Semiconductor Synthetic Biology for Information Processing and Storage Technologies (SemiSynBio)

PROGRAM SOLICITATION
NSF 17-557

National Science Foundation

Directorate for Engineering
    Division of Electrical, Communications and Cyber Systems

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

Directorate for Biological Sciences
    Division of Molecular and Cellular Biosciences

Semiconductor Research Corporation

Intelligence Advanced Research Projects Activity

I A R P A

Submission Window Date(s) (due by 5 p.m. submitter's local time):

    October 02, 2017 - October 30, 2017

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 17-1), which is effective for proposals submitted, or due, on or after January 30, 2017.

SUMMARY OF PROGRAM REQUIREMENTS

General Information

Program Title:

    Semiconductor Synthetic Biology for Information Processing and Storage Technologies (SemiSynBio)

Synopsis of Program:

    The National Science Foundation (NSF), through its Division of Electrical, Communications and Cyber Systems (ECCS) in the Directorate for Engineering (ENG), Division of Computing and Communication Foundations (CCF) in the Directorate for Computer and Information Science and Engineering (CISE), and Division of Molecular and Cellular Biosciences (MCB) in the Directorate for Biological Sciences (BIO), has established a partnership with the Semiconductor Research Corporation (SRC), through its Global Research Collaboration (GRC) program, and the Intelligence Advanced Research Projects Activity (IARPA) to announce a solicitation on the "Semiconductor Synthetic Biology for Information Processing and Storage Technologies (SemiSynBio)". Future ultra-low-energy computing, storage and signal-processing systems can be built on principles derived from organic systems that are at the intersection of chemistry, biology, and engineering. New information technologies can be envisioned that are based on biological principles and that use biomaterials in the fabrication of devices and components; it is anticipated that these information technologies could enable stored data to be retained for more than 100 years and storage capacity to be 1,000 times greater than current capabilities. These could also facilitate compact computers that will operate with substantially lower power than today's computers. Research in support of these goals can have a significant impact on advanced information processing and storage technologies. This focused solicitation seeks high-risk/high-return interdisciplinary research on novel concepts and enabling technologies that will address the 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, engineering, physics,

chemistry, materials science, computer science, and information science that will enable heretofore-unanticipated breakthroughs as well as meet educational goals.

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, Program Director, ENG/ECCS, telephone: (703) 292-8339, email: uvarshne@nsf.gov

- Mitra Basu, Program Director, CISE/CCF, telephone: (703) 292-8910, email: mbasu@nsf.gov

- Arcady Mushegian, Program Director, BIO/MCB, telephone: (703) 292-8528, email: amushegi@nsf.gov

- Shubhra Gangopadhyay, Program Director, ENG/ECCS, 525, telephone: (703) 292-8339, email: sgangopa@nsf.gov

- Richard Brown, Program Director, CISE/CCF, telephone: (703) 292-8910, email: ribrown@nsf.gov

- Devaki Bhaya, Program Director, BIO/MCB, telephone: (703) 292-7131, email: dbhaya@nsf.gov

- Khershed Cooper, Program Director, ENG/CMMI, telephone: (703) 292-7017, email: khcooper@nsf.gov

- Victor Zhirnov, Chief Scientist, Semiconductor Research Corporation, telephone: (919) 941-9454, email: victor.zhirnov@src.org

- David A. Markowitz, Program Manager, IARPA, telephone: (301) 851-7497, email: david.markowitz@iarpa.gov

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

- 47.041 --- Engineering
- 47.070 --- Computer and Information Science and Engineering
- 47.074 --- Biological Sciences

Award Information

Anticipated Type of Award: Continuing Grant

Estimated Number of Awards: 8 to 10

Approximately, 8 to 10 multidisciplinary awards will be made in FY 2018, subject to the availability of funds and quality of proposals.

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

Projects jointly funded by NSF and SRC will be supported by separate NSF and SRC funding instruments. For each project, NSF support will be provided via an NSF grant and SRC support will be provided via an SRC contract.

Proposals responsive to this solicitation will be shared with IARPA. IARPA will view these submissions as white papers, and distribute internally to IARPA Program Managers to determine their interest for possible re-submission directly to IARPA.

Anticipated Funding Amount: $4,000,000

per year for three years dependent on the availability of funds.

Eligibility Information

Who May Submit Proposals:

Proposals may only be submitted by the following:

- Universities and Colleges - Universities and two- and four-year colleges (including community colleges) accredited in, and having a campus located in, the US acting on behalf of their faculty members. Such organizations also are referred to as academic institutions.

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.

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.

In the event that 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.

Proposals submitted in response to this solicitation cannot be duplicates of proposals to any other Federal agency for simultaneous consideration. The only exceptions to this rule are: (1) when the program officers at the relevant Federal agencies have previously agreed to joint review and possible joint funding of the proposal; or (2) proposals for 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.

A minimum of one PI and two co-PIs must participate in a proposal with expertise in the biological sciences, engineering, and computer and information sciences.

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 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

- **Submission Window Date(s)** (due by 5 p.m. submitter's local time):

    October 02, 2017 - October 30, 2017

Proposal Review Information Criteria

Merit Review Criteria:

National Science Board approved criteria apply.

Award Administration Information

Award Conditions:

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

Reporting Requirements:

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

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I. INTRODUCTION

Currently, semiconductor and information technologies are facing many challenges as CMOS/Moore's Law 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 experience in design and fabrication of complex hybrid systems, which incorporate unconventional materials, to meet future information processing needs. The Semiconductor Synthetic Biology for Information Processing and Storage Technologies (SemiSynBio) solicitation seeks to explore synergies between synthetic biology and semiconductor technologies. Today is likely to mark the beginning of a new technological boom to merge and exploit the two fields for information processing and storage capacity.

The goal of the SemiSynBio research program is to foster exploratory, multi-disciplinary, longer-term basic research leading to novel high-payoff solutions for the information technology industry based on recent progress in synthetic biology and the know-how of semiconductor technology. It is also anticipated that research in synthetic biology will benefit by leveraging semiconductor capabilities in design and fabrication of hybrid and complex material systems for extensive applications in biological and information processing technologies. In addition, the educational goal is to train new cadre of students and researchers.

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

II. PROGRAM DESCRIPTION

The significance of the topic lies in part in the potential for a dramatic increase in memory storage capacity. For example, nucleic acids have an 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 proper encoding could meet all of the world's data storage needs in a form that is chemically stable and with retention capability for centuries, a feat that could not currently be supported by projected silicon-based resources. Therefore, it is an opportune time to capitalize on the emerging field of synthetic biology integrated with semiconductor technology to enable the next generation of information processing and storage. SemiSynBio promotes fundamental interdisciplinary research at the interface of biology, engineering, physics, chemistry, materials science, and computer science for information technology.

This program aims to seed and foster collaboration among the faculties in the biological, engineering, physics, chemistry, materials science, computer science, information science and design automation disciplines to develop new cross-disciplinary approaches, including instruction materials, that integrate concepts, tools and methodology from biology, physics, semiconductor engineering and computer engineering. The role of this program is to stimulate non-traditional thinking about the issues facing the semiconductor industry by:

1. Advancing basic research by exploring new programmable models of computation, communication, and memory based on synthetic biology;

2. Enriching the knowledge base and addressing foundational questions at the interface of biology and semiconductors;
3. Promoting the frontier of research in the design of new bio-nano hybrid devices based on sustainable materials, including carbon-based systems that test the physical size limit in transient electronics;
4. Designing and fabricating hybrid semiconductor-biological microelectronic systems based on living cells for next-generation storage and information processing functionalities; and
5. Integrating scaling-up and manufacturing technologies involving electronic and synthetic biology characterization instruments with computer-aided design (CAD)-like software tools.

Within this intellectual framework, submitted proposals should address at least three of the research paths described below in 1-5, and should comprehensively address the most aggressive goals within the chosen approach with an overarching goal of educating a new cadre of students that will meet the need of industries stemming from synthetic biology.

1. **Advancing basic and fundamental research by exploring new programmable models of computation, communication, and memory based on synthetic biology.**

   Understanding principles of information processing in living cells could enable new generations of computing systems. Among the most promising characteristics of biological computing is the extremely low requirement for energy of operation, close to thermodynamic limits. Another relevant characteristic of biological circuits is their physical size: although the progress of silicon technology has been extraordinary, sub-microscopic computers remain beyond our reach. Nature appears to have successfully addressed the sub-microscopic design challenge, and may suggest new solutions for future microsystems for information processing. Advances in the science of synthetic biology are beginning to suggest possible pathways for extending future semiconductor technologies. For example, by using nucleic acids, it might be possible to achieve storage densities that are not approachable by known semiconductor technologies. Potential research issues in storage encompass novel coding and compression algorithms for error-free information recovery, fast and efficient retrieval of specific stored information, optimal size of the DNA strand and, architecture of the memory device. Overall, this topic encourages research ideas motivated by biological information processing and aiming at future highly functional, space-limited, digital and analog computing and semiconductor technologies with high information density and extremely low energy consumption. Research in this domain is expected to spur new approaches toward alternative computing paradigms.

2. **Enriching the knowledge base and addressing foundational questions at the interface of biology and semiconductors.**

   It is becoming increasingly clear that information processing plays a central role in enabling the functionality of biological systems from the molecular to the ecological scales. Semiconductor information processing is providing revolutionary tools and instrumentation for fundamental biological discovery and for its practical applications while increasingly sophisticated computational models and software strategies provide the logical connection between instrumentation, samples, 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 and sets new goals for software engineering to assist in bringing fresh insights. This goal also seeks to devise new methodologies and design principles that embrace the complexity of multi-scale electronic-biological systems integration. The scope includes theoretical foundations, design methodology and standards, research targets aiming at the development of new engines for transformation and integration of synthesis artifacts, and effective methods for programmer interaction and feedback. This topic encourages research that can harness and accelerate the synergies among the three domains of biology, electronics, and software that will address the interface challenges between biology and semiconductors.

3. **Promoting the frontier of research in the design of new bio-nano hybrid devices based on sustainable materials, including carbon-based systems that test the physical size limit in transient electronics.**

   A new materials base is likely to be needed for future electronic hardware. While most of today's electronics use silicon, this may not be a sustainable or optimal approach tomorrow, as billions of heterogeneous sensor nodes are realized as a part of the Internet-of-Things, many of which have short lives and must be discarded. Novel materials systems that can be implemented in future electronic components and systems and that can support sustainability through recycling and bio-degradability are of interest. It may also be possible to reuse and repurpose silicon as is done by some biological species, such as diatoms and glass sponges. These organisms acquire silicon from their environments and use it to build repeatable and complex structures. More study of such systems is also encouraged.

   An electronic materials base will require new fabrication technologies that use synthetic biology to create "cellular factories." Microorganisms can be programmed to produce a range of important chemicals and materials for semiconductor processes that have the desired chemical composition and morphology. An additional requirement is that the manufacturing of these materials, as well as the materials themselves, are engineered to be biologically benign. 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 1gigabit chip could be built in about 5 seconds), with energy utilization of ~10^{-17} Joules per molecule, which is 100 times less than that of conventional subtractive manufacturing. Combining these capabilities of living systems with synthetic nucleic/protein-based self-assembly offers transformative potential for revolutionizing the synthesis of complex electronic architectures.

4. **Designing and fabricating hybrid semiconductor-biological microelectronic systems based on living cells for next-generation information processing functionalities.**

   The hybrid biology-semiconductor 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 machineries and their interactions with semiconductor platforms can potentially offer unprecedented capabilities far beyond conventional electronics-only devices. Emerging hybrid biological-semiconductor platforms will leverage both natural/synthetic biological processes and 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 and performing 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 creation of a hybrid biotic-abiotic feedback system. Advances in this field could stimulate developments of self-powered intelligent sensor systems that integrate biological sensing and energy generation functions with inorganic information/computation capabilities to enable diverse new applications.

5. **Integrating scaling-up and manufacturing technologies involving electronic and synthetic biology characterization instruments with CAD-like software tools.**

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 no large-scale integration in the build-to-test phases of the design cycle. As instrumentation miniaturizes and the demand for high-throughput characterization increases, semiconductors and electronic assembly technologies will become better suited to continue to scale 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 requires breakthroughs in programming languages used in biology and formal verification techniques for large-scale biological engineering. While first-generation synthetic biology has demonstrated many impressive proof-of-concept circuits, full-scale CAD tools will be needed for reliable design of larger and more complex systems, such as cellular-scale models. One recent benchmark is $\sim 10^4$ biological design automation (BDA) designed equivalent "bits" (e.g., DNA base-pairs) versus $\sim 10^9$ 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 biological design automation (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, an essential ingredient of the design cycle, is often not supplemented with predictive outcomes. Therefore, the development of EDA/BDA/SDA interface requires expert input from the three communities.

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

III. AWARD INFORMATION

Anticipated Type of Award: Continuing Grant

Estimated Number of Awards: 8 to 10

Approximately, 8 to 10 multidisciplinary awards will be made in FY 2018, subject to the availability of funds and quality of proposals.

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

Projects jointly funded by NSF and SRC will be supported by separate NSF and SRC funding instruments. For each project, NSF support will be provided via an NSF grant and SRC support will be provided via an SRC contract.

Proposals responsive to this solicitation will be shared with IARPA. IARPA will view these submissions as white papers, and distribute internally to IARPA Program Managers to determine their interest for possible re-submission directly to IARPA.

Anticipated Funding Amount: $4,000,000 per year for three years dependent 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:

- Universities and Colleges - Universities and two- and four-year colleges (including community colleges) accredited in, and having a campus located in, the US acting on behalf of their faculty members. Such organizations also are referred to as academic institutions.

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.

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.

In the event that 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.

Proposals submitted in response to this solicitation cannot be duplicates of proposals to any other Federal agency for simultaneous consideration. The only exceptions to this rule are: (1) when the program officers at the relevant Federal agencies have previously agreed to joint review and possible joint funding of the proposal; or (2) proposals for 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.

A minimum of one PI and two co-PIs must participate in a proposal with expertise in the biological sciences, engineering, and computer and information sciences.

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 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.

In determining which method to utilize in the electronic preparation and submission of the proposal, please note the following:

Collaborative Proposals. All collaborative proposals submitted as separate submissions from multiple organizations must be submitted via the NSF FastLane system. PAPPG Chapter II.D.3 provides additional information on collaborative proposals.

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.

Title of Proposed Project: The title of the proposed project must begin with "SemiSynBio:" followed by an informative title that describes the focus of the project.

Additional Submission Requirement to SRC: All proposals submitted to the NSF SemiSynBio solicitation must also be submitted to SRC according to the proposal and submission guidelines imposed by SRC. SRC will electronically issue a parallel call for proposals with an identical Program Description (https://www.src.org/app/proposal/submit/semisynbio/). It is expected that, at a minimum, the project summary, project description, and references cited will be identical in the proposals submitted separately to NSF and SRC. Additional proposal documentation and materials specific to NSF and SRC may be included in the proposal submissions as specified in the solicitation issued by each party.

Proposals to this solicitation will be shared with the Intelligence Advanced Research Projects Activity (IARPA). IARPA will view submissions to this NSF solicitation as whitepapers, and distribute them internally to IARPA Program Managers to determine their interest for possible resubmission directly to IARPA.

B. Budgetary Information

Cost Sharing:

Inclusion of voluntary committed cost sharing is prohibited.

Budget Preparation Instructions:

Recipients of awards under NSF's SemiSymBio program are required to include funds to attend at least one annual Principal Investigators' (PI) meeting organized by NSF during the award period. Proposals receiving co-funding from SRC will be asked to include the cost of attending additional meetings in the years in which there is not a SemiSymBio PI meeting. SRC will conduct annual reviews and will require certain deliverable reports to monitor the program and project progress.

C. Due Dates

- **Submission Window Date(s)** (due by 5 p.m. submitter's local time):

  October 02, 2017 - October 30, 2017

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 *Investing in Science, Engineering, and Education for the Nation's Future: NSF Strategic Plan for 2014-2018*. 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.

B. Review and Selection Process

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

NSF will manage and conduct the review process of the proposals submitted in accordance with NSF standards and procedures. The review will be coordinated by a Joint Working Group (JWG) of program officers/program managers from NSF and SRC. Relevant information about reviews will be shared with SRC and IARPA program managers as appropriate.

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) 292-7827 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:

Individual awards will be jointly funded by NSF and SRC through separate NSF and SRC funding instruments. NSF awards will be made as continuing grants. SRC awards will be made as SRC contracts. For each award selected for joint funding, NSF and SRC contributions will be as agreed upon by both parties. NSF and SRC will inform selected PIs of the breakdown in funding between the two organizations, and will request revised budgets as appropriate. Beyond the base level of support, either organization may supplement a project for special purposes, such as education or development, without requiring the other party to provide any additional funds. NSF and SRC awards will be made for three-year periods depending on availability of funds.

All joint or separate awards involving SRC funds must also include an executed agreement on intellectual property signed by the representatives of the awardee organizations and SRC. SRC contracts provide for non-exclusive, royalty-free rights to all SRC members for any intellectual property generated as a result of the SRC-funded research.

Recipients of awards under NSF's SemiSymBio program are required to include funds to attend at least one annual Principal Investigators' (PI) meeting organized by NSF during the award period. In addition, SRC funded/co-funded projects should follow SRC provided guidelines.

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.

NSF and SRC will manage their respective awards/contracts in accordance with their own guidelines. Awardees will submit annual project reports to NSF via Research.gov, subject to NSF procedures. Awardees will also submit annual reports to SRC in accordance with SRC procedures provided in this URL-https://www.src.org/app/proposal/submit/semisynbio/.

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, Program Director, ENG/ECCS, telephone: (703) 292-8339, email: uvarshne@nsf.gov

- Mitra Basu, Program Director, CISE/CCF, telephone: (703) 292-8910, email: mbasu@nsf.gov

- Arcady Mushegian, Program Director, BIO/MCB, telephone: (703) 292-8528, email: amushegi@nsf.gov

- Shubhra Gangopadhyay, Program Director, ENG/ECCS, 525, telephone: (703) 292-8339, email: sgangopa@nsf.gov

- Richard Brown, Program Director, CISE/CCF, telephone: (703) 292-8910, email: ribrown@nsf.gov

- Devaki Bhaya, Program Director, BIO/MCB, telephone: (703) 292-7131, email: dbhaya@nsf.gov

- Khershed Cooper, Program Director, ENG/CMMI, telephone: (703) 292-7017, email: khcooper@nsf.gov

- Victor Zhirnov, Chief Scientist, Semiconductor Research Corporation, telephone: (919) 941-9454, email: victor.zhirnov@src.org

- David A. Markowitz, Program Manager, IARPA, telephone: (301) 851-7497, email: david.markowitz@iarpa.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.

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.

> 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) 292-7827
●	**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:

Suzanne H. Plimpton
Reports Clearance Officer
Office of the General Counsel
National Science Foundation
Alexandria, VA 22314

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