) must include the following subsections:

1. **Intellectual Merit**: Describe the vision and goals of the proposed research, approaches and methodologies to attain the goals, the expected outcomes, and the ethical, legal, and social implications of the proposed research following the guidance provided in the PAPPG.
2. **Broader Impacts**: Please follow the guidance provided in the PAPPG to prepare the Broader Impacts section. The following solicitation-specific information should also be included:
    i. The Broader Impacts section should include a subsection labeled "**Key Anticipated Outcomes**" that describes how the proposed project will lead to a significant shift in fundamental engineering knowledge and will have strong long-term potential for significant impact on a national need or a grand challenge.
    ii. The Broader Impacts section should also describe ways in which education and outreach are integrated within the research program to effectively achieve societal impact. Concisely articulate unifying and integrative aspects of the proposed research as well as the innovative ideas of the research.
    iii. The Broader Impacts section must include a **Broadening Participation Plan**. The plan must aim to broaden participation of underrepresented groups in engineering research. For more information see: Enhancing Diversity in Engineering at the end of Introduction, Section I. If needed, you may include additional information, up to five pages, about your Broadening Participation Plan as a Supplementary Document.
3. **Results from Prior NSF Support**: Please follow the guidance provided in the PAPPG for reporting results from prior NSF support.

References Cited: Indicate with an asterisk any cited publications that resulted from prior research funded by NSF for the PI, or co-PIs.

Biographical Sketches for key personnel (PI, co-PIs, and each of the senior personnel listed on the Project Summary page). Use the standard PAPPG format.

Budget: Develop a realistic project budget that is consistent with the proposed activities. Provide detailed budget justifications separately for the lead organization's budget (up to five pages of budget justification), and for each subawardee budget (up to five pages of budget justification for each subaward). Proposed budgets must include funds for travel by at least one PI and at least one graduate student or researcher to attend an annual EFRI grantees' meeting.

Current and Pending Support information must be provided for the PI and each of the co-PIs and Senior Personnel listed in the Project Summary page.

Facilities, Equipment, and Other Resources: Provide a description of available facilities and priorities for their use, if applicable. For EFRI projects requiring additional equipment, justify the need for these resources in the context of the innovative work proposed.

In the **Supplementary Documentation** section, include the following:

1. Provide a **list of key personnel** involved (maximum three pages), with a description of what each person uniquely brings to the project and how their expertise will be integrated to foster synergy;
2. Provide a detailed **management plan** (maximum three pages) including means of communication, data tracking, management of personnel within the project group, management of intellectual property resulting from the project, and timeline of activities;
3. **Mechanisms for sharing the outcomes** of the research with the scientific community, e.g., publications, web sites, *etc.* (maximum two pages). The description should be specific and should describe what, how, and when the community would have access to the outcomes of the project. This is particularly important for projects that will produce tangible research tools and resources;

4. Proposals that include support for post-doctoral researchers must provide a **postdoctoral researcher mentoring plan**;
5. Proposals that include support for trainees such as undergraduate and graduate students must provide a **student mentoring plan** that describes the mentoring activities that will be provided for such individuals
6. **Broadening Participation Plan** - You may include additional information, up to five pages, about the Broadening Participation Plan in the Supplementary Documentation section;
7. Proposals must include a **Data Management Plan** (maximum two pages). The data management plan must include a description for the management, dissemination, and archiving of all digital products generated by the proposed work including data, software, and digital designs (e.g., models for 3D printers). Proposers who feel that the plan cannot fit within the limit of two pages may provide additional detail in an additional Supplementary Document; and
8. A **PowerPoint Slide** summarizing the vision of the EFRI proposal. This slide will be used during review panel discussions.
9. **Cloud Computing Resources** *(*If requesting cloud computing resources through CloudBank.org) include a description of your requests (not to exceed 2 pages) that includes: (1) title of the proposal; (2) the total cost of computing resources, with yearly breakdown; (3) which public cloud providers will be used; and (4) a technical description and justification of the request, along with how the cost was estimated.

The **Data Management Plan** should describe the management of digital assets and intellectual property rights, including plans for sharing data, code, digital designs, information, and materials resulting from the award. Data and other digital products should be identified, and the following described for each of them:

- The types of data, samples, physical collections, software, curriculum materials, and other materials to be produced in the course of the project;
- Metadata to be collected and disseminated with primary data;
- The standards to be used for data and metadata format and content;
- Policies for access and sharing including provisions for appropriate protection of privacy, confidentiality, security, intellectual property, or other rights or requirements;
- Policies and provisions for re-use, re-distribution, and the production of derivatives;
- Release considerations: Timetable, Constraints, Responsible person(s), Public repository used;
- License for use (emphasis on open source licenses such as MIT and GPL);
- All software and code must be in a versioned code repository (e.g., GitHub/BitBucket) and released immediately. Code must be well documented for others to reuse;
- Other digital products including (but not limited to) 3D models for printing, circuit boards designs, phenotyping data, image data, and machine learning models must be included in the data management plan;
- Letters of commitment (uploaded as supplementary document(s)) should be provided from databases or stock centers that agree to distribute project outcomes, including the actions planned and funds needed (if any) for the distribution; and
- In the case of a multi-organizational proposal, the lead organization is responsible for coordinating and managing the intellectual property resulting from the award.

PIs should consult with current data standardization procedures as described by public sites such as DataONE and follow the "The Fair Guiding Principles for Data Management and Stewardship" and those articulated in "Best Practices for Scientific Computing".

Please submit these documents even if the information is unchanged since submission of the preliminary proposal.

Pre-submission Check List:

- No principal investigator (PI) or co-principal investigator (co-PI) is listed as a principal investigator or co-principal investigator on any other EFRI proposal submitted to the EFRI solicitation in this fiscal year;
- The Lead PI or one of the project co-PIs *must* be full-time faculty within an engineering college or department;
- If the proposal has multiple organizations, it must not be submitted as a separately submitted collaborative proposal but as a single proposal with subawards;
- Proposal has a minimum number of 3 PI/co-PIs and a maximum of 5 PI/co-PIs;
- Total budget does not exceed $2,000,000 and is spread over 4 years;
- **Broadening Participation Plan:** All proposals must describe a plan (both in the Project Summary and the Project Description) that promotes the participation of underrepresented groups in engineering;
- **Post-doctoral Researcher Mentoring Plan:** Each proposal that requests funding to support post-doctoral researchers must include, as a supplementary document, a description of the mentoring activities that will be provided for such individuals;
- **Student Mentoring Plan:** Each proposal that requests funding to support undergraduate and/or graduate researchers must include, as a supplementary document, a description of the mentoring activities that will be provided for such individuals;
- **Data Management Plan:** All proposals must describe plans for data management and sharing of the products of research, or explain the absence of the need for such plans;
- A **list of key personnel involved** (maximum three pages), with a description of what each person uniquely brings to the project is provided in the Supplementary Documents section;
- **Collaborators and Other Affiliations (COA)** information is provided in the Single Copy Documents section using the NSF template; and
- A **PowerPoint Slide** summarizing the vision of the EFRI proposal. This slide will be used during review panel discussions.

This checklist is provided to aid in the preparation of the proposal. The burden to ensure that the proposal is complete and meets all solicitation requirements remains with the Principal Investigator.

B. Budgetary Information

Cost Sharing:

Inclusion of voluntary committed cost sharing is prohibited.

Budget Preparation Instructions:

The total budget of the project, including any cloud computing resource request from CloudBank.org, may not exceed the budget limits described in this solicitation. The total cost of the cloud computing resources requested from Cloudbank.org should not be included in the NSF budget, and should be specified only in the associated supplementary document described in Section V.A.

C. Due Dates

- **Letter of Intent Due Date(s)** ***(required)*** (due by 5 p.m. submitter's local time):

  November 10, 2021

  September 12, 2022

- **Preliminary Proposal Due Date(s)** ***(required)*** (due by 5 p.m. submitter's local time):

  December 16, 2021

  October 13, 2022

- **Full Proposal Deadline(s)** (due by 5 p.m. submitter's local time):

  March 10, 2022

  February 07, 2023

D. FastLane/Research.gov Requirements

For Proposals Submitted Via FastLane:

To prepare and submit a proposal via FastLane, see detailed technical instructions available at: https://www.fastlane.nsf.gov/a1/newstan.htm. For FastLane user support, call the NSF Help Desk at 1-800-673-6188 or e-mail fastlane@nsf.gov. The NSF Help Desk answers general technical questions related to the use of the FastLane and Research.gov systems. Specific questions related to this program solicitation should be referred to the NSF program staff contact(s) listed in Section VIII of this funding opportunity.

For Proposals Submitted Via Grants.gov:

Before using Grants.gov for the first time, each organization must register to create an institutional profile. Once registered, the applicant's organization can then apply for any federal grant on the Grants.gov website. Comprehensive information about using Grants.gov is available on the Grants.gov Applicant Resources webpage: https://www.grants.gov/web/grants/applicants.html. In addition, the NSF Grants.gov Application Guide (see link in Section V.A) provides instructions regarding the technical preparation of proposals via Grants.gov. For Grants.gov user support, contact the Grants.gov Contact Center at 1-800-518-4726 or by email: support@grants.gov. The Grants.gov Contact Center answers general technical questions related to the use of Grants.gov. Specific questions related to this program solicitation should be referred to the NSF program staff contact(s) listed in Section VIII of this solicitation.

Submitting the Proposal: Once all documents have been completed, the Authorized Organizational Representative (AOR) must submit the application to Grants.gov and verify the desired funding opportunity and agency to which the application is submitted. The AOR must then sign and submit the application to Grants.gov. The completed application will be transferred to the NSF FastLane system for further processing.

Proposers that submitted via FastLane may use Research.gov to verify the status of their submission to NSF. For proposers that submitted via Grants.gov, until an application has been received and validated by NSF, the Authorized Organizational Representative may check the status of an application on Grants.gov. After proposers have received an e-mail notification from NSF, Research.gov should be used to check the status of an application.

VI. NSF PROPOSAL PROCESSING AND REVIEW PROCEDURES

Proposals received by NSF are assigned to the appropriate NSF program for acknowledgement and, if they meet NSF requirements, for review. All proposals are carefully reviewed by a scientist, engineer, or educator serving as an NSF Program Officer, and usually by three to ten other persons outside NSF either as *ad hoc* reviewers, panelists, or both, who are experts in the particular fields represented by the proposal. These reviewers are selected by Program Officers charged with oversight of the review process. Proposers are invited to suggest names of persons they believe are especially well qualified to review the proposal and/or persons they would prefer not review the proposal. These suggestions may serve as one source in the reviewer selection process at the Program Officer's discretion. Submission of such names, however, is optional. Care is taken to ensure that reviewers have no conflicts of interest with the proposal. In addition, Program Officers may obtain comments from site visits before recommending final action on proposals. Senior NSF staff further review recommendations for awards. A flowchart that depicts the entire NSF proposal and award process (and associated timeline) is included in PAPPG Exhibit III-1.

A comprehensive description of the Foundation's merit review process is available on the NSF website at: https://www.nsf.gov/bfa/dias/policy/merit_review/.

Proposers should also be aware of core strategies that are essential to the fulfillment of NSF's mission, as articulated in *Building the Future: Investing in Discovery and Innovation - NSF Strategic Plan for Fiscal Years (FY) 2018 - 2022*. These strategies are integrated in the program planning and implementation process, of which proposal review is one part. NSF's mission is particularly well-implemented through the integration of research and education and broadening participation in NSF programs, projects, and activities.

One of the strategic objectives in support of NSF's mission is to foster integration of research and education through the programs, projects, and activities it supports at academic and research institutions. These institutions must recruit, train, and prepare a diverse STEM workforce to advance the frontiers of science and participate in the U.S. technology-based economy. NSF's contribution to the national innovation ecosystem is to provide cutting-edge research under the guidance of the Nation's most creative scientists and engineers. NSF also supports development of a strong science, technology, engineering, and mathematics (STEM) workforce by investing in building the knowledge that informs improvements in STEM teaching and learning.

NSF's mission calls for the broadening of opportunities and expanding participation of groups, institutions, and geographic regions that are underrepresented in STEM disciplines, which is essential to the health and vitality of science and engineering. NSF is committed to this principle of diversity and deems it central to

the programs, projects, and activities it considers and supports.

A. Merit Review Principles and Criteria

The National Science Foundation strives to invest in a robust and diverse portfolio of projects that creates new knowledge and enables breakthroughs in understanding across all areas of science and engineering research and education. To identify which projects to support, NSF relies on a merit review process that incorporates consideration of both the technical aspects of a proposed project and its potential to contribute more broadly to advancing NSF's mission "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense; and for other purposes." NSF makes every effort to conduct a fair, competitive, transparent merit review process for the selection of projects.

1. Merit Review Principles

These principles are to be given due diligence by PIs and organizations when preparing proposals and managing projects, by reviewers when reading and evaluating proposals, and by NSF program staff when determining whether or not to recommend proposals for funding and while overseeing awards. Given that NSF is the primary federal agency charged with nurturing and supporting excellence in basic research and education, the following three principles apply:

- All NSF projects should be of the highest quality and have the potential to advance, if not transform, the frontiers of knowledge.
- NSF projects, in the aggregate, should contribute more broadly to achieving societal goals. These "Broader Impacts" may be accomplished through the research itself, through activities that are directly related to specific research projects, or through activities that are supported by, but are complementary to, the project. The project activities may be based on previously established and/or innovative methods and approaches, but in either case must be well justified.
- Meaningful assessment and evaluation of NSF funded projects should be based on appropriate metrics, keeping in mind the likely correlation between the effect of broader impacts and the resources provided to implement projects. If the size of the activity is limited, evaluation of that activity in isolation is not likely to be meaningful. Thus, assessing the effectiveness of these activities may best be done at a higher, more aggregated, level than the individual project.

With respect to the third principle, even if assessment of Broader Impacts outcomes for particular projects is done at an aggregated level, PIs are expected to be accountable for carrying out the activities described in the funded project. Thus, individual projects should include clearly stated goals, specific descriptions of the activities that the PI intends to do, and a plan in place to document the outputs of those activities.

These three merit review principles provide the basis for the merit review criteria, as well as a context within which the users of the criteria can better understand their intent.

2. Merit Review Criteria

All NSF proposals are evaluated through use of the two National Science Board approved merit review criteria. In some instances, however, NSF will employ additional criteria as required to highlight the specific objectives of certain programs and activities.

The two merit review criteria are listed below. **Both** criteria are to be given **full consideration** during the review and decision-making processes; each criterion is necessary but neither, by itself, is sufficient. Therefore, proposers must fully address both criteria. (PAPPG Chapter II.C.2.d(i). contains additional information for use by proposers in development of the Project Description section of the proposal). Reviewers are strongly encouraged to review the criteria, including PAPPG Chapter II.C.2.d(i), prior to the review of a proposal.

When evaluating NSF proposals, reviewers will be asked to consider what the proposers want to do, why they want to do it, how they plan to do it, how they will know if they succeed, and what benefits could accrue if the project is successful. These issues apply both to the technical aspects of the proposal and the way in which the project may make broader contributions. To that end, reviewers will be asked to evaluate all proposals against two criteria:

- **Intellectual Merit:** The Intellectual Merit criterion encompasses the potential to advance knowledge; and
- **Broader Impacts:** The Broader Impacts criterion encompasses the potential to benefit society and contribute to the achievement of specific, desired societal outcomes.

The following elements should be considered in the review for both criteria:

1. What is the potential for the proposed activity to
    a. Advance knowledge and understanding within its own field or across different fields (Intellectual Merit); and
    b. Benefit society or advance desired societal outcomes (Broader Impacts)?
2. To what extent do the proposed activities suggest and explore creative, original, or potentially transformative concepts?
3. Is the plan for carrying out the proposed activities well-reasoned, well-organized, and based on a sound rationale? Does the plan incorporate a mechanism to assess success?
4. How well qualified is the individual, team, or organization to conduct the proposed activities?
5. Are there adequate resources available to the PI (either at the home organization or through collaborations) to carry out the proposed activities?

Broader impacts may be accomplished through the research itself, through the activities that are directly related to specific research projects, or through activities that are supported by, but are complementary to, the project. NSF values the advancement of scientific knowledge and activities that contribute to achievement of societally relevant outcomes. Such outcomes include, but are not limited to: full participation of women, persons with disabilities, and other underrepresented groups in science, technology, engineering, and mathematics (STEM); improved STEM education and educator development at any level; increased public scientific literacy and public engagement with science and technology; improved well-being of individuals in society; development of a diverse, globally competitive STEM workforce; increased partnerships between academia, industry, and others; improved national security; increased economic competitiveness of the United States; and enhanced infrastructure for research and education.

Proposers are reminded that reviewers will also be asked to review the Data Management Plan and the Postdoctoral Researcher Mentoring Plan, as appropriate.

Additional Solicitation Specific Review Criteria

In addition to the two NSF review criteria (intellectual merit and broader impacts), the following criteria will be used in the review of all EFRI proposals. For the preliminary proposals the review criteria will place greater emphasis on the potentially transformative nature and impact of the proposed idea.

- ***TRANSFORMATIVE*** **-** Does the proposed research represent an opportunity for a significant leap or paradigm shift in fundamental engineering knowledge?
- ***NATIONAL NEED/GRAND CHALLENGE*** - Is there potential for making significant progress on a current national need or grand challenge?
- Responsiveness to "**Programmatic Considerations**" for **EFRI-EliS and EFRI-BRAID** proposals as delineated in Section II. Program Description.
- **Broadening Participation Plan** - Does the plan actively promote, increase, and enhance the participation of underrepresented groups in the field of engineering and in engineering research?
- Effectiveness of the proposed **Management Plan**.
- **Ethical, Legal, and Social Implications (ELSI)** - Does the proposal address the ethical, legal, and social implications of the proposed research?
- **Student Mentoring Plan** - Does the proposal present a description of the mentoring activities that will be provided for supported undergraduate and graduate students?

B. Review and Selection Process

Proposals submitted in response to this program solicitation will be reviewed by

Ad hoc Review and/or Panel Review.

Inter-Agency Involvement: National Aeronautics and Space Administration (NASA), Department of Defense - Defense Threat Reduction Agency (DTRA), and the Air Force Office of Scientific Research (AFOSR) are collaborating agencies for the FY 2022/23 solicitation. Representatives from NASA, DTRA, and AFOSR will be permitted to view preliminary and full proposals, recommend reviewers, attend review panels as observers, and receive unattributed proposal reviews.

In developing recommendations for awards, review panels as well as NSF staff will consider: the relative merit of the EFRI proposals using the criteria listed above, the potential national impact of the proposed activity, the balance of awards among scientific fields, geographical distribution, and the combined ability of the proposals to meet the objectives of the EFRI Office. The EFRI Office will not normally award more than one proposal from any one lead institution in this competition.

Reviewers will be asked to evaluate proposals using two National Science Board approved merit review criteria and, if applicable, additional program specific criteria. A summary rating and accompanying narrative will generally be completed and submitted by each reviewer and/or panel. The Program Officer assigned to manage the proposal's review will consider the advice of reviewers and will formulate a recommendation.

After scientific, technical and programmatic review and consideration of appropriate factors, the NSF Program Officer recommends to the cognizant Division Director whether the proposal should be declined or recommended for award. NSF strives to be able to tell applicants whether their proposals have been declined or recommended for funding within six months. Large or particularly complex proposals or proposals from new awardees may require additional review and processing time. The time interval begins on the deadline or target date, or receipt date, whichever is later. The interval ends when the Division Director acts upon the Program Officer's recommendation.

After programmatic approval has been obtained, the proposals recommended for funding will be forwarded to the Division of Grants and Agreements for review of business, financial, and policy implications. After an administrative review has occurred, Grants and Agreements Officers perform the processing and issuance of a grant or other agreement. Proposers are cautioned that only a Grants and Agreements Officer may make commitments, obligations or awards on behalf of NSF or authorize the expenditure of funds. No commitment on the part of NSF should be inferred from technical or budgetary discussions with a NSF Program Officer. A Principal Investigator or organization that makes financial or personnel commitments in the absence of a grant or cooperative agreement signed by the NSF Grants and Agreements Officer does so at their own risk.

Once an award or declination decision has been made, Principal Investigators are provided feedback about their proposals. In all cases, reviews are treated as confidential documents. Verbatim copies of reviews, excluding the names of the reviewers or any reviewer-identifying information, are sent to the Principal Investigator/Project Director by the Program Officer. In addition, the proposer will receive an explanation of the decision to award or decline funding.

VII. AWARD ADMINISTRATION INFORMATION

A. Notification of the Award

Notification of the award is made to *the submitting organization* by a Grants Officer in the Division of Grants and Agreements. Organizations whose proposals are declined will be advised as promptly as possible by the cognizant NSF Program administering the program. Verbatim copies of reviews, not including the identity of the reviewer, will be provided automatically to the Principal Investigator. (See Section VI.B. for additional information on the review process.)

B. Award Conditions

An NSF award consists of: (1) the award notice, which includes any special provisions applicable to the award and any numbered amendments thereto; (2) the budget, which indicates the amounts, by categories of expense, on which NSF has based its support (or otherwise communicates any specific approvals or disapprovals of proposed expenditures); (3) the proposal referenced in the award notice; (4) the applicable award conditions, such as Grant General Conditions (GC-1)*; or Research Terms and Conditions* and (5) any announcement or other NSF issuance that may be incorporated by reference in the award notice. Cooperative agreements also are administered in accordance with NSF Cooperative Agreement Financial and Administrative Terms and Conditions (CA-FATC) and the applicable Programmatic Terms and Conditions. NSF awards are electronically signed by an NSF Grants and Agreements Officer and transmitted electronically to the organization via e-mail.

*These documents may be accessed electronically on NSF's Website at https://www.nsf.gov/awards/managing/award_conditions.jsp?org=NSF. Paper copies may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-8134 or by e-mail from nsfpubs@nsf.gov.

More comprehensive information on NSF Award Conditions and other important information on the administration of NSF awards is contained in the NSF *Proposal & Award Policies & Procedures Guide* (PAPPG) Chapter VII, available electronically on the NSF Website at

https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg.

Special Award Conditions:

Awardees must include in the proposal budget funds for travel by the PI and one graduate student or one researcher to attend an annual EFRI grantees' meeting. Awardees will be required to attend and present their research results and plans annually at an annual EFRI grantees' conference for the duration of their award.

C. Reporting Requirements

For all multi-year grants (including both standard and continuing grants), the Principal Investigator must submit an annual project report to the cognizant Program Officer no later than 90 days prior to the end of the current budget period. (Some programs or awards require submission of more frequent project reports). No later than 120 days following expiration of a grant, the PI also is required to submit a final project report, and a project outcomes report for the general public.

Failure to provide the required annual or final project reports, or the project outcomes report, will delay NSF review and processing of any future funding increments as well as any pending proposals for all identified PIs and co-PIs on a given award. PIs should examine the formats of the required reports in advance to assure availability of required data.

PIs are required to use NSF's electronic project-reporting system, available through Research.gov, for preparation and submission of annual and final project reports. Such reports provide information on accomplishments, project participants (individual and organizational), publications, and other specific products and impacts of the project. Submission of the report via Research.gov constitutes certification by the PI that the contents of the report are accurate and complete. The project outcomes report also must be prepared and submitted using Research.gov. This report serves as a brief summary, prepared specifically for the public, of the nature and outcomes of the project. This report will be posted on the NSF website exactly as it is submitted by the PI.

More comprehensive information on NSF Reporting Requirements and other important information on the administration of NSF awards is contained in the *NSF Proposal & Award Policies & Procedures Guide* (PAPPG) Chapter VII, available electronically on the NSF Website at https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg.

Additional reporting requirement

EFRI awardees who receive supplemental funding through the Research Experience and Mentoring (REM) Program must discuss the impact of the supplemental funding on increasing the participation of underrepresented groups in engineering in their annual and final project reports. Accumulated quantitative data on race, gender and disability are expected. Additional data obtained through the required evaluation should also be provided, including the impact of mentoring on research participants (RPs), and/or changes in the RPs' skill sets, understanding of science/engineering principles, attitudes towards research, and career trajectories as a result of their participation in the program. If awardees have received sequential REM supplements, longitudinal data should be provided.

Each partner organization will receive copies of annual and final reports submitted by awardees for any awards co-funded by that organization after approval by the cognizant NSF program officer.

VIII. AGENCY CONTACTS

Please note that the program contact information is current at the time of publishing. See program website for any updates to the points of contact.

General inquiries regarding this program should be made to:

- EFRI2022@nsf.gov - General questions about the EFRI program
- ELiS@nsf.gov - Question specific to the EFRI-ELis topic
- BRAID@nsf.gov - Questions specific to the EFRI-BRAID topic

- Sohi Rastegar, Office Head, ENG/EFMA, telephone: (703) 292-8305, email: srastega@nsf.gov
- Alias Smith, telephone: (703) 292-8367, email: alismith@nsf.gov
- TOPIC 1, Engineered Living Systems (ELiS) - Mamadou Diallo, telephone: (703)292-4257, email: mdiallo@nsf.gov
- Steven W. Peretti, ENG/CBET, telephone: (703)292-7029, email: speretti@nsf.gov
- David Rockcliffe, BIO/MCB, telephone: (703) 292-7123, email: drockcli@nsf.gov
- Elizabeth K. Mann, MPS/DMR, telephone: (703) 292-4821, email: elmann@nsf.gov
- Khershed P. Cooper, ENG/CMMI, telephone: (703) 292-7017, email: khcooper@nsf.gov
- Usha Varshney, ENG/ECCS, telephone: (703) 292-5385, email: uvarshne@nsf.gov
- TOPIC 2, Brain-Inspired Dynamics for Engineering Energy-Efficient Circuits and Artificial Intelligence (BRAID) - Grace Hwang, telephone: (703)292-4271, email: ghwang@nsf.gov
- Jordan M. Berg, ENG/CMMI, telephone: (703) 292-5365, email: jberg@nsf.gov
- Kenneth C. Whang, CISE/IIS, telephone: (703) 292-5149, email: kwhang@nsf.gov

Edda Thiels, BIO/IOS, telephone: (703) 292-8421, email: ethiels@nsf.gov

- Rosa Lukaszew, ENG/ECCS, telephone: (703) 292-8103, email: rlukasze@nsf.gov
- Sridhar Raghavachari, BIO/IOS, telephone: (703) 292-4845, email: sraghava@nsf.gov

For questions related to the use of FastLane or Research.gov, contact:

- FastLane and Research.gov Help Desk: 1-800-673-6188
- FastLane Help Desk e-mail: fastlane@nsf.gov.
- Research.gov Help Desk e-mail: rgov@nsf.gov

For questions relating to Grants.gov contact:

- Grants.gov Contact Center: If the Authorized Organizational Representatives (AOR) has not received a confirmation message from Grants.gov within 48 hours of submission of application, please contact via telephone: 1-800-518-4726; e-mail:support@grants.gov.

The following Program Officers may also be contaEcted for content-specific questions on the EFRI 2022/23 topics.

TOPIC 1: Engineered Living Systems (ELiS),

- Topic Coordinator: Mamadou Diallo, Program Director, ENG/CBET, email: mdiallo@nsf.gov
- Enriqueta Barrera, Program Director, GEO/EAR, telephone: (703) 292-7780, email: ebarrera@nsf.gov
- Wenda Bauchspies, Program Director, SBE/SES, telephone: (703) 292-5034, email: wbauchsp@nsf.gov
- Giovanna Biscontin, Program Director, ENG/CMMI, telephone: (703) 292-2339, email: gibiscon@nsf.gov
- Khershed Cooper, Program Director, ENG/CMMI, telephone: (703) 292-7017, email: khcooper@nsf.gov
- Steven Peretti, Program Director, ENG/CBET, telephone: (703) 292-7029, email: speretti@nsf.gov
- Bianca Garner, Program Director, BIO/MCB, telephone: (703) 292-8440, email: bgarner@nsf.gov
- Ruyan Guo, Program Director, ENG/ECCS, telephone: (703) 292-7718, email: rguo@nsf.gov
- Bruce Hamilton, Program Director, ENG/CBET, telephone: (703) 292-7066, email: bhamilto@nsf.gov
- Elizabeth Mann, Program Director, MPS/DMR, telephone: 703-292-4821, email: elmann@nsf.gov
- William Olbricht, Program Director, ENG/CBET, telephone: (703) 292-4842, email: wolbrich@nsf.gov
- David Rockcliffe, Program Director, BIO/MCB, telephone: (703) 292-7123, email: drockcli@nsf.gov
- Gerald Schoenknecht, Program Director, BIO/IOS, telephone: (703) 292-5076, email: gschoenk@nsf.gov
- Brandi Schottel, Program Director, ENG/CBET, telephone: (703) 292-4798, email: bschotte@nsf.gov
- Aleksandr Simonian, Program Director, ENG/CBET, telephone: (703) 292-2191, email: asimonia@nsf.gov
- Usha Varshney, Program Director, ENG/ECCS, telephone: (703) 292-5385, email:uvarshne@nsf.gov
- Lisa Carnell, Program Scientist, NASA Biological and Physical Sciences Division, email: lisa.a.scottcarnell@nasa.gov
- Heather Meeks, Department Director, Defense Threat reduction Agency, email: heather.n.meeks4.civ@mail.mil

TOPIC 2: Brain-Inspired Dynamics for Engineering Energy-Efficient Circuits and Artificial Intelligence (BRAID),

- Topic Coordinator: Grace Hwang, ENG/CBET, telephone: (703) 292-4271, email: ghwang@nsf.gov
- Jordan Berg, Program Director, ENG/CMMI, telephone: (703) 292-5365, email: jberg@nsf.gov
- Rosa Lukaszew, Program Director, ENG/ECCS, telephone: (703) 292-8103, email: rlukasze@nsf.gov
- Sridhar Raghavachari, Program Director, BIO/IOS, telephone: (703) 292-4845, email: sraghava@nsf.gov
- Kenneth Whang, Program Director, CISE/IIS, telephone: (703) 292-5146, email: kwhang@nsf.gov
- Edda Thiels, Program Director, BIO/IOS, telephone: (703) 292-8167, email: ethiels@nsf.gov
- Raymond Adomaitis, Program Director, ENG/CBET, telephone: (703) 292-7519, email: radomait@nsf.gov
- Aleksandr Simonian, Program Director, ENG/CBET, telephone: (703) 292-2191, email: asimonia@nsf.gov
- Jonathon Fritz, Program Director, SBE/BCS, telephone: (703) 292-7923, email: jfritz@nsf.gov
- Paul Lane, Program Director, MPS/DMR, telephone: (703) 292-2453, email: plane@nsf.gov
- Soo-Siang Lim, Program Director, SBE/BCS, telephone: (703) 292-7878, email: slim@nsf.gov
- Junping Wang, Program Director, MPS/DMS, telephone: (703) 292-4488, email: jwang@nsf.gov
- Andrew Wells, Program Director, ENG/CMMI, telephone: (703) 292-7225, email: awells@nsf.gov
- Donald Wunsch, Program Director, ENG/ECCS, telephone: (703) 292-7102, email: dwunsch@nsf.gov
- Ying Sun, Program Director, ENG/CBET, telephone: (703) 292-7443, email: yisun@nsf.gov
- Stephen Zehnder, Associate Program Director, ENG/CBET, telephone: (703) 292-7014, email: szehnder@nsf.gov
- Steven Peretti, Program Director, ENG/CBET, telephone: (703) 292-7029, email: speretti@nsf.gov
- Zhilan Feng, Program Director, MPS/DMS, telephone: (703) 292-7523, email: zfeng@nsf.gov
- Hal Greenwald, Group Leader, AFOSR, email: hal.greenwald@us.af.mil

IX. OTHER INFORMATION

The NSF website provides the most comprehensive source of information on NSF Directorates (including contact information), programs and funding opportunities. Use of this website by potential proposers is strongly encouraged. In addition, "NSF Update" is an information-delivery system designed to keep potential proposers and other interested parties apprised of new NSF funding opportunities and publications, important changes in proposal and award policies and procedures, and upcoming NSF Grants Conferences. Subscribers are informed through e-mail or the user's Web browser each time new publications are issued that match their identified interests. "NSF Update" also is available on NSF's website.

Grants.gov provides an additional electronic capability to search for Federal government-wide grant opportunities. NSF funding opportunities may be accessed via this mechanism. Further information on Grants.gov may be obtained at https://www.grants.gov.

ABOUT THE NATIONAL SCIENCE FOUNDATION

The National Science Foundation (NSF) is an independent Federal agency created by the National Science Foundation Act of 1950, as amended (42 USC 1861-75). The Act states the purpose of the NSF is "to promote the progress of science; [and] to advance the national health, prosperity, and welfare by supporting research and education in all fields of science and engineering."

NSF funds research and education in most fields of science and engineering. It does this through grants and cooperative agreements to more than 2,000 colleges, universities, K-12 school systems, businesses, informal science organizations and other research organizations throughout the US. The Foundation accounts for about one-fourth of Federal support to academic institutions for basic research.

NSF receives approximately 55,000 proposals each year for research, education and training projects, of which approximately 11,000 are funded. In addition, the Foundation receives several thousand applications for graduate and postdoctoral fellowships. The agency operates no laboratories itself but does support National Research Centers, user facilities, certain oceanographic vessels and Arctic and Antarctic research stations. The Foundation also supports cooperative research between universities and industry, US participation in international scientific and engineering efforts, and educational activities at every academic level.

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Suzanne H. Plimpton
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