

# National Science Foundation - Future of Semiconductors (FuSe2)

## PROGRAM SOLICITATION

NSF 24-521

## REPLACES DOCUMENT(S):

NSF 23-552



### National Science Foundation

Directorate for Engineering

Engineering Education and Centers

Division of Electrical, Communications and Cyber Systems

Division of Civil, Mechanical and Manufacturing Innovation

Division of Chemical, Bioengineering, Environmental and Transport Systems

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.



Samsung



Micron Technology, Inc.

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

March 14, 2024

## IMPORTANT INFORMATION AND REVISION NOTES

This solicitation aims to cultivate holistic, co-design efforts that enable rapid progress in new semiconductor technologies. The program leverages partnerships between industry and academic institutions to spur innovation and technology transfer, to inform research needs, and to train the future workforce.

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

Industry partners co-funding this solicitation include:

- Ericsson
- Intel Corporation
- Micron Technology
- Samsung

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:

Future of Semiconductors (FuSe2)

#### Synopsis of Program:

Semiconductor microelectronic systems are at a crossroads. Continued advances in capabilities and reductions in costs across computing, sensing, and communications are threatened. Semiconductor technology has long advanced following the trends in miniaturization characterized by *Moore's Law*, underpinned by new materials, processes, devices, and architectures. However, the developments in these underpinning areas have often progressed independent of the application area, which has delayed their incorporation into next-generation technologies. Closing this gap is required to optimize future progress. Semiconductor materials, devices, and computing must be optimally *co-designed*, with simultaneous consideration of elements across the technology chain.

The benefits of co-design to advance semiconductor technology have been widely recognized in a variety of government and industry studies. A 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 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 Future of Semiconductors (FuSe2) solicitation is to cultivate holistic, co-design approaches to fundamental research and workforce education and training in order 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 spurring this innovation, enabling technology transfer, informing research infrastructure needs, and training the future workforce.

The program seeks to fund research as well as education 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 including the minority-serving institutions with a goal to advance semiconductor design and manufacturing. NSF encourages bold, potentially transformative activities that address future semiconductor design and manufacturing challenges as well as shortages in the skilled scientists, engineers, and technician workforce. This solicitation encourages proposers to take a holistic perspective on workforce development, considering the participation of the full spectrum of diverse talent in STEM career paths, advanced technologies, and research capabilities. All proposals must include education and workforce development plans integrated with the proposed research activities. This solicitation seeks proposals to perform fundamental research to enable a new paradigm in semiconductor capabilities through **research grants focused on co-design approaches**. Teams of all sizes, with a minimum of a PI and a co-PI, are encouraged.

**Future of Semiconductor Co-Design Research and Education Grants (FuSe2)** - Awards will be supported in FY 2024 up to \$2M per award for up to a three-year grant period, commensurate with project scope and team size. This program seeks to fund collaborative team research that transcends the traditional boundaries of individual disciplines to achieve program goals.

The three research topic areas identified for support in FY 2024 under this solicitation are:

**Topic 1.** Collaborative Research in Domain-Specific Computing.

**Topic 2.** Advanced Function and High-Performance by Heterogenous Integration.

**Topic 3.** 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 in the title 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](mailto:fuse1@nsf.gov)
- Z. C. Ying, telephone: (703) 292-8428, email: [fuse1@nsf.gov](mailto:fuse1@nsf.gov)
- Geoffrey Brown, telephone: (703) 292-4979, email: [fuse1@nsf.gov](mailto:fuse1@nsf.gov)
- Jason Hallstrom, telephone: 703-292-2997, email: [jahallst@nsf.gov](mailto:jahallst@nsf.gov)
- Sankar Basu, telephone: (703) 292-7843, email: [fuse1@nsf.gov](mailto:fuse1@nsf.gov)
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- Rosa Lukaszew, telephone: (703) 292-8103, email: [fuse1@nsf.gov](mailto:fuse1@nsf.gov)
- Paul A. Lane, telephone: (703) 292-2453, email: [plane@nsf.gov](mailto:plane@nsf.gov)
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- Xiaobo S. Hu, telephone: (703) 292-8910, email: [xhu@nsf.gov](mailto:xhu@nsf.gov)
- Sumanta Acharya, telephone: (703) 292-4509, email: [sacharya@nsf.gov](mailto:sacharya@nsf.gov)
- Vinod K. Lohani, telephone: (703) 292-2330, email: [fuse1@nsf.gov](mailto:fuse1@nsf.gov)
- Eleanor Sayre, telephone: (703) 292-2997, email: [fuse1@nsf.gov](mailto: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 2024, depending on the quality of submissions and the availability of funds:

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.

**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:**

Proposals may only be submitted by the following:

- Non-profit, non-academic organizations: Independent museums, observatories, research laboratories, professional societies and similar organizations located in the U.S. that are directly associated with educational or research activities.
- Institutions of Higher Education (IHEs) - Two- and four-year IHEs (including community colleges) accredited in, and having a campus located in the US, acting on behalf of their faculty members.
- Tribal Nations: An American Indian or Alaska Native tribe, band, nation, pueblo, village, or community that the Secretary of the Interior acknowledges as a federally recognized tribe pursuant to the Federally Recognized Indian Tribe List Act of 1994, 25 U.S.C. §§ 5130-5131.

##### **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**.

An investigator who is a PI or co-PI of a FuSe award based on a proposal submitted in response to the previous FuSe solicitation, [NSF 23-552](#), cannot be a PI or co-PI for this FuSe2 solicitation, but may serve as Senior Personnel. Proposals violating this limitation will be returned without review.

#### Limit on Number of Proposals per Organization:

There are no restrictions or limits.

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

Each FuSe2 project requires a minimum of one PI and one co-PI.

An investigator may serve as a PI, co-PI or Senior Personnel on only **ONE proposal**, including subawardees, 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 subaward 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](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](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):

March 14, 2024

## 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 (*FuSe2*) 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 *FuSe2* 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 considering at least two of the areas in the technology stack (materials, devices, and systems) in the research approach is required for each proposal. Additional considerations of manufacturability, thermal management, recyclability, and impact on the environment are encouraged.

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 *FuSe2* 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.

*FuSe2* 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. *FuSe2* 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 an **"Education 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.

*FuSe2* 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 ensure effective collaboration in the co-design process. A compelling rationale must be presented for the 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 education and 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 *FuSe2* should be interdisciplinary in structure including relevant experts and disciplines from across the CISE, EDU, ENG, MPS, and TIP directorates.

## II. PROGRAM DESCRIPTION

### A. PROGRAM DESCRIPTION

This Future of Semiconductors (*FuSe2*) solicitation will support fundamental research, training, and educational research on co-design of semiconductor systems in the *FuSe2* 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 *FuSe2* proposals should address one of the topic areas presented below in this current solicitation:

#### ***FuSe2*: 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 one PI and one co-PI**), 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. *FuSe2* 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). *FuSe2* 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 proposals must address how their work will contribute to education and workforce development. The 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 education 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 historically underrepresented minority groups in STEM should be clearly discussed. In addition, 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 integrate the research and education & workforce development components.

### Topic 1: Collaborative Research in Domain-Specific Computing

Modern computing systems rely on a deep technology stack, spanning high-level applications, computer and network platforms, and the underlying circuits, devices, and materials used to realize those platforms. We invite proposals that re-imagine computing systems through co-design across this technology stack, or by reinventing the stack altogether. This can be done by considering new ways of looking at the traditional computing stack, by enabling new types of communication across layers of the stack, or by approaching computing system design from a completely new viewpoint. Taken as a whole, these approaches are broadly categorized as **Domain-Specific Computing**. Example domains of interest include (but are not limited to) Application Domains, Computing Strategy Domains, and Technology Domains:

#### Application Domain:

- Compute/data-intensive applications that significantly challenge today's computing and communication fabrics. Examples include artificial intelligence and machine learning (including foundational models), large data analytics, financial computing, graph processing, genomics, combinatorics, physics-based modeling and simulation (e.g., molecular dynamics), and sparse-data computing. Domain-specific compute languages and compiler technology that addresses multiple hardware targets is of interest. Orchestration of multiple hardware accelerators to support a given application or workload is also of interest.
- Highly distributed and heterogeneous computer and network systems, including wireless next-G systems.
- Domain-specific programming languages and compiler technologies that address multiple hardware targets.
- Orchestration of multiple hardware accelerators and memory/storage tiers to support a given application, workload, or domain.
- Advanced electronic design and automation support for targeted application domains, e.g., supporting materials discovery, circuit design, etc.

#### Computing Strategy Domain:

- Non-von Neumann architectures (e.g., application or algorithm utilization of near or in-memory compute), memory-movement minimization through spatial or other distributed memory architectures applied to the domain of interest.
- Emerging computing paradigms, such as quantum-inspired classical computing, biology/physics-inspired computing, Ising machines, and MemComputing.
- Emerging memory and shared memory architectures, with the ability to significantly accelerate memory-intensive applications, from the cloud to the edge.
- Analog computing, including analog in-memory computing and mixed-signal computing for reducing data conversion overhead, tensor processing, etc.
- ASICs for efficient and low power systems.
- Memory-movement minimization through spatial or other distributed memory architectures.
- Self-organizing, self-correcting, and/or adaptive architectures; approximate computing; and other error-tolerant approaches.

- The cloud-edge-IoT computing continuum, including virtualization in edge data centers.
- Disaggregated systems, memory pooled systems.
- Privacy preserving, secure, trustworthy computing.
- Electronic design automation tools for emerging computing paradigms.

#### Technology Domain:

- Near and in-memory computing based on emerging memory technologies such as RRAM, MRAM, FeFET, ECRAM, and others, and their use in the context of specific applications.
- Computing-enabled storage.
- Classical computing with probabilistic bits (p-bits).
- Circuits and architectures for next-G systems.
- Emerging technologies for memory, logic, and interconnect, including non-charge-based devices and systems.
- Co-integration of CMOS with X technologies (X=emerging devices in significant numbers).
- Domain-specific compute architectures that fully leverage 3D and/or 2.5D integration proximity or heterogeneity and associated design tools and approaches for 3D and/or 2.5D architectures.
- AI/ML-inspired and/or novel approaches to design automation of micro- and nano-systems.

The overall goal is to increase the performance, energy efficiency, usability, sustainability, and other aspects of computing systems through co-design approaches that leverage the characteristics of specific domains (e.g., application, computing strategy, technology, etc.). Successful proposals will explain why the proposed research is exploring a specific domain and how the proposed activities will substantially improve the identified evaluation metrics. Proposals are encouraged to include design-space exploration of software and hardware design choices using realistic or proxy workloads from the selected domain in project plans. System prototyping by taking advantage of semiconductor fabs is encouraged, and proposals should clearly explain the system demonstration that will result from the project. Consideration of the significant software challenges (e.g., programming language support, compiler support, operating system support) that must be addressed to efficiently utilize the proposed hardware platforms in heterogeneous systems is strongly encouraged, including consideration of programmability and compatibility issues. Project descriptions must be comprehensive and well-integrated and provide convincing evidence that the collaborative contributions of the project team will be greater than the sum of the parts. Investigators are encouraged to seek partnerships across diverse institutions that together 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, photonic, or hybrid devices & components for sensing, memory, energy, etc. to enable cutting-edge functionality in semiconductor technology. 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 can be processed, stored, communicated, and actuated upon. Co-design projects should include advanced and integrated thermal management solutions for component reliability. 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 plan<sup>1</sup> or sustained always-available communication.

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

#### Heterogeneous Integration & Heterogeneous Technology Ingredients:

- D-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.
- Millimeter-wave and next-generation communications. Secure analog/RF and mixed-signal technologies.
- Microelectronics accelerating the adoption of WiFi-band gap semiconductor technology and increasing the integration of power-conversion with sensing and communication, for high power density, high-bandwidth interconnects.
- Edge processing bringing data analysis closer to the sensors and other sources of data.
- Hetero-integration with novel embedded thermal cooling solutions, thermal isolation of high power-density components, cooling solutions for hot-spot management, and low-thermal resistance interface materials development and integration.
- 3D integration of memory and compute utilizing advanced packaging techniques to achieve greater computation energy efficiency by either reducing the energy of or reducing the need for data movement.
- Bio-inspired sensing-to-action with machine learning architectures balancing power/energy and cost of local or in-memory processing with global considerations.

#### 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.
- Consideration should be given to low global-warming-potential (GWP) refrigerants for thermal management.
- Better/more effective test solutions to catch defects at wafer level. This can include, but is not limited to, better DFT, better BIST engines, better test content, and/or better test hardware to facilitate more effective screening at wafer test.
- Methods to enable more resilient and defect tolerant designs.
- Methods and schemes for improved characterization of chiplets at wafer test to enable intelligent pairing of chiplets at assembly. Better predictive capabilities of how the device will function in the end-use environment based on pre-assembly data. Novel thermal management techniques to manage high power and high-power densities especially in 3D configurations. Specifically, thermal solutions to cool the chips in the bottom of the stack.
- Improved power delivery networks. Specifically, solutions to provide high fidelity power to the top die.

#### **Heterogeneous 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.
- Thermal analysis design tools that integrate across scales from chip-level to the server-level, and applicable to heterogeneous integration.
- System-technology co-optimization framework for ease of design and validation of chiplet systems and for effective use of foundry offerings.

*FuSe2* 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 are 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 critical point 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.

Semiconductor manufacturing is energy-intensive, consumes significant amounts of water, and has a significant environmental impact due to the use of large amounts of chemicals including substances of high concern such as per- and poly-fluoroalkyl substances (PFAS). There is an increasing interest in and emphasis on transitioning to energy-efficient manufacturing practices with reduced environmental impact and lower clean-water usage.

- Proposals are solicited for co-design approaches, namely simultaneous and synergistic materials research and device research, for advanced, energy efficient computing and communication systems.
- Proposals that emphasize exploration of new materials using a holistic approach that combines experiments with theory and/or modeling are solicited.
- Scalable materials synthesis and processing, sustainable and energy-efficient manufacturing processes using earth-abundant and chemicals/materials, minimizing water usage, developing new recyclable methods, and striving for zero waste, and/or materials property (e.g., electrical, optical, mechanical, and thermal) measurements in functioning electronic devices are prioritized.
- Demonstration of materials properties within an actual application or similar prototyping is welcomed.

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

- Novel materials, or innovative combinations of materials, enabling novel, energy-efficient logic and/or memory functions, including non-Neumann logic, such as brain-inspired/neuro-morphic computing.
- Novel materials, or innovative combinations of materials, for next-generation interconnect, heterogeneous integration in devices and packaging at the relevant dimensions (e.g., ultrahigh electrical conductivity, high thermal conductivity, and ultra-low dielectrics). Integration of those materials and control of their interfaces should be considered, as appropriate.

- 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.
- Development of new characterization methods and/or high-resolution imaging technologies for the characterization of materials at the electronic-device or chip level (e.g., electrical or thermal transport, or defect mapping at the atomic/molecular level in a functioning electronic device).

*FuSe2* 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. Proposals 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, e.g., material performance and resultant device/system, energy usage, as well as education and workforce development 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.

## **B. ROLE OF INDUSTRY FUNDING PARTNERS**

The companies specifically listed in this solicitation (Ericsson, Intel, Micron, and Samsung) have committed to providing annual contributions to NSF for the purpose of funding proposals awarded under this solicitation. The reference to "Industry Funding 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.

After completion of the merit review process, NSF may share with representatives of the Industry Funding 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 Funding 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 Funding 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 Funding Partners may make available direct contributions of resources including, but not limited to, fabrication facilities, software (prototypes or products), data sets, and/or other computing infrastructure. No recipient will be required to use any Industry Funding Partner's offered contributions.

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

NSF will share annual project reports and, at the completion of the award, a final project report and a project outcomes report with Industry Funding Partners after those reports have been reviewed and accepted by the cognizant NSF Program Officer.

The award terms and conditions will state that recipients shall grant to the sponsoring parties (NSF and all the Industry Funding 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 Funding Partner will include its subsidiaries and contractors, at its discretion, to the extent that such use is specifically in connection with the Industry Funding Partner's products and/or services.** recipients shall grant the license to each Industry Funding Partner named in the award letter unless the Industry Funding Partner opts to decline the license. Such license shall not extend to recipients' background intellectual property; however, individual recipients and Industry Funding 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 recipients and Industry Funding Partners, nor will any funds provided by NSF to the recipient be contingent upon such negotiations.** Based on the contributions from the Industry Funding Partners, Intel, Micron, and Samsung will be named as sponsoring parties for all awards, and Ericsson will be named as sponsoring parties in a partial set. Recipients 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 recipients 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 Funding 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 Funding 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.

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<sup>1</sup> [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:

Proposals may only be submitted by the following:

- Non-profit, non-academic organizations: Independent museums, observatories, research laboratories, professional societies and similar organizations located in the U.S. that are directly associated with educational or research activities.
- Institutions of Higher Education (IHEs) - Two- and four-year IHEs (including community colleges) accredited in, and having a campus located in the US, acting on behalf of their faculty members.
- Tribal Nations: An American Indian or Alaska Native tribe, band, nation, pueblo, village, or community that the Secretary of the Interior acknowledges as a federally recognized tribe pursuant to the Federally Recognized Indian Tribe List Act of 1994, 25 U.S.C. §§ 5130-5131.

#### 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**.

An investigator who is a PI or co-PI of a FuSe award based on a proposal submitted in response to the previous FuSe solicitation, NSF 23-552, cannot be a PI or co-PI for this FuSe2 solicitation, but may serve as Senior Personnel. Proposals violating this limitation will be returned without review.

#### Limit on Number of Proposals per Organization:

There are no restrictions or limits.

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

Each FuSe2 project requires a minimum of one PI and one co-PI.

An investigator may serve as a PI, co-PI or Senior Personnel on only **ONE proposal**, including subawardees, 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 subaward included as part of a proposal involving multiple organizations.

#### Additional Eligibility Info:

##### Proposals Involving Multiple Organizations:

If multiple organizations are involved in a proposal, it must be submitted as a single proposal with subawards. Collaborative proposals arranged as separate submissions from multiple organizations will not be accepted for this solicitation. PAPPG Chapter

II.D.3 provides additional information on collaborative proposals.

#### **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=pappg](https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg). Paper copies of the PAPPG may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-8134 or by e-mail from [nsfpubs@nsf.gov](mailto: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](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](mailto:nsfpubs@nsf.gov).

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.

#### **Collaborative Proposals:**

If multiple organizations are involved in a proposal, it must be submitted as a single proposal with subawards. Collaborative proposals arranged as separate submissions from multiple organizations will not be accepted for this solicitation. PAPPG Chapter II.D.3 provides additional information on collaborative proposals.

#### **Title:**

Proposal titles should begin with "**FuSe2 Topic X:**" (X = 1, 2, or 3, as a primary topic) then the title.

#### **Project Summary:**

At the beginning of the overview section of the Project Summary, state the main topic or topics being addressed, plus the relevant areas within the technology stack. At least two areas among materials, devices, and computing are required for each FuSe2 proposal. For example, "This project focuses on Topics 3 and 2, considering co-design across materials and devices."

#### **Project Description:**

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

1. Education and Workforce Development Plan (as a component of Broader Impacts)
2. Project Management and Collaboration Plan

The "Education and Workforce Development Plan" section must describe the proposed activities and their expected impact in developing a next-generation semiconductor workforce. The "Project Management and Collaboration Plan" section must describe why the project team is appropriate to realize the project's goals and how the team will ensure effective collaboration in the co-design process. A compelling rationale must be presented for a multi-organization structure.

#### **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 Funding 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 Funding 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):

March 14, 2024

## **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](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 1-800-381-1532 or e-mail [rgov@nsf.gov](mailto: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](mailto: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.

The NSF [Grants.gov Proposal Processing in Research.gov informational page](#) provides submission guidance to applicants and links to helpful resources including the NSF [Grants.gov Application Guide](#), [Grants.gov Proposal Processing in Research.gov how-to guide](#), and [Grants.gov Submitted Proposals Frequently Asked Questions](#). Grants.gov proposals must pass all NSF pre-check and post-check validations in order to be accepted by Research.gov at NSF.

When submitting via Grants.gov, NSF strongly recommends applicants initiate proposal submission at least five business days in advance of a deadline to allow adequate time to address NSF compliance errors and resubmissions by 5:00 p.m. submitting organization's local time on the deadline. Please note that some errors cannot be corrected in Grants.gov. Once a proposal passes pre-checks but fails any post-check, an applicant can only correct and submit the in-progress proposal in Research.gov.

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/](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**

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:

- Does the project identify an overarching foundational problem which requires a co-design approach?
- Are energy-efficient, sustainable device manufacturing processes using earth-abundant and nontoxic materials, minimizing water usage, and striving for zero waste emphasized?
- Does the proposal identify an integrated multi-disciplinary research agenda that defines the roles of all participants? Is the composition of the multi-disciplinary team appropriate for the scope of the proposed activities?
- How are the research tasks synergistically 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.

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 proposers whether their proposals have been declined or recommended for funding within six months. Large or particularly complex proposals or proposals from new recipients 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](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](mailto: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](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:***

Recipients will be required to include appropriate acknowledgment of NSF and Industry Funding Partners support in reports and/or publications on work performed under an award. An example of such an acknowledgment 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 Funding Partners as specified in the Future of Semiconductors (FuSe) program."*

#### ***Industry Funding Partner Engagement with Program Recipients:***

Once the Program awards have been issued, each of the industry partners may engage with the recipients 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 recipients, although recipients 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 recipients, although recipients will not be required to use these offered contributions.
- NSF requires recipients to submit annual project reports and, at the completion of the award, a final project report and a project outcomes 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 recipients project personnel. These arrangements will be optional and upon the mutual consent of the industry partner and respective recipient institutions. No recipient will be required to accept an industry partner researcher.

Additionally, proposers should be prepared for NSF or an NSF-funded coordination entity to facilitate engagement between NSF, partners, and recipients, including on research dissemination, workshops, collaborative engagements, and other activities that support nurturing and growing the FuSe community. Recipients must engage with NSF and/or the coordination entity on these activities throughout the duration of the grant.

### ***Intellectual Property:***

*Recipients 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. Recipients 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 recipients' background intellectual property; however, individual recipients 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 recipients and industry partners, nor will any funds provided by NSF to the recipients be contingent upon such negotiations.* No rights or licenses are granted by the industry partners. Recipients 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 recipients promptly publish all results, data, and software generated in performance of the research.

For primarily research projects funded by the *FuSe* Program, recipients 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](https://www.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](https://www.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](https://www.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](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](mailto:fuse1@nsf.gov)
- Z. C. Ying, telephone: (703) 292-8428, email: [fuse1@nsf.gov](mailto:fuse1@nsf.gov)
- Geoffrey Brown, telephone: (703) 292-4979, email: [fuse1@nsf.gov](mailto:fuse1@nsf.gov)
- Jason Hallstrom, telephone: 703-292-2997, email: [jahallst@nsf.gov](mailto:jahallst@nsf.gov)
- Sankar Basu, telephone: (703) 292-7843, email: [fuse1@nsf.gov](mailto:fuse1@nsf.gov)
- Premjeet Chahal, telephone: (703) 292-7264, email: [fuse1@nsf.gov](mailto:fuse1@nsf.gov)
- Rosa Lukaszew, telephone: (703) 292-8103, email: [fuse1@nsf.gov](mailto:fuse1@nsf.gov)
- Paul A. Lane, telephone: (703) 292-2453, email: [plane@nsf.gov](mailto:plane@nsf.gov)
- Colby A. Foss, telephone: (703) 292-5327, email: [cfoff@nsf.gov](mailto:cfoff@nsf.gov)
- Xiaobo S. Hu, telephone: (703) 292-8910, email: [xhu@nsf.gov](mailto:xhu@nsf.gov)
- Sumanta Acharya, telephone: (703) 292-4509, email: [sacharya@nsf.gov](mailto:sacharya@nsf.gov)
- Vinod K. Lohani, telephone: (703) 292-2330, email: [fuse1@nsf.gov](mailto:fuse1@nsf.gov)
- Eleanor Sayre, telephone: (703) 292-2997, email: [fuse1@nsf.gov](mailto:fuse1@nsf.gov)

For questions related to the use of NSF systems contact:

- NSF Help Desk: 1-800-381-1532

- Research.gov Help Desk e-mail: [rgov@nsf.gov](mailto: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](mailto: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>.

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

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

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

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

- **Location:** 2415 Eisenhower Avenue, Alexandria, VA 22314
- **For General Information** (703) 292-5111  
(NSF Information Center):
- **TDD (for the hearing-impaired):** (703) 292-5090
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## 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 proposers 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 proposers or nominees as part of a joint application review process, or in order to coordinate programs or policy; and to another Federal agency, court, or party in a court or Federal administrative proceeding if the government is a party. Information about Principal Investigators may be added to the Reviewer file and used to select potential candidates to serve as peer reviewers or advisory committee members. See [System of Record Notices, NSF-50](#), "Principal Investigator/Proposal File and Associated Records," and [NSF-51](#), "Reviewer/Proposal File and Associated Records." Submission of the information is voluntary. Failure to provide full and complete information, however, may reduce the possibility of receiving an award.

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

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