

Future of Semiconductors (FuSe)

PROGRAM SOLICITATION

NSF 23-552

REPLACES DOCUMENT(S):

NSF 22-589



National Science Foundation

Directorate for Engineering
Engineering Education and Centers
Division of Electrical, Communications and Cyber Systems
Division of Civil, Mechanical and Manufacturing Innovation

Directorate for Mathematical and Physical Sciences
Division of Materials Research
Division of Chemistry

Directorate for Computer and Information Science and Engineering

Directorate for Technology, Innovation and Partnerships

Directorate for STEM Education



Intel Corporation



Ericsson Inc.



IBM Corp.



Samsung

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

April 24, 2023

IMPORTANT INFORMATION AND REVISION NOTES

The solicitation aims to cultivate a broad coalition of researchers and educators from the science and engineering communities that utilizes a holistic, co-design approach to enable rapid progress in new semiconductor technologies. Partnerships between industry and academic institutions are essential to spur innovation and technology transfer, to inform the research needs, and to train the future workforce.

Industry Partners co-funding this FuSe solicitation:

- Ericsson
- IBM
- Intel
- Samsung

The eligibility criteria for who may serve as PI and the limit on number of proposals per PI or co-PI have been revised.

Any proposal submitted in response to this solicitation should be submitted in accordance with the *NSF Proposal & Award Policies & Procedures Guide* (PAPPG) that is in effect for the relevant due date to which the proposal is being submitted. The NSF PAPPG is regularly revised and it is the responsibility of the proposer to ensure that the proposal meets the requirements specified in this solicitation and the applicable version of the PAPPG. Submitting a proposal

prior to a specified deadline does not negate this requirement.

SUMMARY OF PROGRAM REQUIREMENTS

General Information

Program Title:

National Science Foundation - Future of Semiconductors (FuSe)

Synopsis of Program:

The current state of semiconductor microelectronic systems is at a crossroads. Continued advances in the capabilities of many technologies as well as the cost of the applications of these technologies across computing, sensing, and communications are threatened. The technology has expanded following the trends in miniaturization long characterized by *Moore's Law*, underpinned by new materials, processes, devices, and architectures. The developments in these underpinning areas have often progressed independent of the application area, which has delayed their incorporation into the next-generation technologies. Closing that gap between the essential components in the technology chain is now required to ensure further progress. The materials, devices, and systems need to be *co-designed*, that is, they need to be designed with simultaneous consideration of elements of the technology chain.

The benefits of a co-design approach as a principal methodology to advance semiconductor technology have been widely recognized in a variety of government and industry studies. This holistic, co-design approach can more rapidly create high-performance, robust, secure, compact, energy-efficient, and cost-effective solutions. The technological drivers include the need to: dramatically reduce the energy consumption of computation and communication technologies; reduce the impact of device and system manufacturing on the environment; increase performance speed and capacity; and develop new computing systems.

The goal of this solicitation is to cultivate a broad coalition of researchers and educators from across science and engineering communities that utilizes a holistic, co-design approach to fundamental research and workforce education and training, to enable rapid progress in new semiconductor technologies. The future of semiconductor manufacturing will require the design and deployment of diverse new technologies in materials, chemical and materials processes, devices, and architectures through the development of application-driven systems. Partnerships between industry and academic institutions are essential to spur innovation and technology transfer, to inform the research needs, and to train the future workforce.

The program seeks to fund research as well as curriculum and workforce development to improve science, technology, engineering, and mathematics (STEM) education at the nation's institutions of higher education, spanning two-year colleges and four-year universities and inclusive of minority-serving institutions, to advance semiconductor design and manufacturing. NSF encourages bold, potentially transformative activities that address future semiconductor manufacturing technical challenges and shortages in the skilled scientist, engineer, and technician workforce. This solicitation encourages proposers to include a holistic perspective on workforce regarding diversity and equitable access to STEM career paths and education by engaging the academic community to broaden access and exposure to advanced technologies and research capabilities. All proposals should address workforce development plans and research.

This solicitation seeks proposals to perform fundamental research to enable the development of a new paradigm in semiconductor capabilities through supporting **research grants for teams that are practicing co-design approaches and solutions as well as facilitating and coalescing new teams with a vision for co-design methodologies**. Teams of all sizes and co-design research proposals of all scopes (i.e., beyond the scope of research that could be submitted to a regular NSF program) are encouraged.

Future of Semiconductor Co-Design Research and Education Grants (FuSe-REG) - Awards will be supported in FY 2023 up to \$2M per award for up to a three-year grant period, commensurate with the scope and team size. This program seeks to fund collaborative team research that transcends the traditional boundaries of individual disciplines to achieve the program goals.

The three research topic areas identified for support in FY 2023 under this solicitation are:

- Collaborative Research in Domain-Specific Computing;
- Advanced Function and High-Performance by Heterogenous Integration; and
- New Materials for Energy-Efficient, Enhanced-Performance and Sustainable Semiconductor-Based Systems.

Details are provided under Program Description in Section II. Each proposal should explicitly identify at least one of these research topic areas to focus on, though proposals which merge ideas from multiple topic areas are encouraged. Every proposal should address co-design covering at least two of the areas in the technology stack (materials, devices, and systems) in the research approach.

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.

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.

- Nadia A. El-Masry, telephone: (703) 292-4975, email: fuse1@nsf.gov
- Geoffrey Brown, telephone: (703) 292-4979, email: fuse1@nsf.gov
- Z. C. Ying, telephone: (703) 292-8428, email: fuse1@nsf.gov
- Sankar Basu, telephone: (703) 292-7843, email: fuse1@nsf.gov
- Erik Brunvand, telephone: (703) 292-8950, email: fuse1@nsf.gov
- Premjeet Chahal, telephone: (703) 292-7264, email: fuse1@nsf.gov
- Rosa Lukaszew, telephone: (703) 292-8103, email: fuse1@nsf.gov

- Birgit Schwenzer, telephone: (703) 292-4771, email: fuse1@nsf.gov
- George M. Janini, telephone: (703) 292-4971, email: fuse1@nsf.gov
- Vinod K. Lohani, telephone: (703) 292-2330, email: fuse1@nsf.gov
- Eleanor Sayre, telephone: (703) 292-2997, email: fuse1@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
- 47.076 --- STEM Education
- 47.084 --- NSF Technology, Innovation and Partnerships

Award Information

Anticipated Type of Award: Standard Grant or Continuing Grant

Estimated Number of Awards: 15 to 20

In FY 2023, depending on the quality of submissions and the availability of funds:

~ 20 *FuSe* Research and Education Grants will be awarded as Standard awards or Continuing grants for periods of up to three years and at up to \$2M per grant.

Proposals Involving Multiple Organizations. The Proposal & Award Policies & Procedures Guide (PAPPG) describes two kinds of collaborative proposal formats. This solicitation allows both a **single proposal submission** with subawards administered by the lead organization (Chapter II.E.3.a) or submissions using the format of a collaborative proposal, in which each participating organization submits its own proposal (Chapter II.E.3.b).

Anticipated Funding Amount: \$40,000,000

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

Eligibility Information

Who May Submit Proposals:

The categories of proposers eligible to submit proposals to the National Science Foundation are identified in the *NSF Proposal & Award Policies & Procedures Guide* (PAPPG), Chapter I.E. Unaffiliated individuals are not eligible to submit proposals in response to this solicitation.

Who May Serve as PI:

By the submission deadline, any PI, co-PI, or other senior project personnel must hold either:

- a tenured or tenure-track position, or
- a primary, full-time, paid appointment in a research or teaching position

with exceptions granted for family or medical leave, as determined by the submitting institution.

Individuals with primary appointments at for-profit non-academic organizations, or at overseas branch campuses of U.S. IHEs are not eligible.

Researchers from foreign academic institutions who contribute essential expertise to the project may participate as senior personnel or collaborators but may not receive NSF support.

Limit on Number of Proposals per Organization:

There are no restrictions or limits.

Limit on Number of Proposals per PI or co-PI: 2

An investigator may only serve as a PI, co-PI or Senior Personnel on only **two proposals**, including sub-awardees, submitted in response to this solicitation. If an investigator exceeds this limit, proposals received within the limit will be accepted based on earliest date and time of proposal submission. The remainder will be returned without review. This limitation includes proposals submitted by a lead organization and any subawards included as part of a proposal involving multiple organizations.

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 24, 2023

Proposal Review Information Criteria

Merit Review Criteria:

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

Award Administration Information

Award Conditions:

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

Reporting Requirements:

Standard NSF reporting requirements apply.

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I. INTRODUCTION

The *Future of Semiconductors* initiative (FuSe) is a cross-directorate program supported by NSF's Directorates for Computer and Information Science and Engineering (CISE), Engineering (ENG), STEM Education (EDU), Technology, Innovation and Partnerships (TIP), and Mathematical and Physical Sciences (MPS).

The goal of *FuSe* is to support fundamental research enabling the co-design of semiconductor materials, devices and systems that will propel US semiconductor manufacturing and applications beyond the limits of Moore's law and discover new application spaces as well as grow the semiconductor research and development talent pool. "Co-design" is emphasized to encourage cross-fertilization among broad areas of research sponsored by the NSF, specifically research that crosses traditional directorate boundaries at NSF (e.g., CISE, ENG, EDU, MPS, TIP, etc.) and that do not fit well with existing programs. Co-design simultaneously considers the material/device/system performance, manufacturability, recyclability, and impact on the environment.

The program seeks to develop new semiconductor systems through this intimate convergent co-design of the essential elements of the process, linking the critical components of the application in a single integrated process. Current practice focuses on independent research and discovery in each area separately, and advances are often not effectively translated to practice. The *FuSe* program will support advances and research where materials, devices and systems, are discovered and developed in an integrated way, which can better facilitate knowledge transfer between these research areas.

FuSe complements existing research activities in the current research areas in semiconductor-based science and technology, both within NSF and other federal agencies, but focuses on the co-design of one or more steps in the application development process. This approach should lead to the discovery of new applications and cross-fertilization to improve the performance fabrication, design security, energy efficiency and process sustainability in existing technologies. *FuSe* proposals should provide a clear vision of the application area impacted by the research and can include ties to industry to enable rapid adoption of new discoveries. They should provide a vision statement describing the new capabilities that could be enabled by the proposed research, and the potential industrial, educational, and societal benefits.

The increasing demand for greater information and communications technology (ICT) is projected to require a larger percentage of the world's total energy production. While ICT currently consumes only a minor percentage of the total energy used worldwide, it is increasing at a rapid rate. Along with greater energy demands are the associated increases in water consumption and greenhouse gas production, challenging the process sustainability. Thus, energy efficiency and sustainability should be a consideration in all proposals. Both experimental and computational approaches will be needed as well as potentially data mining and analytics to accelerate the co-design process.

All proposals should describe the implications of the proposed activities on the education of the skilled technical workforce in co-design approaches, and semiconductor industry. (Skilled technical workforce refers broadly to settings ranging from technical institutes and community colleges to advanced research.) The development of a skilled workforce versed in the organizational and technical aspects of co-design is critical for advancing semiconductor technologies and needs to be addressed. This program aims to advance STEM education and training of a future skilled workforce for semiconductor technologies spanning across the many disciplines required to bring these technologies into reality, such as materials, chemistry, physics, and chemical, industrial, or electrical and computer engineering. Example job roles that this solicitation aims to develop include but are not limited to manufacturing technicians, process, and semiconductor design engineers. All teams responding to this solicitation must include a "*Educational and Workforce Development*" section describing the proposed activities and expected impact of the grant.

The results of this program, when translated to practice, should advance the US semiconductor manufacturing industry and organizational structures, enable new capabilities among a broad range of related industries, enhance U.S. competitiveness in developing and producing new products, bolstering economic growth, benefiting society at large, and educating students and other workforce participants with the skills required for leadership in the burgeoning industries. Results will help the manufacturing enterprise minimize environmental impact; reduce energy consumption in both the manufacturing and use; manage waste; and optimize fabrication/design security and the use of resources.

FuSe proposals should demonstrate the need for sustained support of a multidisciplinary team using a convergence research approach. Inclusion of minority-serving institutions is encouraged. Proposals must describe why the project team is appropriate to realize the project's goals and how the team will assure effective collaboration in the co-design process. A compelling rationale must be presented for a multi-organization structure of the project. Therefore, proposers responding to this solicitation must include a "*Project Management and Collaboration*" section.

Proposals may take advantage of significant efforts underway to improve the nation's competitiveness in the semiconductor and advanced electronic and computing fields. For example, proposals may leverage activities of other initiatives in US government agencies and Industry. Proposers are also encouraged to leverage existing educational programs within or outside of NSF in creative ways.

Proposals submitted in response to this solicitation must address both semiconductor research and semiconductor workforce development in a broad sense, and they must integrate a combination of innovative tools and techniques from computational, engineering and materials sciences.

Proposals to *FuSe* should be interdisciplinary in structure including relevant experts and disciplines from across the CISE, ENG, TIP, EDU and MPS directorates.

II. PROGRAM DESCRIPTION

II. A. PROGRAM DESCRIPTION

This Future of Semiconductors (*FuSe*) solicitation will support fundamental research, training, and education research on co-design of semiconductor systems in the *FuSe-REG* description below. Proposals of all sizes are encouraged. The budget should reflect the scope of the problem and team size required to accomplish the research goals. The *FuSe-REG* proposals should address one of the topic areas presented below in this current solicitation:

FuSe-REG: Future of Semiconductors Research and Education Grants

Each proposal should have an explicit co-design research agenda that spans at least two of the three areas of materials-devices-systems. The proposal can be centered in one of the topic areas (Domain-Specific Computing, Advanced Function and High Performance by Heterogeneous Integration, or New Materials for Energy Efficient, Enhanced-Performance, and Sustainable Semiconductor-Based Systems), however co-design across both the areas of materials-devices-systems and topic areas is encouraged. The solicitation discussion of each topic area is not intended to be limiting, and the examples mentioned do not indicate they are of any special interest to the NSF. They are presented only to illustrate possible considerations in each topic area. Successful proposals will explain why the proposed research will substantially improve chosen evaluation metrics. Project descriptions must be comprehensive, well-integrated, and convincing that the collaborative contributions of the project team will be greater than the sum of each individual contribution. If possible, the proposals are encouraged to move from discovery to prototyping or use demonstration. Investigators are encouraged to seek out partnerships in a wide and diverse class of institutions that together can provide new and compelling approaches to the proposed research.

Awards will support fundamental, multidisciplinary (minimum of two PIs), and integrative research and education to enable co-design research, with sustainable

development, as a key consideration and application in one or more of the topic areas described below. *FuSe-REG* awards will provide up to three years of support at a level up to \$2M per award. The funding is intended to support PIs with complementary expertise, graduate students, some senior personnel (including post-doctoral researchers), and their collective research and training needs (e.g., materials, supplies and travel). *FuSe-REG* proposals must describe the current state of art in the relevant application area and the specific challenges that will be addressed by the proposed research. They must present a compelling rationale and convincing technical approach to co-design to address these challenges. Proposals should clearly explain how the proposed research will provide new capabilities that may impact the future of semiconductors, including capabilities in education and workforce development. A rationale for the work, role of participating PIs, and budget must be presented. Proposals including a translation to industry plan are desirable. Proposals should explain the potential benefits and challenges of co-design within the application area to the economy, environment, and society. Partnerships with two-year, minority-serving, and other educational institutions to educate the skilled technical workforce are encouraged.

Education and Workforce Development Guidelines

Recognizing that a necessary element of the future of semiconductors is developing the human capacity for future research, all research proposals must address how their work will contribute to education and workforce development. The research proposals must include within the Broader Impact Description a section titled "*Education and Workforce Development Plan*" that clearly articulates the education and workforce development goals. Enough details regarding the proposed educational and workforce development activities targeted at equipping students with skills and/or up-skilling the existing workforce needed in the future technologies should be provided. For proposals that plan to engage students, a plan for recruitment, retention, and graduation of students from under-represented minority groups should be clearly discussed. In addition, the plans for assessing the effectiveness of the education and workforce development plan should be presented. PIs are strongly encouraged to develop the "*Education and Workforce Development Plan*" in collaboration with experts in education, curriculum development, and academic assessment. Emphasis should be placed on the efforts that will be made to integrate the research and education & workforce development components.

Topic 1: Collaborative Research in Domain-Specific Computing

Modern computing systems rely on a deep abstraction stack of technology ranging from high-level applications through computer and network systems, to circuits, devices, and materials. In this solicitation we invite proposals that re-imagine computing systems by collaborating across traditional levels of the abstraction stack, or by breaking or circumventing that traditional stack completely. This can be done by considering new ways of looking at the traditional computing stack, by enabling communication across layers of the stack including not only hardware/software co-design, but by approaching design from a completely new viewpoint. Taken as a whole, these approaches can be broadly categorized as **Domain-Specific Computing**. Examples of domains of interest are (but are not limited to):

Application Domain:

- Artificial intelligence and machine learning including foundational models as well as hardware/software support for application domains e.g., materials discovery, circuit design, robotics, physics-based simulations etc., brain-inspired computing, large data processing, financial computing, wireless next-G systems, graph-based, genomic, and sparse-data computing, etc. Design of highly distributed and heterogenous computer and network systems are also of interest.

Computing Strategy Domain:

- Non-von Neumann architectures, self-organizing, self-correcting, and adaptive architectures, approximate computing, Cloud-Edge-IoT computing continuum, Virtualization in edge data centers, quantum inspired classical computing, Ising machines and synchronization in oscillators, memcomputing, computing paradigms inspired by models of physics and biology, analog and mixed signal computing, tensor processing, privacy preserving, secure, trustworthy, and error-tolerant approaches, etc. ASICs for efficient and low power systems are also entertained.

Technology Domain:

- Processing in memory, MRAMS and non-volatile memory including their use in the context of AI accelerators 3D and/or 2.5D architectures, circuits and systems for 5G/6G, classical computing with probabilistic bits (p-bits), co-integration of CMOS with X technologies (X=emerging devices in significant numbers), emerging technologies for memory, logic, and interconnect, including non-charge-based devices and systems, AI/ML inspired and/or novel approaches to design automation of micro- and nano- systems including methods, energy-efficient and sustainable approaches, etc.

The overall goal is to increase the performance, energy efficiency, usability, sustainability, or other aspects of computing systems by exploiting the characteristics of a broad domain including e.g., high performance, extremely scalable, distributed, heterogeneous, large-scale computing systems. Successful proposals will explain why the proposed research is exploring a specific domain, and how the proposed activities will substantially improve chosen evaluation metrics. System prototyping by taking advantage of semiconductor fabs is encouraged. Project descriptions must be comprehensive, well-integrated, and convincing that the collaborative contributions of the project team will be greater than the sum of each individual contribution. Investigators are especially encouraged to seek out partnerships in a wide and diverse class of institutions that together can provide new and compelling approaches to the proposed research. Details should be included about how the chosen domain features are central to the research goals.

Topic 2: Advanced Function and High Performance by Heterogeneous Integration

This topic aims to accelerate the adoption of advanced electronic, memory, photonic, energy, or sensing devices & components in the semiconductor technology to enable cutting-edge functionality. It supports holistic co-design of heterogeneous systems across devices, circuits, and algorithms, by integrating novel components and materials compatible with CMOS or future technologies. Co-design projects envisioned in this topic would focus on system-level strategies enabling the most robust, compact, energy-efficient, and cost-effective solutions that address how analog and digital information is sensed, processed, stored, communicated, and actuated upon. The research planned in this track should include co-optimization of functionalities, potentially crossing boundaries of sensing, analog processing, digital processing, machine learning and detection etc., enabling smarter world-machine interfaces as outlined by the semiconductor industry's decadal plan¹ or sustained always-available communication.

Examples that embrace heterogeneous integration with advanced functionalities are (but are not limited to):

Heterogeneous Integration Heterogeneous Technology Ingredients:

- 3D-based hetero-integration of different functionalities such as – but not limited to - CMOS platform integration with advanced analog hardware for high energy efficiency, high speed, compactness, tailored bandwidth/frequency/temperature, and scalability as well as potentially novel memories and sensors.
- Bio-inspired sensing-to-action with machine learning architectures balancing power/energy and cost of local or in-memory processing with global considerations.

- Millimeter-wave and next-generation communications. Secure analog/RF and mixed-signal technologies.
- Microelectronics accelerating the adoption of wide-bandgap semiconductor technology and increasing the integration of power-conversion with sensing and communication, for high power density, high-bandwidth interconnects.

Package Platform Heterogeneous Integration:

- Platform integration and development supporting versatile chiplet-based system design. Enabling processing and design tools associated with new materials, devices, and integrated systems.
- Advanced active, high-density, and functional packaging and processing approaches.
- Novel thermal management techniques to manage high power and high-power densities especially in 3D configurations.
- Improved power delivery networks.

Heterogenous Integration System Design Tools and Characterization Technologies:

- New manufacturing and key metrologies for use in characterization, functionality validation, process improvements, failure analysis and fault isolation.
- System, platform, circuit, interface, and packaging level design tools.
- System-technology co-optimization framework for ease of design and validation of chiplet systems and for effective use of foundry offerings.

FuSe proposals on this topic area must describe the current state-of-the-art in the relevant application area, the specific challenges that will be addressed by the proposed research and include the plans to validate or demonstrate the co-designs relevant to the current and advanced industry technologies. Prototyping design and fabrication, at all levels, through NSF supported centers and fabs or by collaborations with industrial foundries are encouraged. A device-focused *FuSe* project should develop methodologies or computer simulation tools to establish intrinsic performance limits of the targeted functionality. The project also should carry out research on devices, circuits, algorithms, and fabrication or assembly processes to minimize the extrinsic variability of components, as well as to allow for low-cost and potentially wide-scale deployment. *FuSe* proposals should articulate the underlying fundamental research and the innovation anticipated, in terms of models, tools and/or simulations that demonstrate how the proposed hetero-integration and/or analog mixed-signal designs enable dramatic improvements in productivity and predictability. Successful *FuSe* proposals should illuminate how the advancement will have broader impact on the design and adaptation of the related technologies to be integrated with the future of semiconductor technology.

Topic 3: New Materials for Energy Efficient, Enhanced-Performance and Sustainable Semiconductor-Based Systems

The continued advances in microelectronic miniaturization with smaller and more powerful devices is taxed with a concomitant increase in energy consumption. While the energy efficiency of electronics has been steadily improving, this trend is being challenged with the ever-increasing number of computations needed for all aspects of modern life. The field is currently approaching a paradigm shift as traditional Moore's law silicon transistor scaling is no longer yielding commensurate energy efficiency benefits. This comes at a time when much more computing power is needed to deal with emerging data-intensive applications that rely on artificial intelligence (AI) and machine learning (ML) to generate new sectors of the economy and to revitalize American manufacturing.

Proposals are solicited for convergent approaches employing the co-design of scalable atomically precise materials synthesis and processing with device design for energy efficient computing and communication systems. Proposals that emphasize energy-efficient applications, sustainable and energy-efficient manufacturing processes using earth-abundant and nontoxic materials, minimizing water usage, and striving for zero waste are prioritized. Demonstration of materials properties within an actual application or similar prototyping is welcome.

Potential areas of interest are (but are not limited to):

- Materials enabling novel, energy-efficient logic and/or memory functions, such as two-dimensional or phase change materials and complex oxides.
- Materials that enable new non-von-Neumann logic, such as brain inspired/neuromorphic computing.
- Materials and interfaces of relevance to packaging and hetero-integration architectures.
- Materials with ultrahigh electrical conductivity and ultra-low-K dielectric at the relevant dimensions for modern electronic devices.
- Materials with high thermal conductivity at the relevant dimensions, which supports hetero-integration in devices and packaging as described in Topic 2.
- Materials to enable patterning with the next generation of extreme ultraviolet (EUV) and high-numerical-aperture EUV lithography photo resists as well as novel bottom-up patterning approaches such as directed self-assembly.
- Materials by design, including control of interfaces, to improve packaging at the relevant dimensions (see Topic 2 for more information).
- Materials that enable electrical signal interfacing between biological materials and CMOS.
- Materials for high-efficiency power devices, such as wide-gap semiconductors.
- Processes that enable novel device architectures, especially those that use earth-abundant elements and nontoxic chemicals.
- Development of new transport (thermal, electrical, ...) characterization and high-resolution imaging technologies for the characterization of these materials at the atomic/molecular level and for the mapping of defects.

FuSe proposals must describe the current state of the art in the relevant application area and the specific challenges that will be addressed by the proposed research. They must present a compelling rationale and convincing technical approach for co-design to address these challenges. Proposals must clearly explain how the materials development will ultimately improve existing devices or lead to new device designs, devices or system capabilities that are not currently available. Proposals should be multidisciplinary and include appropriate metrics for material performance and resultant device/system, energy usage, as well as education and workforce development in the materials sector necessary for fostering co-design semiconductor concepts. While not a requirement, proposals that include a potential path for manufacturing scale-up, such as prototyping, and translation into industry are desirable. Proposals should explicitly address the potential benefits and challenges of co-design within the application area to the economy, environment and to society.

II. B. ROLE OF INDUSTRY FUNDING PARTNERS

The companies specifically listed in this solicitation (Ericsson, IBM, Intel, and Samsung) have committed to providing annual contributions to NSF for the purpose of funding proposals awarded under this solicitation. The reference to "industry partners" in this section refers specifically to these four entities and their role as funding partners in this solicitation. The contributions from these partners have been agreed upon based on a shared belief in the importance of making progress in the research, education, and workforce development goals identified in this program.

Prior to award, these industry partners *will not participate in or observe the review of proposals*. After completion of the merit review process, NSF may share with representatives of the industry partners the subset of proposals which are under consideration for funding by NSF, along with corresponding unattributed reviews and panel summaries. Proprietary or privileged information provided by the PI in the separate "Single Copy Documents" section of the proposal will not be shared with reviewers or industry partner representatives. NSF will take into consideration the input of all industry funding partners prior to making final funding decisions but will retain final authority for making all award decisions.

NSF will administer awards under the Program in accordance with standard NSF policies and procedures. All awards will be subject to standard NSF terms and conditions. Industry partners will not oversee the activities or use of funds by grantees under this Program but may engage with grantees as outlined below. Specifically, post-award, industry partners may make available direct contributions of resources including, but not limited to, software (prototypes or products), data sets, and/or other computing infrastructure. No awardee will be required to use any industry partner's offered contributions.

After an award, an industry partner may also arrange to fund its own personnel as researchers to directly participate, part-time or full-time, with awardee project personnel. These arrangements will be optional and upon the mutual consent of the industry partner and respective awardee institutions. No awardee will be required to accept an industry partner researcher.

NSF will share annual and final project reports with industry partners after those reports have been reviewed and accepted by the cognizant NSF Program Officer.

The award terms and conditions will state that awardees shall grant to the sponsoring parties (NSF and all the industry partners named in the award letter) a non-exclusive, worldwide, paid-up, non-transferable, irrevocable royalty-free license to all intellectual property rights in any inventions conceived or first reduced to practice in the performance of the Program work under the funding agreement. **[Note: the Bayh-Dole Act provides similar rights to the U.S. Government for patents on inventions made under federal funding.] The license to each industry partner will include its subsidiaries and contractors, at its discretion, to the extent that such use is specifically in connection with the industry partner's products and/or services.** Awardees shall grant the license to each industry partner named in the award letter unless the industry partner opts to decline the license. Such license shall not extend to awardees' background intellectual property; however, individual awardees and industry partners may negotiate, voluntarily, in good faith, a mutually acceptable resolution to background intellectual property, if desired, **though NSF shall neither enforce nor participate in any such negotiations between awardees and industry partners, nor will any funds provided by NSF to the awardee be contingent upon such negotiations.** No rights or licenses are granted by the industry partners. Based on the contributions from the industry partners, Intel and Samsung will be named as sponsoring parties for all awards, and Ericsson and IBM will be named as sponsoring parties in a partial set. Awardees may delay the publishing of data and software describing inventions to first permit the filing of patent applications. That said, NSF terms and conditions will require that awardees promptly publish all results, data, and software generated in performance of the research.

Proposals to this program may not list or describe any kind of agreed or assumed arrangement to use the contributions described above or any other collaborative arrangement with this solicitation's industry partners, beyond what is described in the eligibility section of this solicitation. Proposals that include such arrangements or collaborations with these partners will be returned without review. Exception: Proposers are not restricted from making use of the widely accessible products or services of industry partners.

Proposers to this program should not directly contact industry partners with questions pertaining to their company's participation in this solicitation. All questions should be directed to the NSF program points of contact listed in the solicitation.

¹ [Decadal Plan for Semiconductors - SRC](#)

III. AWARD INFORMATION

Approximately 20 awards are anticipated, each up to \$2,000,000 total and up to 3 years in duration, subject to the availability of funds and quality of proposals received.

The budget should be commensurate with the scope of the proposed research. 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:

The categories of proposers eligible to submit proposals to the National Science Foundation are identified in the *NSF Proposal & Award Policies & Procedures Guide* (PAPPG), Chapter I.E. Unaffiliated individuals are not eligible to submit proposals in response to this solicitation.

Who May Serve as PI:

By the submission deadline, any PI, co-PI, or other senior project personnel must hold either:

- a tenured or tenure-track position, or
- a primary, full-time, paid appointment in a research or teaching position

with exceptions granted for family or medical leave, as determined by the submitting institution.

Individuals with primary appointments at for-profit non-academic organizations, or at overseas branch campuses of U.S. IHEs are not eligible.

Researchers from foreign academic institutions who contribute essential expertise to the project may participate as senior personnel or collaborators but may not receive NSF support.

Limit on Number of Proposals per Organization:

There are no restrictions or limits.

Limit on Number of Proposals per PI or co-PI: 2

An investigator may only serve as a PI, co-PI or Senior Personnel on only **two proposals**, including sub-awardees, submitted in response to this solicitation. If an investigator exceeds this limit, proposals received within the limit will be accepted based on earliest date and time of proposal submission. The remainder will be returned without review. This limitation includes proposals submitted by a lead organization and any subawards included as part of a proposal involving multiple organizations.

Additional Eligibility Info:

Guidelines for the Participation of Partner Companies and Affiliated Individuals in Proposals:

Guidelines for Partner Companies:

A partner company is not permitted to participate in proposals to the program.

Guidelines for Individuals Affiliated with Partner Companies:

Individuals affiliated with a partner company may participate in proposals to the program subject to certain limitations and allowances. These limitations and allowances apply to individuals who are currently employed by, consulting for, or on an active agreement to provide services for the company. Specifically:

- Such individuals may not participate in their capacity with the company.
- Such individuals may participate if they (i) hold a primary appointment at another organization not partnered on the program (e.g., a primary academic appointment at an institution of higher education), as applicable to and defined by that organization, and (ii) do so strictly in their capacity at that other organization.

Proposals that violate the above restrictions may 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=papppg. 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.

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 Research.gov. PAPPG Chapter II.E.3 provides additional information on collaborative proposals.

See PAPPG Chapter II.D.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.

Cover Sheet:

Title: Proposal titles should begin with "FuSe:" then the title.

Project Description:

In addition to the content specified in the PAPPG, including the requirement for a separate section labeled "Broader Impacts", the Project Description should contain specific additional sections with the following titles required, as indicated, and described in the above Sections I and II:

1. Education and Workforce Development Plan
2. Project Management and Collaboration

The "Education and Workforce Development" section must describe the proposed activities and expected impact of the grant in the education and development of a co-design workforce.

The "Project Management and Collaboration" section must describe why the project team is appropriate to realize the project's goals and how the team will assure effective collaboration in the co-design process. A compelling rationale must be presented for a multi-organization structure of the project.

Letters of Collaboration:

Letters of collaboration should follow the format specified in the PAPPG Chapter II.D.2. Proposers must not include letters of collaboration from any of the participating industry partners listed in this solicitation. Any proposal that deviates from these guidelines will be returned without review.

Single Copy Documents (if applicable):

Proposers may wish to include proprietary or privileged information as part of their proposals. Per PAPPG Chapter II.E.1, NSF defines such information as "patentable ideas, trade secrets, privileged or confidential commercial or financial information, disclosure of which may harm the proposer". While providing this information is not required, a proposer to the *FuSe* program who wishes to include proprietary or privileged information *must* provide all such information in the proposal as a Single-Copy Document. That is, this information shall not appear in other parts of the proposal. In keeping with NSF's practice, the Single Copy Document will not be shared with reviewers or industry partners.

While NSF will make every effort to prevent unauthorized access to such material, the Foundation is not responsible or in any way liable for the release of such material.

Note: Because proprietary or privileged information may only be specified in the Single Copy Document, PIs should not check the "Proprietary or Privileged Information" box on the Cover Sheet; that box applies only to such content appearing in the body of a proposal.

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 24, 2023

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 Research.gov 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 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 *Leading the World in Discovery and Innovation, STEM Talent Development and the Delivery of Benefits from Research - NSF Strategic Plan for Fiscal Years (FY) 2022 - 2026*. 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.D.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.D.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

- What does the project identify an overarching foundational problem which requires a co-design approach to accelerate the eventual manufacture?
- Are energy-efficient, sustainable device manufacturing processes using earth-abundant and nontoxic materials, minimizing water usage, and is striving for zero waste emphasized?
- Identify the integrated multi-disciplinary research agenda or plan presented that defines the roles of all participants. Is the composition of the multidisciplinary team appropriate for the scope of the proposed activities and engage PIs from along the technology stack?
- How are the research tasks synthetically integrated across the identified research focus area? Does the proposal address the associated research risks and present mitigation plans?
- How effectively does the proposal present a compelling argument that the proposed educational activities will equip students and other workforce participants with the skills to engage in the evolving semiconductor industry and broaden participation by building on best practices and evidence-based approaches?

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 Site Visit Review.

Additional Review Criteria:

Solicitation specific review criteria are provided in the FuSe solicitation as elaborations of the NSF Intellectual Merit and Broader Impacts criteria. These additional criteria will help focus attention on factors that increase the influence on the broader industry, and also highlight considerations unique to the goals of the program.

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 or the Division of Acquisition and Cooperative Support 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 an NSF Grants and Agreements Officer. 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.

Administrative and National Policy Requirements

Build America, Buy America

As expressed in Executive Order 14005, *Ensuring the Future is Made in All of America by All of America's Workers* (86 FR 7475), it is the policy of the executive branch to use terms and conditions of Federal financial assistance awards to maximize, consistent with law, the use of goods, products, and materials produced in, and services offered in, the United States.

Consistent with the requirements of the Build America, Buy America Act (Pub. L. 117-58, Division G, Title IX, Subtitle A, November 15, 2021), no funding made available through this funding opportunity may be obligated for an award unless all iron, steel, manufactured products, and construction materials used in the project are produced in the United States. For additional information, visit NSF's [Build America, Buy America](#) webpage.

Special Award Conditions:

Acknowledgement of Support:

Awardees will be required to include appropriate acknowledgment of NSF and industry partners support in reports and/or publications on work performed under an award. An example of such an acknowledgement would be: *"This material is based upon work supported by the National Science Foundation under grant no. (NSF grant number) and is supported in part by funds from federal agency and industry partners as specified in the Future of Semiconductors (FuSe) program."*

Industry Partner Engagement with Program Awardees:

Once the Program awards have been issued, each of the industry partners may engage with the awardees in the following way

- Attend annual PI meetings.
- Provide software (prototypes or products), hardware (prototypes or products), semiconductor design collateral, data sets, other computing infrastructure, and/or other such support to all awardees, although awardees will not be required to use these offered contributions.
- Provide resources (e.g., fabrication and/or packaging of research prototypes, access to test and/or instrumentation facilities) and opportunities (e.g., seminars, internships) to all awardees, although awardees will not be required to use these offered contributions.
- NSF requires awardees to submit annual project reports and, at the completion of the award, a final project report. NSF will share these reports with the industry partners after they have been reviewed and accepted by the cognizant NSF Program Officer. The industrial partner may opt to decline to receive these reports. Further, industrial partners agree not to disclose any non-public information to any institution of higher education or organization outside of the company.
- An industry partner may also arrange to fund its own personnel as researchers to directly participate, part-time or full-time, with awardee project personnel. These arrangements will be optional and upon the mutual consent of the industry partner and respective awardee institutions. No awardee will be required to accept an industry partner researcher.

Additionally, proposers should plan that NSF or an NSF-funded coordination entity will facilitate engagement between NSF, partners, and awardees, including on research dissemination, workshops, collaborative engagements, and other activities that support nurturing and growing the *FuSe* community. Awardees must engage with NSF and/or the coordination entity on these activities throughout the duration of the grant.

Intellectual Property:

Awardees shall grant to industry partners named in the award letter, a non-exclusive, worldwide, paid-up, non-transferable, irrevocable royalty-free license to all intellectual property rights in any inventions conceived or first reduced to practice in the performance of the Program work under the funding agreement. [Note: the Bayh-Dole Act provides similar rights to the U.S. Government for patents on inventions made under federal funding.] The license to each industry partner will include its subsidiaries and contractors, at its discretion, to the extent that such use is specifically in connection with the industry partner's products and/or services. Awardees shall grant the license to each industry partner named in the award letter unless the industry partner opts to decline the license. Such license shall not extend to awardees' background intellectual property; however, individual awardees and industry partners may negotiate, voluntarily, in good faith, a mutually acceptable resolution to background intellectual property, if desired, though *NSF shall neither enforce nor participate in any such negotiations between awardees and industry partners, nor will any funds provided by NSF to the awardee be contingent upon such negotiations.* No rights or licenses are granted by the industry partners. Awardees may delay the publishing of data and software describing inventions to first permit the filing of patent applications. That said, NSF terms and conditions will require that awardees promptly publish all results, data, and software generated in performance of the research.

For primarily research projects funded by the *FuSe* Program, *awardees of the program will agree to distribute all final source code that has been authored while working on a FuSe program award under a Berkeley Software Distribution (BSD), Apache, or other equivalent open-source license.* Software licenses that require as a condition of use, modification and/or distribution that the software or other software incorporated into, derived from, or distributed with the software be licensed by the user to third parties for the purpose of making and/or distributing derivative works are not permitted. Licenses that are not appropriate include any version of GNU's General Public License (GPL) or Lesser/Library GPL (LGPL), the Artistic License (e.g., PERL), or the Mozilla Public License. Exceptions to this policy may be granted by NSF and the industrial participants to address the problem of participation in established open-source objects or standards already licensed under GPL, LGPL, or other copyright open-source licenses.

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:

- Nadia A. El-Masry, telephone: (703) 292-4975, email: fuse1@nsf.gov
- Geoffrey Brown, telephone: (703) 292-4979, email: fuse1@nsf.gov
- Z. C. Ying, telephone: (703) 292-8428, email: fuse1@nsf.gov
- Sankar Basu, telephone: (703) 292-7843, email: fuse1@nsf.gov
- Erik Brunvand, telephone: (703) 292-8950, email: fuse1@nsf.gov
- Premjeet Chahal, telephone: (703) 292-7264, email: fuse1@nsf.gov
- Rosa Lukaszew, telephone: (703) 292-8103, email: fuse1@nsf.gov
- Birgit Schwenzer, telephone: (703) 292-4771, email: fuse1@nsf.gov
- George M. Janini, telephone: (703) 292-4971, email: fuse1@nsf.gov
- Vinod K. Lohani, telephone: (703) 292-2330, email: fuse1@nsf.gov
- Eleanor Sayre, telephone: (703) 292-2997, email: fuse1@nsf.gov

For questions related to the use of NSF systems contact:

- NSF Help Desk: 1-800-673-6188
- 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 (FASSED) 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.F.7 for instructions regarding preparation of these types of proposals.

The National Science Foundation has Telephonic Device for the Deaf (TDD) and Federal Information Relay Service (FIRS) capabilities that enable individuals with hearing impairments to communicate with the Foundation about NSF programs, employment or general information. TDD may be accessed at (703) 292-5090 and (800) 281-8749, FIRS at (800) 877-8339.

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

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