Semiconductor Synthetic Biology Circuits and Communications for Information Storage (SemiSynBio-III)

PROGRAM SOLICITATION
NSF 22-557

REPLACES DOCUMENT(S):
NSF 20-518

National Science Foundation

Directorate for Engineering
Division of Electrical, Communications and Cyber Systems

Directorate for Computer and Information Science and Engineering
Division of Computing and Communication Foundations

Directorate for Biological Sciences
Division of Molecular and Cellular Biosciences

Directorate for Mathematical and Physical Sciences
Division of Materials Research

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

April 25, 2022

IMPORTANT INFORMATION AND REVISION NOTES

Please Note:

If a proposal involves multiple organizations, it must be submitted as a single proposal with subawards. Separately submitted collaborative proposals are not permitted and will be returned without review.

The title of the proposal should begin with "SemiSynBio-III:"

Important Information

Innovating and migrating proposal preparation and submission capabilities from FastLane to Research.gov is part of the ongoing NSF information technology modernization efforts, as described in Important Notice No. 147. In support of these efforts, research proposals submitted in response to this program solicitation must be prepared and submitted via Research.gov or via Grants.gov, and may not be prepared or submitted via FastLane.

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:

Semiconductor Synthetic Biology Circuits and Communications for Information Storage (SemiSynBio-III)

Synopsis of Program:

The National Science Foundation (NSF), through its Divisions of Electrical, Communications and Cyber Systems (ECCS), Computing and Communication Foundations (CCF), Molecular and Cellular Biosciences (MCB), and Materials Research (DMR) announces a solicitation on the Semiconductor Synthetic Biology Circuits and Communications for Information Storage (SemiSynBio-III). Future computing systems with ultra-low energy storage can be built on principles derived from organic systems that are at the intersection of biology, physics, chemistry, materials science, computer science and engineering. Next-generation information storage technologies can be envisioned that are driven by biological principles with use of biomaterials in the fabrication of devices and systems that can store data for more than 100 years with storage capacity 1,000 times more than current storage technologies. Such a research effort can have a significant impact on the future of information

storage technologies. This focused solicitation seeks high-risk/high- return interdisciplinary research on novel concepts and enabling technologies that will address the fundamental scientific issues and technological challenges associated with the underpinnings of synthetic biology integrated with semiconductor technology. This research will foster interactions among various disciplines including biology, physics, chemistry, materials science, computer science and engineering that will enable in heretofore-unanticipated breakthroughs.

INFORMATIONAL WEBINAR: The SemiSynBio-III program will host an informational webinar in March 2022 to discuss and answer questions about the solicitation. Details on how to join this webinar will be posted on the program web page.

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.

- Usha Varshney, ECCS/ENG, telephone: (703) 292-5385, email: uvarshne@nsf.gov
- Mitra Basu, CCF/CISE, telephone: (703) 292-8649, email: mbasu@nsf.gov
- Ramon Gonzalez, MCB/BIO, telephone: (703) 292-8046, email: ramgonza@nsf.gov
- Paul A. Lane, DMR/MPS, telephone: (703) 292-2453, email: plane@nsf.gov

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

- 47.041 --- Engineering
- 47.049 --- Mathematical and Physical Sciences
- 47.070 --- Computer and Information Science and Engineering
- 47.074 --- Biological Sciences

Award Information

Anticipated Type of Award: Standard Grant or Continuing Grant

Estimated Number of Awards: 8 to 10

Anticipated Funding Amount: $12,000,000

Individual projects will be funded at up to $1,500,000 for three years depending on 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 Principal Investigator (PI) must be at the faculty level as determined by the submitting organization. A minimum of one PI and two co-PIs must participate.

A minimum of one PI and two co-PIs must participate in a proposal, representing expertise in at least three disciplines selected from Biological Sciences, Materials Science, Computer Science and Engineering. A leader addressing each of the three Research Themes must be identified. Interdisciplinary expertise is an advantage in this context. The proposal must specify in a separate paragraph in the introductory section, how the three disciplines are integrated in their research approach.

Limit on Number of Proposals per Organization:

There are no restrictions or limits.

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

An investigator may participate as PI, co-PI or senior personnel in no more than one proposal submitted in response to this solicitation. It is the responsibility of the submitting institution to ensure that the PI and all the co-PIs are participating in only one proposal.

If an individual exceeds this limit, proposals will be accepted based on earliest date and time of the proposal submission, i.e., the first proposal received will be accepted and the remainder will be returned without review. No exceptions will be made.

Proposal Preparation and Submission Instructions

A. Proposal Preparation Instructions

- **Letters of Intent:** Not required
- **Preliminary Proposal Submission:** Not required
- **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

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

  April 25, 2022

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:

Standard NSF reporting requirements apply.

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I. INTRODUCTION

Semiconductor- based information technologies are facing many challenges as Moore's Law for Complementary Metal Oxide Semiconductors (CMOS) approaches its physical limits, with no obvious replacement technologies in sight. Several recent breakthroughs in synthetic biology have demonstrated the suitability of biomolecules as carriers of stored digital data for memory applications. At the same time, the semiconductor industry has accumulated unique tools and expertise in design and fabrication of complex hybrid systems, which incorporate unconventional materials, to meet future information storage needs.

Understanding the principles of information processing, circuits, and communications in living cells could enable new generations of storage techniques. The most promising characteristic of biological systems are in their extremely low- energy operation, which is close to the thermodynamic limits and their small physical size. Although the progress of silicon technology has been extraordinary, sub-microscopic computing systems remain elusive. On the other hand, Nature addresses the sub-microscopic design challenges and offers new solutions for future nano and quantum systems for information processing and storage.

SemiSynBio-III seeks to further explore and exploit synergies between synthetic biology and semiconductor technology. The integration of these fields has the potential to lead to a new technological boom for information processing and storage. The goal of the SemiSynBio-III research program will be to foster exploratory, multi-disciplinary, longer-term basic research leading to novel high-payoff solutions for the information storage and information processing industry based on recent progress in synthetic biology and the know-how of the semiconductor technology. It is also anticipated that fundamental research in synthetic biology integrated with semiconductor capabilities will benefit design and fabrication of hybrid and complex biomaterial systems for extensive applications in biological communications, information processing technologies, sensing and personalized medicine.

The community is ready to address the topic, as a growing number of physicists, chemists, mathematicians, materials scientists, computer scientists and engineers are starting to apply their expertise to synthetic biology, hybrid living cell structures, cell-inspired and cell-based physical phenomenon to microelectronics and computational storage systems. This new direction complements the growing use of semiconductor micro-fabrication technologies in synthetic biology. Indicators of success will be a demonstration of a new generation of prototypical highly robust and scalable bio-storage systems inspired by mixed-signal electronic design for future computing applications.

II. PROGRAM DESCRIPTION

Biologically inspired technologies based on biomolecule-based modalities offer the potential for a dramatic increase in computing, sensing, and information storage capabilities. For example, nucleic acids have the potential for information storage density that is several orders of magnitude higher than any other known storage technology. In theory, a few kilograms of nucleic acid with the sequence designed using proper encoding could meet all the world's data storage needs in a form that is chemically stable for centuries, a feature that is not matched by the projected longevity of current electronic, magnetic, or optical technologies based on inorganic semiconductors. Therefore, it is an opportune time to continue to capitalize on novel approaches of synthetic biology integrated with semiconductor technology to enable the next generation of information storage platforms.

SemiSynBio-III promotes fundamental interdisciplinary research at the interface of biology, physics, chemistry, material science, computer science and engineering. This program aims to seed and foster collaborations among the researchers in biology, physics, chemistry, materials science, computer science, and engineering disciplines to develop new cross-disciplinary projects and curricula that will model and integrate concepts, tools and methodology. The goal of this program is to stimulate non-traditional thinking about the issues facing the semiconductor industry by:

1. Developing computational and experimental models of bio-molecular and cellular-based systems.
2. Addressing fundamental research questions at the interface of biology and semiconductors.
3. Designing sustainable bio-materials for novel bio-nano hybrid architectures and circuits that test the limits in transient electronics.
4. Fabricating hybrid biological-semiconductor electronic systems with storage functionalities.
5. Scaling-up and characterization of integrated hybrid synthetic bio-electronic storage systems.

Within this intellectual framework, submitted proposals should address at least three of the following Research Themes. Each proposal must select Theme 3 and at least one from Themes 1 and 2, and at least one from Themes 4 and 5. The proposal should comprehensively address the most ambitious goals within the chosen approach, and should also include as an integral component an objective of educating a new cadre of students that will meet the need of industries in the joint expertise of semiconductor and synthetic biology.

A minimum of one PI and two co-PIs must participate in a proposal, representing expertise in at least three disciplines selected from Biological Sciences, Materials Science, Computer Science and Engineering. A leader addressing each of the three Research Themes must be identified. Interdisciplinary expertise is an advantage in this context. The proposal must specify in a separate paragraph in the introductory section, how the three disciplines are integrated in their research approach.

Research Theme 1. Developing computational and experimental models of bio-molecular and cellular-based systems.

Information processing plays a central role in enabling the functionality of biological systems, from the molecular to the ecological scale. Semiconductor technology has provided revolutionary tools and instrumentation for synthesis and sequencing of biomolecules. Sophisticated computational techniques such as predictive multi-scale models and advanced algorithmic strategies offers logical connection between devices, storage systems, and data sets. Deriving the principles and rules that govern the formation, functioning, and evolution of simple and complex biological systems is still a challenge that sets new goals for physical and computer scientists to assist in bringing fresh insights. Some examples of research challenges in modeling biomolecules-based storage include information distortion that occurs during encoding and decoding; intrinsic limits of nucleic acid synthesis and sequencing technologies that reduces storage density; in vivo storage which could make use of cellular machinery for inter- and intra-cell communications; and the need for novel predictive algorithms to reduce errors and uncertainty in the system. This goal seeks new methodologies, models, and design principles that embrace the complexity of multi-scale integrated bio-electronic systems. The scope includes novel computational and experimental models addressing multi-scale simulation of hybrid systems, design methodology and standards, and research targets aiming at the development and integration of artifacts, design principles and feedback. This topic encourages models that can harness and accelerate the synergies among multiple domains of biology, materials, electronics, and computing of engineered systems that will address the inter-facial challenges between biology and semiconductors for robust and reliable information storage design.

Research Theme 2. Addressing fundamental research questions at the interface of biology and semiconductors.

This topic encourages gaining better understanding of mechanisms of cellular organization and functions that would improve synthetic systems with the capacity for random-access, high-speed communication and compact memory storage. For example, as seen in the eukaryotic chromatin structure, nature has developed elegant strategies for genome compaction, phase separation, and domain formation. Genetic elements such as super-enhancers and the mechanisms such as formation of condensates illustrate how biophysical phenomena can be used to control information processing. Advances in synthetic biology are beginning to suggest possible pathways for exploiting eukaryotic genome architecture to enable random-access memory for next generation of

communications and information storage technologies. An understanding of chromatin architecture and the influence of genome architecture on biochemical information processing may lead to design of random-access memory systems based on DNA or other biomolecule, where access to memory elements is controlled using biophysical cues. Potential research issues in storage encompass novel coding and compression algorithms for error-free communications, fast and efficient information recovery of specific stored information, architecture of the memory device, and optimal design of DNA or other biomolecule-based memory systems. Exploiting inter-facial challenges between biological information processing systems and information encoding in electronic systems, offers the potential for integration of biological circuits, communication, and storage for next generation of information storage systems. Overall, this topic encourages research ideas motivated by biological information processing and aiming at future highly functional, digital and analog computing with semiconductor technologies having high information density and extremely low energy consumption. Research in this domain is expected to spur new methods in biomolecule storage systems.

Research Theme 3. Designing sustainable bio-materials for novel bio-nano hybrid architectures and circuits that test the limits in transient electronics.

A new materials base is needed for future electronic hardware. Currently most electronics use silicon, which may not be sustainable for future demand of data storage produced or optimally preserved in the future, as billions of heterogeneous sensor nodes are realized as a part of the Internet of Things. Waste generated from used electronics is also a serious problem. Novel bio-materials systems that can be implemented in future electronic devices, components, and systems and can support sustainability through biodegradability are of interest. Research that identifies viable options for data storage, is of interest for the SemiSynBio-III program. In addition to biological systems in which long-term storage is encoded in ordered macromolecules such as DNA, smaller and more chemically diverse biomolecules, such as proteins and metabolites, that represent large aggregate amounts of information describing the working state of an organism are also encouraged.

Novel electronic materials base will require new fabrication technologies that use synthetic biology to create "cellular factories." Living systems fabricate complex nanometer-scale structures with high yield and low energy utilization. For example, biomolecule self-assembly occurs at a rate of ~10^{18} molecules per second (at biological growth rates, a 1Gb chip could be built in about 5 s), with energy utilization of ~10^{17} J/molecule, which is 100 times less than that of conventional subtractive manufacturing. Microorganisms can be programmed to produce a range of novel materials for semiconductor processes that have the desired chemical composition and morphology. Combining these capabilities of living systems with nucleic acid-based, protein-based or other bio-polymer-based self-assembly offers transformative potential for revolutionizing the synthesis of complex electronic architectures and circuits for information storage. Moreover, engineered bio-systems may store and access information not only in the form of genetically encoded bio-polymers, but also in the form of chemically diverse small molecules, metabolic networks and other biological networks, An additional attractive property of these materials is that they are likely to be amenable to bioengineering, scalable, and potentially biodegradable.

Research Theme 4. Fabricating hybrid biological- semiconductor electronic systems with communications and storage functionalities.

The hybrid biological-semiconductor electronic systems can be employed in a broad spectrum of critical applications with ground-breaking scientific, economic, and societal impacts. Leveraging the built-in or synthetically programmed cellular circuits and machineries and their interactions with semiconductor platforms can potentially offer unprecedented capabilities that will be far beyond conventional electronics. Emerging hybrid biological-semiconductor platforms will leverage both natural and synthetic biological processes and advanced semiconductor technologies. In such hybrid platforms, living cells and tissues can function as a "Biological Front-End" layer with the cellular biochemical processes serving as an organic interface to the external environment to perform synthesis, biological sensing, actuation, signal processing, and energy harvesting. In parallel, the underlying semiconductor platforms can form a "Semiconductor Back-End" layer for information computation, control, communication, storage, and energy supply. If reliable two-way communication schemes for both information and energy are achieved between the "Biological Front-End" and "Semiconductor Back-End" with a high spatiotemporal resolution and massively parallel operations, one can expect a creation of a hybrid biotic-abiotic feedback system that may involve entirely new functionalities for antegrade/ retrograde data storage systems. Advances in this field could also stimulate developments of self-powered intelligent sensor systems that integrate biological sensing and energy-generation functions with computing capabilities to enable communications and information storage for diverse applications.

Research Theme 5. Scaling-up and characterization of integrated hybrid synthetic bio-electronic storage. systems.

Currently, semiconductor technologies have directly enabled remarkable progress in sequencing, microscopy, and other types of instrumentation, as well as in big data analysis in biology. However, synthetic biology is at an early stage of engineering due to limited automation and absence of large-scale integration in the build-to-test phases of the design cycle. As progress in instrumentation miniaturization and high-throughput characterization technologies increases, the demand for semiconductors and electronic assembly technologies will become better suited to be integrated into the biological domain as essential platforms. New tools for characterization and metrology for hybrid bio-electronic systems are needed. The incorporation of these technologies will further require a step-change in the way that Software Design Automation (SDA) for synthetic biology will be approached. Synthetic biology designs should be verified to be trustworthy and economical and thus breakthroughs are required in programming languages used in biology and formal verification techniques for large-scale synthetic bio-engineered system. While the first-generation synthetic biology has demonstrated many impressive proof-of-concept circuits, full-scale computer-aided design tools will be needed for reliable design of larger and more complex systems for communications and information storage, such as cellular-scale models. One recent benchmark is ~104 biological design automation (BDA) designed equivalent "bits" (DNA base-pairs) versus ~109 electronic design automation (EDA) "bits" (e.g. binary switches on a chip). Leveraging advanced EDA tools and concepts for complex design could enable a radical increase in the complexity of BDA capabilities. Currently, the biological design cycle is slow, expensive, and laborious, and in most cases, design is carried out empirically using a small number of parts. Experimental evolution that is an essential ingredient of the design cycle supplemented with predictive outcomes and multi-scale simulations of hybrid systems are strongly encouraged. Therefore, challenges associated with the development of EDA/BDA/SDA interface requires expert input from the multiple communities are also encouraged.

Note: All proposals should also address the goal of educating a new cadre of students, scientists and engineers that will meet the needs of industries stemming from the interfacing of semiconductors with synthetic biology.

III. AWARD INFORMATION

Anticipated Type of Award: Continuing Grant or Standard Grant

Estimated Number of Awards: 8 to 10

Anticipated Funding Amount: $12,000,000

Individual projects will be funded at up to $1,500,000 for three years depending on the availability of funds.

Estimated program budget, number of awards and average award size/duration are subject to the availability of funds.

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 Principal Investigator (PI) must be at the faculty level as determined by the submitting organization. A minimum of one PI and two co-PIs must participate.

A minimum of one PI and two co-PIs must participate in a proposal, representing expertise in at least three disciplines selected from Biological Sciences, Materials Science, Computer Science and Engineering. A leader addressing each of the three Research Themes must be identified. Interdisciplinary expertise is an advantage in this context. The proposal must specify in a separate paragraph in the introductory section, how the three disciplines are integrated in their research approach.

Limit on Number of Proposals per Organization:

There are no restrictions or limits.

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

An investigator may participate as PI, co-PI or senior personnel in no more than one proposal submitted in response to this solicitation. It is the responsibility of the submitting institution to ensure that the PI and all the co-PIs are participating in only one proposal.

If an individual exceeds this limit, proposals will be accepted based on earliest date and time of the proposal submission, i.e., the first proposal received will be accepted and the remainder will be returned without review. No exceptions will be made.

Additional Eligibility Info:

Proposals submitted in response to this solicitation cannot be duplicates of proposals to any other Federal agency for simultaneous consideration. The only exception to this rule is: Proposals from PIs who are beginning investigators (individuals who have not been a PI or co-PI on a Federally funded award with the exception of doctoral dissertation, postdoctoral fellowship, or research planning grants). For proposers who qualify under this latter exception, the box for "Beginning Investigator" must be checked on the Cover Sheet.

If a proposal involves multiple organizations, it must be submitted as a single proposal with subawards. Separately submitted collaborative proposals are not permitted and will be returned without review.

V. PROPOSAL PREPARATION AND SUBMISSION INSTRUCTIONS

A. Proposal Preparation Instructions

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

- Full Proposals submitted via Research.gov: Proposals submitted in response to this program solicitation should be prepared and submitted in accordance with the general guidelines contained in the *NSF Proposal and Award Policies and 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. The Prepare New Proposal setup will prompt you for the program solicitation number.
- 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.

If a proposal involves multiple organizations, it must be submitted as a single proposal with subawards. Separately submitted collaborative proposals are not permitted and will be returned without review.

The title of the proposal should begin with "SemiSynBio-III:"

B. Budgetary Information

Cost Sharing:

Inclusion of voluntary committed cost sharing is prohibited.

C. Due Dates

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

  April 25, 2022

D. Research.gov/Grants.gov Requirements

For Proposals Submitted Via Research.gov:

To prepare and submit a proposal via Research.gov, see detailed technical instructions available at: https://www.research.gov/research-portal/appmanager/base/desktop?_nfpb=true&_pageLabel=research_node_display&_nodePath=/researchGov/Service/Desktop/ProposalPreparationandSubmission.html. For Research.gov user support, call the Research.gov Help Desk at 1-800-673-6188 or e-mail rgov@nsf.gov. The Research.gov Help Desk answers general technical questions related to the use of the Research.gov 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: 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 Research.gov 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 acknowledgment 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

- Comment on the extent to which the project comprehensively addresses at least three themes within the chosen approach, including one from Theme 1

and Theme 2, and one from Theme 4 and Theme 5.
- Comment on the extent to which the project integrates expertise from at least three disciplines selected from Biological Science, Material Science, Computer Science, and Engineering, with each discipline represented by either the PI or a co-PI on the proposal.
- Comment on the extent to which the project fulfills the objective of educating a new cadre of students that will meet the need of industries operating at the interface of semiconductor technology and synthetic biology.

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 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:

Recipients of awards under SemiSymBio-III program are required to include funds to attend at least one annual Principal Investigators' (PI) meeting organized by NSF during the award period.

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:

- Usha Varshney, ECCS/ENG, telephone: (703) 292-5385, email: uvarshne@nsf.gov
- Mitra Basu, CCF/CISE, telephone: (703) 292-8649, email: mbasu@nsf.gov
- Ramon Gonzalez, MCB/BIO, telephone: (703) 292-8046, email: ramgonza@nsf.gov
- Paul A. Lane, DMR/MPS, telephone: (703) 292-2453, email: plane@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.

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.

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.

The National Science Foundation promotes and advances scientific progress in the United States by competitively awarding grants and cooperative agreements for research and education in the sciences, mathematics, and engineering.

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) 292-8134
- **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 System of Record Notices, NSF-50, "Principal Investigator/Proposal File and Associated Records," and NSF-51, "Reviewer/Proposal File and Associated Records." 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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