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Emerging Frontiers in Research and Innovation 2018 (EFRI-2018)

1. Chromatin and Epigenetic Engineering (CEE)

2. Continuum, Compliant, and Configurable Soft Robotics Engineering (C3 SoRo)

PROGRAM SOLICITATION
NSF 17-578

REPLACES DOCUMENT(S):
NSF 16-612

National Science Foundation

Directorate for Engineering
Emerging Frontiers and Multidisciplinary Activities

Directorate for Biological Sciences

Directorate for Computer & Information Science & Engineering

Air Force Office of Scientific Research

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

September 29, 2017

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

October 25, 2017

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

February 23, 2018

IMPORTANT INFORMATION AND REVISION NOTES

Any proposal submitted in response to this solicitation should be submitted in accordance with the revised *NSF Proposal & Award Policies & Procedures Guide* (PAPPG) (NSF 18-1), which is effective for proposals submitted, or due, on or after January 29, 2018.

SUMMARY OF PROGRAM REQUIREMENTS

General Information

Program Title:

EMERGING FRONTIERS IN RESEARCH AND INNOVATION (EFRI): Chromatin and Epigenetic Engineering (CEE) and Continuum, Compliant, and Configurable Soft Robotics Engineering (C3 SoRo)

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 the following two research areas:

Chromatin and Epigenetic Engineering (CEE)
- Continuum, Compliant, and Configurable Soft Robotics Engineering (C3 SoRo)

This solicitation will be coordinated with the Directorate for Biological Sciences (BIO) and the Directorate for Computer and Information Science and Engineering (CISE).

EFRI seeks proposals with 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 WEBCAST: The Emerging Frontiers and Multidisciplinary Activities (EFMA) Office will host an informational webinar on September 7th, 2017 at 1:00 PM EST to discuss the EFRI program and answer questions about the FY 2018 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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Applicable Catalog of Federal Domestic Assistance (CFDA) Number(s):

- 12.800 --- Air Force Office of Scientific Research
- 47.041 --- Engineering
- 47.070 --- Computer and Information Science and Engineering
- 47.074 --- Biological Sciences

Award Information

Anticipated Type of Award: Standard Grant

Estimated Number of Awards: 13

(4-year awards)

Anticipated Funding Amount: $26,000,000

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.

Who May Serve as PI:

The lead Principal Investigator (PI) must be full-time, tenured or tenure-track faculty as determined by the submitting organization. A minimum of one PI and two co-PIs must participate. At least one member of the project team (PI or co-PI) 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

The principal investigator and co-principal investigators may participate in only one proposal per year submitted to this solicitation. It is the responsibility of the submitting institution to ensure that the PI and all co-PIs are participating in only one proposal per year submitted to this solicitation.

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 FastLane: *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):

  September 29, 2017
- Preliminary Proposal Due Date(s) *(required)* (due by 5 p.m. submitter's local time):

  October 25, 2017
- Full Proposal Deadline(s) (due by 5 p.m. submitter's local time):

  February 23, 2018

Proposal Review Information Criteria

Merit Review Criteria:

National Science Board approved criteria. Additional merit review considerations 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:

Standard NSF reporting requirements apply.

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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) Chromatin and Epigenetic Engineering (CEE), and 2) Continuum, Compliant, and Configurable Soft Robotics Engineering (C3 SoRo). Proposals must meet the detailed requirements delineated in this solicitation.

(1) Chromatin and Epigenetic Engineering (CEE)

The EFRI topic Chromatin and Epigenetic Engineering represents an interdisciplinary research area that will result in development of new strategies for reversible regulation or engineering of the systems of gene expression to modulate the phenotype and function of a living organism. The engineering of biology at the molecular and cellular level represents a grand challenge, both for engineering and for biology, and holds the promise of potentially transformative impacts. This EFRI topic relates closely to one of NSF's 10 Big Ideas for long-term discovery and innovation, "Understanding the Rules of Life: Predicting Phenotype", and seeks not only to create new knowledge but further to apply this knowledge to achieve phenotypic re-engineering. Precise regulation of cells, not merely through genetic manipulation but also through engineering changes at the epigenomic level, may enable us to combat disease, engineer crop plant improvements, and design organisms that can remediate environmental problems or adapt to environmental change.

To realize the vision of engineering biology, we need to be able to engineer or control the expression of the systems of genes that confer these organismal traits, the phenotype. Gene transcription occurs in a highly complex, dense and dynamic nano-environment. Regulation of gene transcription is mediated via interaction of regulatory molecules with genetically encoded regulatory elements. Access of these transcription factors, as well as the basic transcriptional machinery, is controlled in part by epigenetic determinants. The epigenome imposes this layer of transcriptional regulation through covalent modifications of the macromolecules comprising chromatin (DNA and histones), resulting in altered packing of DNA around the structural histone proteins and hence altered chromatin conformation. Non-coding RNAs afford a further level of epigenetic control. The epigenome thus provides a critical control point for

genome function by modulating the three-dimensional organization of chromatin and chromosome dynamics within the nucleus. Decoding and designing strategies to regulate these epigenetic processes can best be achieved through a convergence of engineering approaches, molecular dynamics and molecular systems modeling, computational genomics, and nanoscale measurement and imaging. It is expected that transformative research in this area will include some of these elements.

(2) Continuum, Compliant, and Configurable Soft Robotics Engineering (C3 SoRo)

The EFRI topic Continuum, Compliant, and Configurable Soft Robotics Engineering (C3 SoRo) supports interdisciplinary research to create an engineering science of soft robotics. This research is expected to fill fundamental gaps in the understanding of soft robots characterized by continuum structures bearing loads with highly compliant materials or components. The soft robots studied will be capable of maintaining core functionality over a wide range of morphological configurations. Such robots promise substantial advantages over traditional rigid robots in accomplishing open-ended tasks in an unstructured environment and in physical interfaces with biological organisms, including humans. Robots with a mix of mobility, strength, and configurability matching or exceeding what is found in the natural world would allow unprecedented extension of human perception and action to inaccessible and hostile environments. Furthermore, wearable or implantable soft robots mechanically compatible with living soft tissue could mitigate disability or augment the natural abilities of the human body. To achieve these goals will require a re-engineering of power and information systems, the creation of new active soft material systems, the development of rigorous predictive models of deformation, and the formulation of new theories of movement and manipulation. While there have been numerous demonstrations of the exciting potential of soft robotics, a fundamental engineering framework is needed to fully realize the promise of these pioneering results. Such a framework would guide the emergence of a new field of soft robotics, driven by collaborations between researchers in engineering, computer science, biology, material science, chemistry, and mathematics.

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 (see detailed definition below) in Engineering, the Office of Emerging Frontiers in Research and Innovation 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 2018 Solicitation. One goal is to increase the participation of underrepresented groups in the field of engineering and in engineering research. 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 term "underrepresented groups" refers to and includes the following: women, persons with disabilities, and ethnic and racial groups which are in the minority in engineering including African Americans, Hispanics, Native Americans, Alaska Natives, and Pacific Islanders.

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. It may include, but is not limited to, any of the following menu of activities as appropriate for your project and the circumstances of your institution(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;
- STUDENT AND POST-DOCs - Inclusion of persons from underrepresented groups as graduate student, undergraduate student, and post-doctoral researchers;
- RESEARCH EXPERIENCES FOR UNDERGRADUATES (REU) - A plan to apply for post-award supplements to engage undergraduate researchers, using REU supplement;
- RESEARCH EXPERIENCE AND MENTORING (EFRI-REM) - A plan to apply for post-award supplements to enhance research goals through diversification of the EFRI research teams (see, URL for related information from previous year);
- MINORITY-SERVING INSTITUTIONS - Engaging faculty and/or student researchers at minority serving institutions 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 supplements 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;
- EXISTING INSTITUTIONAL PROGRAMS - Enhance/collaborate with existing diversity programs at your home institution and/or nearby institutions;
- MENTORING - Senior Personnel serve as role models and mentors for an underrepresented student population;
- TUTORING OPPORTUNITY - 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 EFRI Office encourages the 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.

II. PROGRAM DESCRIPTION

The "Required Elements" listed below for each topic are expected to be addressed in both the preliminary proposals as well as in the full proposals.

1) Chromatin and Epigenetic Engineering (CEE)

While DNA encodes genetic information in its linear sequence, providing a blueprint for protein assembly, gene expression is critically affected by the spatial organization of chromatin within the nucleus. Although determinants of higher level chromatin organization are

poorly understood, chromatin conformation can be influenced by covalent modifications of the constituent macromolecules (DNA and associated histones), as well as by chromatin dynamics, molecular crowding, and other physical and physicochemical interactions. This chromatin nano-environment may modulate the interaction of DNA with regulatory molecules, including transcription factors and non-coding RNAs, thus impacting global patterns of gene expression. The goal of this EFRI topic is to develop new engineering approaches to investigate and regulate the global systems of gene expression achieved through modulation of the epigenetic landscape.

Understanding the regulation of the chromatin nano-environment has the potential to power the engineering of living systems, to create new transformative strategies for the treatment of disease, to solve persistent environmental problems, as well as to uncover new plant traits for the benefit of agriculture. To understand and achieve these goals requires:

- development of novel nanoscopic technologies to manipulate, image and measure nanoscale chromatin structure, dynamics, and environment in live cells, enabling us to relate molecular modifications and interactions to chromatin structure and ultimately to phenotype;
- systems-level modeling to understand epigenetic control of phenotype, integrating molecular and physical data obtained in physiologically accurate physicochemical environments;
- application of these tools to engineer desired traits into a model system, such as a model of human disease, a crop plant, an energy-producing microorganism, or an environmentally sensitive organism, to provide a meaningful test of the models and technology.

Thrust Areas

Each proposal submitted in response to this topic of the EFRI solicitation must address at least two of the three thrusts outlined below:

Thrust 1: Nanoscale technologies for analysis of chromatin in living systems.

Although the genetic and histone codes can be substantially characterized through molecular assays, decoding the role of the supra-nucleosomal chromatin code and chromatin nano-environment requires the development and application of new nanoscale imaging, manipulation, or measurement methods. For example, advances in biophotonic technology may overcome the limitations in traditional super-resolution microscopy technologies such as PALM or STORM, and could open new opportunities for studying biological macromolecules. Imaging chromatin in living cells at single digit nanometer resolution under label-free conditions could revolutionize our understanding of chromatin structure, dynamics and function. Additionally, use of two or more complementary techniques simultaneously may be advantageous, with significantly improved signal-to-noise ratio, which may be achieved, for example, through enhanced light-matter interaction and new data-driven signal processing algorithms. Development of new nanodevices, such as DNA origami nanocalipers, may offer capabilities that surpass those of established tools, such as optical and magnetic tweezers and atomic force microscopy, for making direct measurements of conformational dynamics of chromatin under conditions that mimic the local perturbations caused by histone modification or protein binding. Application of these and other breakthrough technologies for imaging, measuring, and potentially manipulating chromatin would have a transformative impact, revealing new insights about how chromatin structure influences function in normal and disease states, and thereby potentially identifying new targets for chromatin-level engineering.

Thrust 2: Molecular systems modeling.

The wealth of currently available genome-scale data on chromatin modifications, three-dimensional organization, and transcriptional activity in multiple eukaryotic cell types, from yeast to humans and plants, constitutes an immense resource. Integration of these data with information derived from nanoscale imaging and measurement using systems-level mathematical modeling should reveal how chromatin features control gene expression. Importantly, every molecular event involved in gene expression can be modulated by physicochemical phenomena including molecular crowding, chromatin dynamics, and other nonspecific molecular interactions. To accurately model the biology of crowded chromatin nano-environments will therefore require incorporation of: molecular profiles of chromatin modifications and transcriptional output; physicochemical properties, including mechanical constraints on folding and diffusion rates or binding affinities of chromatin-associated proteins; and perturbing effects of intrinsic or extrinsic signals. Deploying multiscale modeling approaches, from molecular dynamics simulations to more coarse-grained methods such as cellular automata, in combination with theories from physics, should provide a means for integrating complex data and theory to shed new light on the relationship between chromatin structure and function. This information could provide the basis for formulating new hypotheses, in turn leading to new experiments to probe the chromatin-to-phenotype connection.

Thrust 3: Chromatin-level epigenetic engineering.

A transformative challenge is to develop engineering techniques to control cell function and organismal phenotype via control of the epigenome and chromatin structure. Many lines of evidence point to the role of the chromatin nano-environment in regulating global patterns of gene expression and thus key cellular or organismal functions. A number of pervasive human diseases, including cancer, atherosclerosis, and neurodegenerative diseases, have been traced to dysregulation at the level of chromatin. In plants, adaptation to environmental stresses, such as drought or extreme temperature changes, can be mediated by chromatin-level changes in gene expression. Chromatin-level engineering offers potential utility for solving fundamental questions in chromatin biology, as well as for advancing solutions to real-world problems. Synthetic biology approaches can be used to engineer specific epigenomic changes as a way of probing cause-and-effect relationships between chromatin structure/dynamics and gene expression. Chromatin-level engineering might be employed in cancer cells to reprogram and thereby normalize the global pattern of gene expression in cancer cells, or in plants to introduce beneficial traits, such as stress tolerance. Similar epigenetic engineering strategies might conceivably be harnessed to generate carbon dioxide-consuming, energy-producing species, or to modify organisms to better adapt to changing environments. Utilizing tools and theory from physical sciences to understand chromatin-based regulation of gene expression is expected to lead to new transformative applications in human health, bio-economy, and ecology.

EFRI-CEE Programmatic Considerations

Interdisciplinary Research: This field will benefit tremendously from research that draws on many disciplines, including engineering and biology. Proposals must include one investigator from an appropriate engineering discipline, and it is strongly encouraged that proposals also include a participant from a biological discipline. Projects should be designed to leverage interdisciplinary expertise bridging engineering, biological, and other specialties to build new knowledge at the intersection of the disciplines, but fully informed by

each. Each team must address at least two of the three thrust areas.

Ethical Considerations: Progress in the field of epigenetic engineering offers parallel opportunities for phenotypic editing to those provided by genome editing. Therefore, it is essential that PIs consider the ethical, environmental and regulatory implications of their proposed research, and discuss these issues as appropriate to their application. The recent report from the National Academies of Science and Medicine, *Human Genome Editing: Science, Ethics, and Governance*, provides recommendations with respect to human genome editing which could also usefully be applied to phenotypic modification achieved via epigenetic engineering.

2) Continuum, Compliant, and Configurable Soft Robotics Engineering (C3 SoRo)

While proficient at repetitive tasks in a structured environment, traditional rigid robots fall far short of biological organisms in versatility and adaptability. To create “soft robots” that can achieve the remarkable functionality seen in the animal kingdom, or that can be physically worn by or implanted in humans, will require a re-engineering of power and information systems, the creation of new materials, and the formulation of new theories of movement and manipulation. The goal of this EFRI topic is to create an engineering science of soft robotics.

This emerging technical area and the ensuing interdisciplinary activities should be coordinated by engineering-led teams including contributions from researchers in computer science, biology, material science, chemistry, and mathematics. Highly innovative proposals are sought that build upon established and emerging research in dynamics and control, mechanics of materials and structures, materials engineering, formal design theory, biomechanics and mechanobiology, biomedical engineering, cellular and biochemical engineering, ion transport and electrochemistry, electronics and photonics, circuits and devices. Projects should include relevant activities in each of the following three thrust areas, with clear innovation in at least one of the first two: 1) Dynamic Modeling, 2) Distributed Sensing, Actuation, and Computation, and 3) Validation & Testing.

Although biology provides a rich source of instructive examples for soft robotics, and collaboration with biologists under this topic is strongly encouraged, it should be stressed that fundamental discoveries in organismal biology or biomimicry are not the main goal, and thus such collaborations should maintain focus on leveraging prior results from biology that are relevant to the science and engineering of soft robotics.

Continuum, Compliant, and Configurable Robots

For the purposes of this solicitation the term "soft robot" is defined as continuum robots composed of compliant materials and structure, capable of functioning under large configuration changes. These characteristics are condensed as "continuum, compliant, and configurable," or "C3", robots. These terms may have different meanings in different contexts. The definitions below are intended to apply only for the purposes of this solicitation. Proposals focused on systems exhibiting all of these characteristics are strongly preferred.

Continuum robots have a high dimensional configuration space. The continuum requirement is intended to exclude rigid structures with a relatively small number of discrete joints, where compliance is introduced solely through serial elastic elements in the joints or through the addition of soft exteriors. The continuum requirement is *not* meant to exclude robots that approximate continuum behavior through the use of a large number of discrete degrees of freedom. Of greatest interest are robots that make substantial use of their configuration space for manipulation and locomotion, for example, by using structural shape changes to directly manipulate objects, rather than only to control the position and orientation of an end effector.

Compliant robots exhibit high structural compliance in response to environmental inputs. The structural compliance requirement is intended to exclude, for example, continuum robots with shape determined only by control inputs independent of external load. In contrast, a structurally compliant robot will substantially change its shape in response to external forces. Because of the response to external loads, a structurally compliant robot that is subject to environmental forces or that acts against a significant load will access a larger configuration space than would result only from the application of allowable input values. Enhanced functionality through structural compliance is a defining feature of soft robotics. Structures with controllable compliance or otherwise variable compliance are of particular interest. It is also desirable to consider soft-skinned robots with compliant exterior surfaces. In such robots, contact - including contact with other parts of the robot itself - will occur over a distributed, deformed region. Intrinsically compliant robots, made entirely of compliant materials, will naturally exhibit both structural compliance and compliant contact mechanics.

Configurable robots retain a useful degree of functionality over a wide range of structural configurations. Structural reconfiguration may result actively, from a controlled action of the robot itself, or it may occur passively, as a result of external influences. For example, a configurable robot that is traveling through a narrow aperture may use internal actuation to actively change shape, or it may passively change shape due to the constraint forces. Maintaining functionality may be achieved through changing the control mode. Thus, for example, a configurable robot might use flexible appendages in a walking gait on an open planar surface, but switch to peristaltic motion when traveling through a small-diameter pipe. The objective is to explore soft solutions that accommodate reconfiguration.

Research Thrusts

The objective of this topic is to advance a foundational science of soft robotics engineering for unstructured manipulation and/or locomotion using highly compliant structures in an uncertain and variable environment. Interdisciplinary projects are sought to pursue breakthroughs in the following three thrust areas:

1. Dynamic Modeling of C3 Robots
2. Distributed Sensing, Actuation, and Computation
3. Validation & Testing

Thrust 1: Dynamic Modeling of C3 Robots

The first research thrust focuses on abstract and theoretical representations of C3 robots. The goal is to formulate and validate a family of computable mathematical representations of dynamic, intrinsically compliant materials and structures - including those with extended regions of self-contact and/or contact with external rigid or compliant structures, and those with variable compliance - suitable for uses from high-fidelity simulation to parametric design to real-time motion planning and control. Formal theories of design, building on these representations, are also of potential interest.

The modeling, analysis, and control of a traditional rigid robot builds naturally upon the finite configuration space defined by the joint

motions. By contrast, natural organisms often have a much larger configuration space -- for example, continuous appendages such as tentacles may be reasonably modeled as having infinitely many degrees of freedom. Such flexibility provides natural organisms with the ability to respond in new ways to unexpected demands, but from an engineering perspective it is computationally prohibitive to explore all the available options, especially while responding to an evolving situation in real time. New perspectives on motion control and path planning are called for to take full advantage of high dimensional configuration spaces. Similarly, effective use of compliant appendages, and appendages with variable compliance, for locomotion and manipulation involves complex forces arising at interfaces. These may be interfaces between the appendage and rigid objects, between the appendage and flexible objects, and even between the appendage and itself. Means of modeling, estimating, and controlling these interface forces, while accounting for complex, nonlinear material behaviors under potentially large deformations as well as rotations and contact conditions, would be a major advance towards realizing the potential of soft robots. Here, the flexibility of the configurational space or morphology requires that any modeling effort goes beyond the proof of validation on simplified test specimens and/or idealized loading conditions.

Thrust 2: Distributed Sensing, Actuation, and Computation

The second research thrust focuses on advancing critical aspects for implementation of C3 robots. The objective is to create and realize devices and architectures implementing the models generated in Thrust 1. These devices should be compatible with open-loop and feedback control of complex, highly compliant and controllably compliant structures, including methods of distributed computation, sensing, and actuation, and including means for storing and distributing power and information, and assembly and integration. Bio-inspired approaches are of interest, as are hybrid approaches combining synthetic materials and living tissue.

Abstract theories of soft robot configuration representation, task planning, and motion control are of limited value without the means to sense and actuate highly articulated soft structures, and without the attendant ability to store, process, and transmit information and power. Many different solutions have been proposed for each of these functions, but none has yet emerged as a practical platform for functional devices. Areas of interest include sensors, actuators, circuits, interconnects, and packaging, and information processing systems capable of functioning while embedded in a highly compliant structure. The deployment of novel materials with relevant new capabilities, including controllable interface properties, or integrated distributed sensing, actuation, and/or processing, is of interest, but these elements should be explored in the context of architectures capable of achieving local state awareness and distributed control, rather than focusing on the development of isolated materials and components. Associated with development of these novel multifunctional materials, constitutive theories are also needed to explore their potential and suitability in a rigorous manner. Complex materials models can encumber open-loop or feedback control under dynamic environments with crippling inefficiency. Reduced-order, surrogate, or data-driven material or structural models are encouraged; however, verification and validation are essential.

Thrust 3: Validation & Testing

The goal of the third research thrust is to fabricate and demonstrate physical platforms for experimental validation, rigorous proofs of concept, and comprehensive evaluation of robots in a variety of tasks and situations. Though many approaches have been proposed for specific component designs, very little progress has been made towards integrating the various functional elements into practical systems. To encourage breadth, relevance, and robustness in the results of this research, this topic requires demonstration of elements from topics 1 and 2, integrated in a robust testbed and capable of achieving an illustrative goal under non-ideal conditions. Such systems should achieve the topic goal of maintaining functionality under substantial morphological variation. Proposed hardware efforts should reflect feasible pathways to integrated soft robotics solutions with system level functionality, rather than embodying a targeted implementation of a specific concept with limited options for further growth.

EFRI-C3 SoRo Programmatic Considerations

Interdisciplinary Research: Proposed research on this topic should involve strong collaborations between engineers and researchers from other disciplines, such as computer scientists, biologists, material scientists, chemists, and mathematicians. Projects should also involve collaborations among engineering disciplines such as, for example, dynamics and control, mechanics of materials and structures, materials engineering, formal design theory, biomechanics and mechanobiology, biomedical engineering, cellular and biochemical engineering, electrochemistry, and electronics and photonics.

Proposed projects should convincingly show the potential to advance fundamental understanding in two or more of these engineering disciplines, and should relate these advances to a problem that meaningfully incorporates all three of the research thrusts - that is, with foundational advances in modeling and control, supported by convincing plans for experimental validation and testing.

Responsible Innovation: Careful consideration should be given to the knowledge, outcomes and potential technologies generated by the proposed research. It is important that PIs and their project teams are mindful of the ethical, social, economic, legal and environmental implications surrounding innovations in soft robotics. It is expected that the proposed scientific and technical activities will be used to create socially responsible innovations for solving complex problems. Submitted proposals should integrate these considerations, where applicable, within the context and scope of the research.

III. AWARD INFORMATION

The anticipated budget for this program solicitation is $26,000,000 in FY 2018; each award will be funded as a ‘Standard Grant'. The anticipated number of awards for this solicitation is up to 13 awards. Each project team may receive support of up to a total of $2,000,000 spread over four years, pending the availability of funds. 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.

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 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.

Who May Serve as PI:

The lead Principal Investigator (PI) must be full-time, tenured or tenure-track faculty as determined by the submitting organization. A minimum of one PI and two co-PIs must participate. At least one member of the project team (PI or co-PI) 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

The principal investigator and co-principal investigators may participate in only one proposal per year submitted to this solicitation. It is the responsibility of the submitting institution to ensure that the PI and all co-PIs are participating in only one proposal per year submitted to this solicitation.

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 institution. Each letter must include the following:

1. THE TITLE- Title of the EFRI proposal, preceded by the words “EFRI CEE:” or “EFRI C3 SoRo:”.
2. THE TEAM- Names, departmental and university 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 NSF Proposal & Award Policies & Procedures Guide (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 not 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 3

  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.

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 existing programs. Review of the preliminary proposals will include particular emphasis on the 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 universities involved in a preliminary proposal, it must be submitted as a single proposal with subawards and not as separately submitted collaborative proposals. 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 NSF Proposal & Award Policies & Procedures Guide (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 participate. 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 CEE Preliminary Proposal:" or "EFRI C3 SoRo 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 institution, and a list of co-PIs and senior personnel together with their institutions;
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 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 two-page biographical sketches must be provided for the PI, co-PIs and other senior personnel listed on the project summary page.

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

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 any subawards. However, the budget justification should include planned levels for subawards to any partner institution. Enter the anticipated total level of subaward support on line G5, Subawards.

In the Supplementary Documentation section, include the following:

1. 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.

In the Single Copy Documents section, include the following:

1. Collaborators and Other Affiliations: *Please note* that NSF is initiating a new pilot on the submission of Collaborators and Other Affiliations (COA) information. Effective April 24th 2017, NSF will require the use of a specific spreadsheet template for identifying COA information. More information on this and a link to the required NSF COA spreadsheet template can be found at the following site - https://nsf.gov/bfa/dias/policy/coa.jsp. Please note that failure to submit a Collaborators and Other Affiliations Single Copy Document for each PI, co-PI and other senior project personnel may result in a proposal being returned without review.

In addition, the proposers must send the following document via email immediately after submission of their proposal. After receipt of the proposal number from FastLane, send an email to: efri2018@nsf.gov. The subject heading of the email should note the proposal number and the lead institution. Attach the following document

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

Remember to email this PowerPoint slide to: efri2018@nsf.gov; do not use FastLane.

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 the end of December 2017, invited PIs 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 Grants.gov or via the NSF FastLane system.

- 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) 292-7827 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) 292-7827 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 universities 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 both *ad hoc* and panel reviews. The following exceptions and additions to the NSF Proposal & Award Policies & Procedures Guide (PAPPG) 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. 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 entered into FastLane 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 CEE:" or "EFRI C3 SoRo:". 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 institution or organization, and a list of co-PIs and senior personnel together with their institutions and organization or both;
2. 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; and
3. The broader impacts of the proposed work, including the potential long-term impact on national needs and 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 by FastLane or will be returned without review.

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

1. Results from Prior Research: Please follow the guidance provided in the NSF Proposal & Award Policies & Procedures Guide (PAPPG) for reporting results from prior NSF support. Please also describe the prior research of each PI or co-PI funded by NSF that is *directly* relevant to the proposed project.
2. Proposed Research: Describe the vision and goals of the proposed research, approaches and methodologies to attain the goals, and the expected outcomes.
3. The project description should end with a subsection labeled "Impact" that describes how the proposed project will lead to a significant shift in fundamental engineering knowledge and have strong long-term potential for significant impact on a national need or a grand challenge. The proposal 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. The Impact subsection 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 in the Supplementary Documentation section.

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 format.

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.

Budget: Develop a realistic project budget that is consistent with the proposed activities. Provide detailed budget justifications separately for the lead institution's budget (up to three pages of budget justification), and for each subawardee budget (up to three 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.

Facilities and Equipment: Provide a description of available facilities and priorities for its 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. Proposals must include a data management plan (maximum one page). The contents of the data management plan should include: (1) the types of data to be produced, (2) the standards that would be applied for data format and metadata content, and (3) access policies and provision;
4. Proposals that include support for post-doctoral researchers must provide a post-doc mentoring plan;
5. Mechanisms for sharing the outcomes of the research with the scientific community, *e.g.* publications, web sites, and significant data bases, *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; and
6. Broadening Participation Plan - You may include additional information, up to five pages, about the Broadening Participation Plan in the Supplementary Documentation section.

In the Single Copy Documents section, include the following:

1. Collaborators and Other Affiliations: *Please note* that NSF is initiating a new pilot on the submission of Collaborators and Other Affiliations (COA) information. Effective April 24th 2017, NSF will require the use of a specific spreadsheet template for identifying COA information. More information on this and a link to the required NSF COA spreadsheet template can be found at the following site - https://nsf.gov/bfa/dias/policy/coa.jsp. Please note that failure to submit a Collaborators and Other Affiliations Single Copy Document for each PI, co-PI and other senior personnel may result in a proposal being returned without review.

In addition, the proposers must send the following document via email immediately after submission of their proposal. After receipt of the proposal number from FastLane, send an email to: efri2018@nsf.gov. The subject heading of the email should note the proposal number, the PI and the lead institution. Attach the following document

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

Remember to email this slide to: efri2018@nsf.gov no later than 24hrs after the proposal submission deadline; do not use FastLane.

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.
- 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 is not 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: As a reminder, each proposal that requests funding to support postdoctoral 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) is provided in the Single Copy Documents section using the new NSF spreadsheet template
- Immediately after submission, an E-mail is sent to: efri2018@nsf.gov with a one-page project summary as a PowerPoint slide. The subject heading of the email should note the proposal number, the PI and the lead institution.

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

B. Budgetary Information

Cost Sharing:

Inclusion of voluntary committed cost sharing is prohibited.

C. Due Dates

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

  September 29, 2017

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

  October 25, 2017

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

  February 23, 2018

The deadline for Letters of Intent (LOIs) to the EFRI FY2018 solicitation is September 29, 2017. An LOI is required in order to submit an EFRI FY2018 Preliminary Proposal. The deadline for Preliminary Proposal submission is October 25, 2017. The Full Proposal deadline is February 23, 2018.

D. FastLane / Grants.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 FastLane Help Desk at 1-800-673-6188 or e-mail fastlane@nsf.gov. The FastLane Help Desk answers general technical questions related to the use of the FastLane system. 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: http://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 are strongly encouraged to use FastLane 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 underrepresented minorities 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 have a higher weight on the 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-CEE and EFRI-C3 SoRo 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.

B. Review and Selection Process

Proposals submitted in response to this program solicitation will be reviewed by Ad hoc Review and/or Panel Review.

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 is striving to be able to tell applicants whether their proposals have been declined or recommended for funding within six months. The time interval begins on the date of receipt. The interval ends when the Division Director accepts the Program Officer's recommendation.

A summary rating and accompanying narrative will be completed and submitted by each reviewer. In all cases, reviews are treated as confidential documents. Verbatim copies of reviews, excluding the names of the reviewers, 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.

In developing its 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.

In all cases, 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 and 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.

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) 292-7827 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 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.

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:

- Sohi Rastegar, Director, ENG/EFMA, telephone: (703) 292-8305, email: srastega@nsf.gov
- Kerstin Mukerji, Program Manager, ENG/EFMA, telephone: (703) 292-5390, email: kmukerji@nsf.gov
- TOPIC 1, Chromatin and Epigenetic Engineering (CEE), telephone: (703) 292-7942, email: lesterow@nsf.gov
- Leon Esterowitz, Program Director, ENG/CBET, telephone: (703) 292-7942, email: lesterow@nsf.gov
- Louise R. Howe, Program Manager, ENG/EFMA, telephone: (703) 292-2548, email: lhowe@nsf.gov
- Shubhra Gangopadhyay, Program Director, ENG/ECCS, telephone: (703) 292-2485, email: sgangopa@nsf.gov
- Karen C. Cone, Program Director, BIO/MCB, telephone: (703) 292-4967, email: kccone@nsf.gov
- Anne W. Sylvester, Program Director, BIO/IOS, telephone: (703) 292-7168, email: asylvest@nsf.gov
- Mitra Basu, Program Director, CISE/CCF, telephone: (703) 292-8649, email: mbasu@nsf.gov
- TOPIC 2, Continuum, Compliant, and Configurable Soft Robotics Engineering (C3 SoRo), telephone: (703) 292-5365, email: jberg@nsf.gov

Jordan M. Berg, Program Director, ENG/CMMI, telephone: (703) 292-5365, email: jberg@nsf.gov

- Atul Kelkar, Program Director, ENG/CMMI, telephone: (703) 292-2162, email: akelkar@nsf.gov
- Siddiq Qidwai, Program Director, ENG/CMMI, telephone: (703) 292-2211, email: sqidwai@nsf.gov
- Usha Varshney, Program Director, ENG/ECCS, telephone: (703) 292-8339, email: uvarshne@nsf.gov
- Reid G. Simmons, Program Director, CISE/IIS, telephone: (703) 292-4767, email: resimmon@nsf.gov

For questions related to the use of FastLane, contact:

- FastLane Help Desk, telephone: 1-800-673-6188; e-mail: fastlane@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 topic coordinators may also be contacted for content specific questions on the EFRI 2018 topics:

- TOPIC 1: Chromatin and Epigenetic Engineering (CEE) , Leon Esterowitz, telephone: (703) 292-7942, email: lesterow@nsf.gov
- TOPIC 2: Continuum, Compliant, and Configurable Soft Robotics Engineering (C3 SoRo) , Jordan Berg, telephone: (703) 292-5365, email: JBERG@nsf.gov

AFOSR CONTACTS:

- Kenneth Goretta, Program Officer, USAF/AFOSR/GHz-THz Electronics & Materials, (703) 696-7349, email: kenneth.goretta@us.af.mil
- B.L. (Les) Lee, Program Officer, USAF/AFOSR/Mechanics of Multifunctional Materials & Microsystems, (703) 696-8483, email: byung.lee@us.af.mil
- Jaimie Tiley, Program Officer, USAF/AFOSR/Multi-scale Structural Mechanics & Prognosis, (703) 696-8427, email: jaimie.tiley@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 http://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.

Facilitation Awards for Scientists and Engineers with Disabilities (FASED) provide funding for special assistance or equipment to enable persons with disabilities to work on NSF-supported projects. See the *NSF Proposal & Award Policies & Procedures Guide* Chapter II.E.6 for instructions regarding preparation of these types of proposals.

The National Science Foundation has Telephonic Device for the Deaf (TDD) and Federal Information Relay Service (FIRS) capabilities that enable individuals with hearing impairments to communicate with the Foundation about NSF programs, employment or general

information. TDD may be accessed at (703) 292-5090 and (800) 281-8749, FIRS at (800) 877-8339.

The National Science Foundation Information Center may be reached at (703) 292-5111.

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To get the latest information about program deadlines, to download copies of NSF publications, and to access abstracts of awards, visit the NSF Website at https://www.nsf.gov

- Location: 2415 Eisenhower Avenue, Alexandria, VA 22314
- For General Information (NSF Information Center): (703) 292-5111
- TDD (for the hearing-impaired): (703) 292-5090
- To Order Publications or Forms:

  Send an e-mail to: nsfpubs@nsf.gov

  or telephone: (703) 292-7827
- To Locate NSF Employees: (703) 292-5111

PRIVACY ACT AND PUBLIC BURDEN STATEMENTS

The information requested on proposal forms and project reports is solicited under the authority of the National Science Foundation Act of 1950, as amended. The information on proposal forms will be used in connection with the selection of qualified proposals; and project reports submitted by awardees will be used for program evaluation and reporting within the Executive Branch and to Congress. The information requested may be disclosed to qualified reviewers and staff assistants as part of the proposal review process; to proposer institutions/grantees to provide or obtain data regarding the proposal review process, award decisions, or the administration of awards; to government contractors, experts, volunteers and researchers and educators as necessary to complete assigned work; to other government agencies or other entities needing information regarding applicants or nominees as part of a joint application review process, or in order to coordinate programs or policy; and to another Federal agency, court, or party in a court or Federal administrative proceeding if the government is a party. Information about Principal Investigators may be added to the Reviewer file and used to select potential candidates to serve as peer reviewers or advisory committee members. See Systems of Records, NSF-50, "Principal Investigator/Proposal File and Associated Records," 69 Federal Register 26410 (May 12, 2004), and NSF-51, "Reviewer/Proposal File and Associated Records," 69 Federal Register 26410 (May 12, 2004). Submission of the information is voluntary. Failure to provide full and complete information, however, may reduce the possibility of receiving an award.

An agency may not conduct or sponsor, and a person is not required to respond to, an information collection unless it displays a valid Office of Management and Budget (OMB) control number. The OMB control number for this collection is 3145-0058. Public reporting burden for this collection of information is estimated to average 120 hours per response, including the time for reviewing instructions. Send comments regarding the burden estimate and any other aspect of this collection of information, including suggestions for reducing this burden, to:

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