Emerging Frontiers In Research And Innovation 2015 (EFRI-2015)

Two-Dimensional Atomic-layer Research and Engineering (2-DARE)

PROGRAM SOLICITATION
NSF 15-502

REPLACES DOCUMENT(S):
NSF 13-583

National Science Foundation

Directorate for Engineering
Emerging Frontiers in Research and Innovation

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

Air Force Office of Scientific Research

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

November 07, 2014

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

January 09, 2015

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

April 13, 2015

By Invitation Only

IMPORTANT INFORMATION AND REVISION NOTES

Any proposal submitted in response to this solicitation should be submitted in accordance with the revised NSF Proposal & Award Policies & Procedures Guide (PAPPG) (NSF 15-1), which is effective for proposals submitted, or due, on or after December 26, 2014. The PAPPG is consistent with, and, implements the new Uniform Administrative Requirements, Cost Principles, and Audit Requirements for Federal Awards (Uniform Guidance) (2 CFR § 200).

SUMMARY OF PROGRAM REQUIREMENTS

General Information

Program Title:

Emerging Frontiers in Research and Innovation (EFRI)
Two-dimensional Atomic-layer Research and Engineering (2-DARE)

Synopsis of Program:

The Directorate for Engineering at the National Science Foundation has established the Office of Emerging Frontiers in Research and Innovation (EFRI) to serve a critical role in focusing on important emerging areas in a timely manner. This solicitation is a funding opportunity for interdisciplinary teams of researchers to embark on rapidly advancing frontiers of fundamental engineering research. For this solicitation, we will consider proposals that aim to investigate emerging frontiers in the following research area:

Two-Dimensional Atomic-layer Research and Engineering (2-DARE)

This solicitation is coordinated with the Directorate for Mathematical & Physical Sciences within NSF. Additionally, interest within other Federal agencies, specifically Air Force Office of Scientific Research (AFOSR), may lead to an interagency effort. Submitted proposals may be shared with interested representatives from AFOSR.

EFRI seeks proposals with transformative ideas that represent an opportunity for a significant shift in fundamental engineering knowledge with a strong potential for long term impact on national needs or a grand challenge. The proposals must also meet the detailed requirements delineated in this solicitation.

Cognizant Program Officer(s):

Please note that the following information is current at the time of publishing. See program website for any updates to the points of contact.

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

- 12.800 --- Air Force Office of Scientific Research
- 47.041 --- Engineering
- 47.049 --- Mathematical and Physical Sciences

Award Information

Anticipated Type of Award: Standard Grant

Estimated Number of Awards: 7 to 8

(4-year awards)

Anticipated Funding Amount: $15,000,000

Pending the availability of funds.

Eligibility Information

Who May Submit Proposals:

Proposals may only be submitted by the following:

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

Who May Serve as PI:

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

Limit on Number of Proposals per Organization:

There are no restrictions or limits.

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

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

Proposal Preparation and Submission Instructions

A. Proposal Preparation Instructions

- **Letters of Intent:** Submission of Letters of Intent is required. Please see the full text of this solicitation for further information.
- **Preliminary Proposals:** Submission of Preliminary Proposals is required. Please see the full text of this solicitation for further information.
- **Full Proposals:**
  - Full Proposals submitted via FastLane: NSF Proposal and Award Policies and Procedures Guide, Part I: Grant Proposal Guide (GPG) Guidelines apply. The complete text of the GPG is available electronically on the NSF website at: http://www.nsf.gov/publications/pub_summ.jsp?ods_key=gpg.
  - 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: http://www.nsf.gov/publications/pub_summ.jsp?ods_key=grantsgovguide).

B. Budgetary Information

- **Cost Sharing Requirements:** Inclusion of voluntary committed cost sharing is prohibited.
- **Indirect Cost (F&A) Limitations:** Not Applicable
- **Other Budgetary Limitations:** Not Applicable

C. Due Dates

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

  November 07, 2014

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

  January 09, 2015

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

  April 13, 2015

  By Invitation Only

Proposal Review Information Criteria

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

Award Administration Information

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

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

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I. INTRODUCTION

The Office of Emerging Frontiers in Research and Innovation (EFRI) provides funding opportunities for interdisciplinary teams of researchers to embark on rapidly advancing frontiers of fundamental engineering research. EFRI seeks proposals with potentially transformative ideas that represent an opportunity for a significant shift in fundamental engineering knowledge with a strong potential for long term impact on national needs or a grand challenge. For this solicitation, EFRI will consider proposals that aim to investigate emerging frontiers in the following research area: **T**wo-**D**imensional **A**tomic-layer **R**esearch and **E**ngineering(**2-DARE**).

AFOSR is pleased to collaborate with NSF in the pursuance of revolutionary scientific breakthroughs related to **2-DARE**. AFOSR program officers will collaborate with NSF in the review, selection and potential funding of proposals submitted under this solicitation. AFOSR manages the basic research investment for the U.S. Air Force (USAF). As a part of the Air Force Research Laboratory (AFRL), AFOSR's technical experts foster and fund research within AFRL, universities, and industry laboratories. Using a carefully balanced research portfolio, program officers seek to create revolutionary scientific breakthroughs, enabling USAF and U.S. industry to produce world-class, militarily significant, and commercially valuable products. Proposers interested in learning more about AFOSR's mission and research interests should consult the AFOSR website, http://www.wpafb.af.mil/afrl/afosr/.

Interest within AFOSR may lead to proposals submitted under the **2-DARE** topic being shared with interested representatives from AFOSR for potential co-funding consideration.

The rapid and recent advances in graphene, a single sheet of carbon atoms arranged in a two-dimensional (2D) honeycomb crystal lattice, have raised tantalizing questions for other examples of 2D materials which might have distinct and useful properties. Such possibilities have opened our eyes to an entire world of 2D crystals. Examples of 2D layered materials include hexagonal boron nitride (h-BN), transition metal dichalcogenides, the chalcogenides of group III, group IV and group V, transition metal oxides, tertiary compounds of carbo-nitrides, and other traditionally non-layered structures such as germananes (atomic layers of germanium) and silicenes (silicon-based layered structures).

Given the wide range of compositions of 2D-layered materials beyond graphene, it is not surprising that they offer a rich spectrum of properties. For example, h-BN, a layered material closest in structure to graphene, is an insulator, while monolayers of some transition metal di-chalcogenides such as MoS_2 and WS_2 are direct band-gap semiconductors. The rich variety of properties that 2D layered material systems offer can potentially be engineered on-demand, and they create exciting prospects for device and technological applications, such as in electronics, sensing, photonics, flexible electronics, energy harvesting and storage, thermal management, mechanical structures, catalysis, separation, bio-engineering, and gas adsorption in the future. Reports exist of non-graphene 2D atomic layers integrated into devices which exhibit exceptional performance; for example, transistors derived from 2D monolayers of MoS_2 show ON/OFF ratios many orders of magnitude higher than the best graphene transistors at room temperature, with comparable mobilities. Other successful applications reported include enhanced thermal storage, thermoelectric performance, and gas adsorption with heterogeneous 2D material systems. Attempts to synthesize atomic layers from some of these non-graphene layered structures via chemical as well as vapor phase deposition methods have also emerged recently. A variety of studies on the synthesis, chemical modification methods, device fabrication and testing, and theoretical exploration of structure-property correlations have been proposed on stable 2D atomic layered materials systems, and the field is about to see a significant explosion of activities in the near future.

It is therefore timely for this EFRI call to promote the exploration of the exciting prospects of non-graphene 2D atomic layers and devices that can stimulate technologically significant applications in the coming years. It is important to emphasize that this solicitation is exclusively focused on "beyond" graphene materials and their device applications. Proposals focusing exclusively on graphene will not be considered in this solicitation. However, proposals incorporating graphene in 2D heterostructures and other related structures are permissible.

Although the idea of separating individual layers from 2D layered solids is straightforward, the challenges for obtaining large single crystal domains for chemical modification, characterization and modeling, transfer onto appropriate substrates, device fabrication and performance optimization are significant. This solicitation is targeted toward addressing these key issues, exemplified in Thrust areas 1-3 below, for advancing the fundamental research and the application of 2D layers of non-graphene compositions. The scientific activity in this emerging area will impact several interdisciplinary developments in the next decade and will positively impact learning in the science and engineering disciplines. Some of the areas impacted also include national grand challenge areas such as energy, electronics beyond Moore's Law, electromagnetics, photonics, and healthcare. This solicitation also contributes to the goals of the National Nanotechnology Initiative (http://www.nano.gov/)

Promotion of research in the area of 2D layered materials and their applications under the NSF **2-DARE** topic area is poised to make a significant impact on basic collaborative research through an agency-wide initiative such as EFRI, and also through an interagency collaboration with the AFOSR under AFOSR's Basic Research Initiatives (BRI) program.

ENHANCING DIVERSITY IN ENGINEERING - THE BROADENING PARTICIPATION PLAN

The Directorate for Engineering (ENG) promotes diversity in all aspects of its programs. In keeping with ENG's priority to broaden the participation of underrepresented groups(see detailed definition below) in Engineering, the Office of Emerging Frontiers in Research and Innovation is addressing the need to enhance diversity in all fields of Engineering by **requiring all EFRI projects to include a "Broadening Participation Plan"** as part of the EFRI 2015 Solicitation. One goal is to increase the participation of underrepresented groups in the field of engineering and in engineering research. This requirement will not only promote diversity in the human resources engaged in these EFRI projects but will also expand diversity of thought, ideas, and approaches brought together by EFRI in defining and solving important research questions.

The term "underrepresented groups" refers to and includes the following: women, persons with disabilities, and ethnic and racial groups which are in the minority in engineering including African Americans, Hispanics, Native Americans, Alaska Natives, and Pacific Islanders.

The Broadening Participation Plan must be described as part of Broader Impacts of the proposal both in the Project Summary and in the Project Description. It may include, but is not limited to, any of the following menu of activities as appropriate for your project and the circumstances of your institution(s):

- PI, Co-PI, or other SENIOR PERSONNEL - Inclusion of persons from underrepresented groups as PI, co-PI, and/or other senior personnel, as appropriate for the project;
- STUDENT AND POST-DOCs - Inclusion of persons from underrepresented groups as graduate student, undergraduate student, and post-doctoral researchers;
- REU - A plan to apply for post-award supplements to engage undergraduate researchers, using REU supplement;
- RESEARCH EXPERIENCE AND MENTORING (EFRI-REM) - A plan to apply for post-award supplements to enhance research goals through diversification of the research team (see, URL for related information from previous year);
- MINORITY SERVING INSTITUTIONS - Engaging faculty and/or student researchers at minority serving institutions in the research project;
- COMMUNITY COLLEGES - Engaging faculty and/or student researchers at community colleges in the research project;
- RESEARCH EXPERIENCE FOR TEACHERS - A plan to apply for post-award supplements to engage teachers through the RET program;
- RESEARCH EXPERIENCE FOR HIGH SCHOOL STUDENTS - Provide research opportunities for members of underrepresented groups at the high school level;
- EXISTING INSTITUTIONAL PROGRAMS - Enhance/collaborate with existing diversity programs at your home institution and/or nearby institutions;

MENTORING - Senior Personnel serve as role models and mentors for an underrepresented student population;
- TUTORING OPPORTUNITY - Provide tutoring opportunities for underrepresented middle school, high school, and undergraduate students;
- K-12 OUTREACH - Outreach activities that will interest and attract underrepresented K-12 students to engineering undergraduate programs.

The EFRI Office encourages the proposers to be creative in the planning of activities to attract and retain members of underrepresented groups to the fields of engineering and engineering research when developing their Broadening Participation Plans.

II. PROGRAM DESCRIPTION

Two-Dimensional Atomic-layer Research and Applications (2-DARE)

The "Required Elements" listed below for the **2-DARE** topic area are expected to be addressed in both the preliminary proposal and the full proposal.

This emerging technical area and the ensuing interdisciplinary activities will be in perfect synergy with already well-established graphene science and will impact fields such as materials science, chemistry, physics and engineering in the next decade. Thus the lessons learned from graphene research should accelerate research and streamline goals for successfully addressing the scientific and technological challenges in 2D layered materials research under this NSF **2-DARE** topic, as further outlined in Thrust areas 1-3 below:

Thrust Areas

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

1. Exploration of material properties and device applications
2. Synthesis and nanomanufacturing
3. Theory and modeling

A competitive proposal must have a collaborative and highly integrated approach. Thrust 1 lists three areas: (a) electrical, optical and magnetic properties and device applications; (b) thermal properties; and (c) mechanical, structural, chemical and biological applications. It is envisioned that many of the proposals that include Thrust 1 will focus on one of those areas, while some may incorporate more than one area in Thrust 1.

Thrust 1: Exploration of Material Properties and Device Applications

Besides unveiling the fundamental properties of 2D layered material systems, the application of such materials in novel device platforms is highly encouraged. Processing of atomic layers and preparation of morphologies, chemical modification, doping, and patterning have been landmarks of research in graphene, and are likely to be areas of active research in 2D layered systems. The structural characteristics and modifications will undoubtedly impact the electrical, optical, magnetic, thermal, mechanical, and chemical properties of these 2D layered materials. The need for high-quality, defect free materials, and for developing processes that enable easy integration of such thin atomic layers into device architectures and mechanical structures will all be areas of high relevance to this call.

At the same time, development of characterization tools and new protocols to understand the structure of materials at various scales is an important goal in new materials development. Atomic-level, real space imaging and spectroscopic techniques and global spectroscopy methods such as Raman spectroscopy, are likely to play an important role in the 2D beyond graphene field. New tools and methods for the fundamental characterization of 2D materials, nanoscale interfaces, and junctions will be necessary to understand and control the properties of these nanolayered systems. Characterization tools, particularly utilizing non-invasive techniques, and the development of new methods to analyze 2D atomic layers would enable accelerated development of the field, since proper materials characterization has been the bottleneck in many recent materials areas, including that of graphene. Thus, focused group efforts in developing characterization techniques and tools through collaborations with interdisciplinary groups - material growers, theorists and characterization experts - is highly encouraged. Furthermore, partnering with government labs, such as the National Institute of Standards and Technology (NIST), that offer unique metrology capabilities that may be valuable in the development of new characterization tools and techniques, as well as with industry, that may also offer unique characterization capabilities, are encouraged.

The particular material properties of interest and their device applications (where applicable) are outlined in more detail in Parts (a) - (c) of Thrust 1.

a) Electrical, Optical and Magnetic Properties and Device Applications

Recently, atomic layers of transition metal dichalcogenides with inherent and appreciable band gaps have attracted tremendous attention for promising applications in electronics, photonics and other related areas. Given their pristine interfaces, which enable low-power and low-dissipation devices, such materials can potentially replace conventional semiconductors for ultra-scaled, thin-body transistor applications. Other layered structures, such as hexagonal boron nitride (h-BN), are attractive candidates for atomically-thin dielectrics, allowing for the design of various device architectures with metal/dielectric/semiconductor interfaces. Heterostructure field-effect-transistors (FETs) or tunneling-FET devices formed by stacking 2D semiconductors as the channel, 2D insulator layers as the dielectric, and 2D metallic layers (graphene, $TaSe_2$, etc.) as gates and interconnects can enable energy-efficient transistor devices for digital and analog circuit applications. In this regard, the importance of preparing mono-, bi-, and few-atomic layer materials with good control and the ability to modify chemical doping, carrier density and contact resistance, to modify and control lattice structures of atomic layers, and to tailor electronic, optical and magnetic properties will be of paramount importance. Similarly, for memory devices, layers can be formed by charge trapping using heterostructured stacks or 2D-magnetic materials ($FeSe_2$, $CoSe_2$, etc.).

In addition, the direct band-gaps of monolayers of some of the 2D layered materials, and the ability for band-gap engineering through compositional variations will allow ultra-wide wavelength tunability, from the terahertz, through the IR, to the ultraviolet. The band gap engineering in stacked artificial structures from 2D atomic layers of different compositions can lead to entirely new device platforms that go beyond the possibilities for graphene devices. As an example, the THz regime ranging from 0.1 THz to 10 THz, presents attractive opportunities for sensors useful in homeland security as well as in pharmacology, where 2D materials may make a unique contribution. In addition, through phonon engineering, thermal transport across interfaces can be tuned and optimized,

which will play an important role in determining the performance of ultra-high-density nanoscale circuits that are limited by heat management issues. By generating and detecting coherent phonon wave packets in these structures, one can investigate how phonons can cross interfaces efficiently between different layers and how they interact with charge carriers and spins, with the aim of utilizing this knowledge in device applications.

Two-dimensional layered semiconductor materials are also very attractive for optical applications since they can lead to strong light emission, as demonstrated in recent photoluminescence experiments. Observation of photoluminescence in 2D layered materials needs to be explored further in order to maximize quantum yield, which can have a pay-off for photo-sensing applications. In the case of MX_2 (with stoichiometry MX_2 where M = transition metal, X = is a group VI element) the d-orbital conductivity of the metallic components makes them interesting materials for exploring optical properties. Depending on the choice of material, compositional variations, and layer thickness, the optical absorbance in such materials can be engineered, making them particularly attractive for photo-detectors and photo-voltaic applications. Exploring interface effects through the creation of super-lattices of these van der Waals solids can potentially enable new properties that lay the foundation for a paradigm shift in device platforms combining, electronic, optical, magnetic and related effects which go beyond the promise of graphene and other state-of-the-art materials.

Flexible and transparent electronics, such as paper-like displays and wearable electronics, need to sustain large deformation while maintaining their intended functionalities. Due to the unique combination of high strength, excellent out-of-plane flexibility, low-broadband absorption and outstanding and diverse electronic properties, some of the 2D-nitrides, oxides and sulfides can be envisioned as promising candidates for conformal conductors, semiconductors and dielectrics in flexible and transparent electronics applications.

The relevant topics for the exploration of electronic, photonic, and magnetic properties in 2D materials and their potential device applications include but are not limited to the following:

- Basic science and discovery for generating entirely new 2D layered materials which exhibit interesting properties that are strongly informed by modeling investigations. Examples include:
    - Exploring new 2D materials with unique structural traits, such as those with multiple Dirac cones, which offer prospects for qualitatively new science and potentially game-changing technologies in the future, or exploring the valley states in MX_2 and other 2D material systems which offer new prospects in the emerging area of "valleytronics".
    - Super-lattices synthesized using van der Waals epitaxy or related techniques that couple 2D materials with differing electronic, optical, magnetic, and other properties to realize van der Waals solid hetero-structures for enabling a paradigm shift in device platforms.
    - Investigating the role of contacts and mechanisms for doping of 2D materials, which are critical for practical device applications
    - Exploration of exotic physical phenomena such as exciton condensates in 2D layered systems where fundamentally new physical phenomena can be unveiled
    - Collective interactions of nanocomponents assembled on 2D atomic layers

- Device applications of interest for 2D materials include but are not limited to the following:
    - Nanoelectronics for beyond Moore's Law architectures, for low-power, logic, energy-efficient devices
    - Memory, magnetic and spintronic devices
    - High-frequency devices for signal treatment and generation from RF, microwave to THz electronics
    - Electronic devices for power and switching applications
    - Plasmonic and sensing devices
    - Light-emission devices for light-emitting-devices (LEDs) and lasers
    - Light-absorption devices such as photo-detectors and photo-voltaics
    - Flexible electronics, including transparent conducting electrodes

b) Thermal Properties and Device Applications

While 2D heterogeneous materials provide intriguing opportunities for high density nano-electronics and high-power/high-frequency RF devices, thermal management in these devices can become a challenge. Stacking 2D materials such as h-BN, MX_2, Bi_2Te_3, silicon, phosphorous and germanium into heterostructures can yield transistors and electronic devices with improved properties, but these devices may be associated with highly non-equilibrium thermal dissipation, and it is not clear if these devices can be operated reliably at temperatures below the desired threshold. Because of the absence of phonon-scattering between layers, it is expected that the thermal conductivity of an ideal 2D system will be considerably higher than the values reported for three-dimensional stacks, and this enhanced conductivity may be beneficial from a thermal management perspective. Indeed, some reported measurements and predictions in unconstrained graphene indicate values that are higher than their basal values. However, the exact mechanisms and the role of in-plane and out-of-plane phonons need to be better understood for the general class of 2D layers. When the 2D layer such as graphene or h-BN is constrained by an amorphous layer, substantial reduction in the thermal conductivity is observed. The thermal interface resistance is believed to be controlled by flexural phonons and/or the coupling with the surface or bulk modes in the constraining layer, but these mechanisms are poorly understood and need further experimental and computational studies. The supporting interface appears to play a role even in many layers of 2D stacked materials, with recent studies showing that phonons in greater than 30-layer graphene reaching the silicon interface before being scattered. Significant anisotropy is observed in the phonon transport in stacked 2D layers along basal planes and across basal planes. Edge effects also play a role in phonon scattering and dispersion. Phonon-electron coupling and the mechanisms that control their behavior across heterogeneous boundaries are poorly understood. Clearly, additional studies are needed to gain a better understanding of phonon transport in and across 2D layers and across heterogeneous boundaries and supporting interfaces (both insulators and metals). Development and application of suitable measurement techniques and validated simulations that can support the improved understanding and optimization of the phonon transport behavior are also sought as part of this solicitation.

Thermoelectrics is another intriguing application, where 2D structures may provide enhanced performance. Recent theories have suggested quantum enhancement of the in-plane thermoelectric power factor in 2D Bi_2Te_3 and Bi_2Se_3 materials, but it is not clear if interface disorders can be manipulated to preferentially suppress phonon transport over electron transport, and additional measurements, simulations and modeling are required.

Other potential applications include thermal storage, where the high conductivity of ultrathin layers, if engineered with high specific heat, can potentially lead to a class of new materials that are suitable for energy storage. In the same vein, recent studies have demonstrated higher gas-adsorption capabilities of h-BN and graphene domains. Improved understanding and optimization of these applications are also encouraged.

Relevant topics include, but are not limited to:

- Thermal management in electronic, RF and other high-heat-flux devices utilizing 2D materials beyond graphene
- Fundamental investigation and optimization of phonon transport in 2D layers, including studies of anisotropy, phonon-electron coupling, edge effects, layer-to-layer effects, and interface effects on the phonon transport behavior. Both

predictive approaches and diagnostic approaches are encouraged, including the development of improved tools
- Thermoelectrics and thermal storage applications of 2D materials and performance optimization
- Gas adsorption and storage with heterogeneous 2D materials

c) Mechanical, Structural, Chemical and Biological Properties and Device Applications

Graphene is expected to be the highest strength 2D layered material, with h-BN a possible high-strength reinforcement that promises improved oxidation resistance. While graphene does not have significantly higher strength than carbon nanotubes or graphite fibers, the 2D structure of graphene and other 2D layered materials give them almost unlimited potential for favorable orientation in a matrix, for example along lines of stress or in directions of maximum desired heat flux. Therefore, 2D layered materials may be ideally suited to reinforce fibers and composite structures. It has also been suggested that 2D-flakes, including graphene, impart electrical conductivity to polymeric fibers at very low loadings if they are appropriately dispersed. This raises the possibility of creating inexpensive fabrics that dissipate static charge or provide electromagnetic shielding.

The working layers of many chemical and electronic devices are at the interfaces between dissimilar materials. Thus the development of 2D materials which incorporate all the desirable properties of such devices, but are only a few atoms deep, promises considerably less "footprint" and necessarily reduces the materials and disposal costs. In countless applications, the use of few-layer devices offers other advantages inherent in an ultra-thin material with high-surface-to-volume ratio. With proper orientation, 2D layered materials could potentially lead to 3D scaffolds that could be catalytically active or serve as scaffolds for biological applications. Three-dimensional porous scaffolds from 2D layers of oxides and sulfides, prepared via chemical methods, can be used as high capacity electrodes in energy storage. Similarly, scaffolded, large-surface area structures can be used as catalysts, as for example in the evolution of hydrogen by water splitting, for which the large surface area can provide enormous improvements in efficiency. These ultra-thin materials may also provide novel coatings that protect surfaces from high temperature oxidation (e.g. nanoscale h-BN coatings), from corrosion, or from the friction and wear at sliding surfaces.

Two-dimensional layered materials such as graphene and graphene oxide also appear to be showing promise in the life sciences and bio-medical applications for advancing therapeutics, imaging, and disease-related diagnostics, which may also be areas of exploration for non-graphene 2D compositions. Specifically, there are reports that demonstrate the use of graphene and graphene oxide in cancer diagnostics and photothermal therapy, Alzheimer's disease, stem cell scaffold materials, drug and gene delivery platforms, and as effective imaging agents. Though the use of 2D layered materials for the life-sciences is still in its infancy, this solicitation will invite the potential exploration of such materials in these bio-related applications.

Relevant areas of interest include, but are not limited to the following:

- Electrodes, especially transparent conductive electrodes for macroelectronics and for organic electronics (PV, LED)
- Catalysts, such as in hydrogen evolution in water splitting, for which the large surface area provides enormous improvements in efficiency
- Composite materials, by providing electrical and/or thermal conductivity, high strength, and/or high toughness
- Energy storage, by providing high surface and rapid electron or ion transport for batteries, super capacitors, and fuel cells, or for hydrogen storage
- Water purification and desalination
- Lubricants
- Bio-sensing applications
- Advancing therapeutics, imaging, disease-related diagnostics and drug delivery

Thrust 2: Synthesis and Nanomanufacturing

The synthesis of high-quality materials by methods that can be employed to manufacture devices and systems of proven utility with consistently high-quality at low-cost is the critical challenge in the emergence of any new technology. Today, essentially no such methods exist for 2D layered materials or composite structures incorporating them. Therefore, research aimed at the innovation of new and improved synthesis routes with clear application to the large-scale production of useful devices at reasonable cost are of particular interest. Relevant topics include, but are not limited to:

- Physical vapor deposition (PVD), chemical vapor deposition (CVD), atomic layer deposition (ALD), van der Waals epitaxy or other vapor phase processes for producing large area films suitable for production
- Solution methods such as solvent-based exfoliation and ion intercalation for production of high-quality 2D layered materials
- Other techniques, such as bioprocessing methods for producing 2D layered materials and their associated supporting structures
- Methods for patterning films, fabricating active devices and providing the interconnects and feed-throughs needed to create integrated circuits
- Methods for orienting 2D layered materials in polymeric, metallic or ceramic matrices to produce high-performance composite structures
- Roll-to-roll, continuous processing of 2D layered materials systems on flexible substrates
- Methods for mixing 2D layered materials into matrices so that they can be processed on realistic, industry standard processing machines for fiber drawing, injection molding, casting, etc.
- Innovation of novel machine concepts for processing composites with 2D layered material additives or reinforcement.

Collaboration with industrial partners, especially with equipment manufacturers and small businesses with first-hand understanding of nanomaterials manufacturing of graphene and 2D layered materials, is highly encouraged. Proposals in this area should show familiarity with recent challenges in manufacturing, processing, scaling and commercializing graphene and other similar materials, and in the realization of devices based on these new 2D-layered materials. Projects which specifically address these challenges and which show promise to overcome barriers to applications and materials scale-up are especially encouraged. Academic-industry collaborations, such as the NSF GOALI program, could serve as a model for such collaborations.

Thrust 3: Theory and modeling

Theory and modeling is vital to any new field, particularly in nanotechnology and for research on nanomaterials. Proposals in this thrust are strongly encouraged as there is a critical need for better understanding the observed properties, as well as, prediction of new characteristics. The role of theory and modeling to investigate structure-property correlations in 2D layered materials, and the development of modeling tools for the exploration of 2D atomic layers and devices will be important for accelerating research. In this regard, theory can be used effectively for enabling a combinatorial approach to 2D materials design, along the lines of the national Materials Genome Initiative, which is likely to play an important role in this emerging field.

Theory and modeling efforts that identify new 2D atomic layers with specific properties that enable device development, new hybrid material systems using 2D atomic layer building blocks, strain engineered approaches, and new physical properties predicted for 2D layered material systems and their engineered structures are encouraged. Theory or models developed and simulations undertaken must be done so with extensive verification and validation, so that the uncertainties in these approaches can be minimized.

Small groups of theorists focusing on different aspects, such as computational materials design of 2D atomic layers, defect engineering and structure-property correlations in 2D atomic layers, and/or electronic and optical properties and device performance of 2D atomic layer based structures are encouraged to conduct theoretical studies in partnership with experimentalists.

Programmatic Considerations

Among the programmatic considerations, the following features are deemed important under this **2-DARE** solicitation in order to realize the promise of this field over the coming years:

- **Interdisciplinary Research:** Progress in the field of 2D materials and devices beyond graphene will benefit tremendously from research that draws on many disciplines including physics, chemistry and engineering; thus it is only natural to enable scientists and engineers to work together more effectively in research teams involving synthesis, chemistry, characterization, theory, and/or device fabrication and testing. Each team must address a minimum of 2 thrust areas, with preference given to proposals that include all 3 thrusts.
- **Materials Property Database:** There is a need to establish a fundamental materials properties database for 2D materials which can be publicly accessed. While not required for each proposal, a proposal that includes development of a materials property database will be valued.
- **Industrial Partnerships:** Reaching out to American industry partners will be critical to developing scalable techniques for synthesizing these materials and for outreach in training students who can work with the industrial partners. Creation of academia-industry axes in the development of applications and subsequent commercialization of technologies based on 2D layers will be important.
- **Post-award Supplements For Environmental Implications:** Supplements will be available to PIs who propose to investigate the potential environmental impact and concerns of such 2D material systems.
- **International Exchange:** Exchange programs for students and PIs with international hosts who are engaged in strong programs in the 2D materials and devices area may be supported. This may be leveraged through a follow-up proposal submission that is sent directly to the AFOSR for consideration.

III. AWARD INFORMATION

The budget for this program solicitation is $15,000,000 in FY-2015; each award will be funded as a ‘Standard Grant'. The anticipated number of awards for this solicitation is between 7-8 awards. Each project team may receive support of up to a total of $2,000,000 spread over four years, pending the availability of funds. It is not expected that all awards will receive the maximum amount; the size of awards will depend upon the type of research program proposed. It should be noted that interest within other Federal agencies, specifically Air Force Office of Scientific Research (AFOSR), may lead to interagency co-funding or support.

IV. ELIGIBILITY INFORMATION

Who May Submit Proposals:

Proposals may only be submitted by the following:

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

Who May Serve as PI:

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

Limit on Number of Proposals per Organization:

There are no restrictions or limits.

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

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

V. PROPOSAL PREPARATION AND SUBMISSION INSTRUCTIONS

A. Proposal Preparation Instructions

Letters of Intent *(required):*

A one-page Letter of Intent is required. The letter should be submitted via FastLane no later than the date specified in this solicitation. The subject heading of the letter should include a brief title of the proposal and the name of the lead institution. Each letter must include the following:

1. THE TITLE- Title of the EFRI proposal, preceded by the words “**EFRI 2-DARE**:”.
2. THE TEAM- Names, departmental and university affiliation, and expertise of the Principal Investigator and at least two co-Principal Investigators.
3. THE SYNOPSIS (GOALS)- Brief description of the specific goals of the proposal (maximum of 250 words).

These letters of intent are not used as pre-approval mechanisms for the submission of preliminary proposals and no feedback is provided to the submitters. The Letters of Intent are not reviewed but are used to assess the overall response to the solicitation. They help NSF anticipate review requirements for preliminary proposals.

Letter of Intent Preparation Instructions:

When submitting a Letter of Intent through FastLane in response to this Program Solicitation please note the conditions outlined below:

- Sponsored Projects Office (SPO) Submission is not required when submitting Letters of Intent
- A Minimum of 2 and Maximum of 4 Other Senior Project Personnel are allowed
- A Minimum of 0 and Maximum of 3 Other Participating Organizations are allowed
- Submission of multiple Letters of Intent is not allowed

Preliminary Proposals *(required):* Preliminary proposals are required and must be submitted via the NSF FastLane system.

Preliminary proposals will be reviewed by panels of outside experts. Based on the reviews, a limited number of PIs will be invited to submit full proposals. By January 30, 2015, successful PIs should expect to receive an invitation from the EFRI Office to submit a full proposal.

Preliminary proposals should provide a brief overview of the project and should include sufficient information to allow assessment of the main ideas and approaches and how it is appropriate as an EFRI proposal as opposed to existing programs.

Preliminary Proposal Preparation Instructions:

Preliminary proposals must be submitted via FastLane in accordance with the instructions below. Preliminary proposals that are not compliant with this solicitation will be returned without review. It is the submitting organization's responsibility to ensure that the proposal is compliant with all applicable requirements. If there are multiple universities involved in a preliminary proposal, it must be submitted as a single proposal with subawards and not as separately submitted collaborative proposals. Preliminary proposals must contain the items listed below and strictly adhere to the specified page limitations. No additional information may be provided as an appendix or by links to web pages. Figures and tables must be included within the applicable page limit. All elements of the proposal, including legends and tables, must meet all formatting requirements for font size and characters per inch as specified in the NSF Grant Proposal Guide (GPG).

Preliminary proposals must include the following items:

Cover Sheet: Select the EFRI program solicitation number from the pull down list. Check the box indicated for preliminary proposal. Entries on the cover sheet are limited to the principal investigator and a maximum of four co-principal investigators. A minimum of two co-principal investigators must participate. Additional project leaders or senior personnel should be listed on the project summary page and entered into FastLane as senior investigators.

Title of Proposed Project: The title for the proposed EFRI project must begin, as appropriate, with either "**EFRI 2-DARE Preliminary Proposal:"**. The title must state clearly and succinctly the major emerging frontier in research and innovation that is the focus for the project.

Project Summary: The project summary may not be more than one page in length and must consist of three parts:

1. In the Overview section, include the title of the project, the name of the PI and the lead institution and a list of co-PIs and senior personnel along with their institutions;
2. Provide a succinct summary of the ***intellectual merit*** of the proposed project. This should include the transformative nature of the proposed research and the significant leap or paradigm shift in fundamental engineering knowledge it will achieve; and
3. Describe the ***broader impacts*** of the proposed work, including the potential long-term impact on national needs or a grand challenge.

Proposals that do not separately address in the project summary both intellectual merit and broader impacts will be returned without review.

Project Description: Project description of the preliminary proposal is limited to five pages and will include the following three sections:

1. **Vision and Goals -** Describe the vision and specific goals of the proposed research in approximately one page;
2. **Approach and Methodology** - Describe the approach and methodology that will be used to achieve the vision and goals in approximately three pages; and
3. **Impact** - Describe how the synergy of experts from different disciplines in the proposed research will achieve a significant advancement in fundamental engineering knowledge and will have a strong potential for long-term impact on national needs or a grand challenge in approximately one page. Include a succinct statement of your preliminary Broadening Participation Plan.

Proposals to be considered by AFOSR for co-funding must include in the Project Description a brief explanation of the aspects of the proposal reflecting the Air Force interests and an explicit statement indicating Air Force relevance.

References Cited: Indicate with an asterisk any cited publications that resulted from prior research funded by NSF for the PI, or co-PI (s).

Biographical sketches: The standard NSF two-page biographical sketches must be prepared for the PI, co-PIs and other senior personnel listed on the project summary page.

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

Budget: The preliminary proposal will include a budget for each of the four years proposed. FastLane will automatically provide a cumulative budget. Preliminary proposals should not include any subcontracts. However, the budget justification should include planned levels for subcontracts to any partner institution. Enter the anticipated total level of subcontract support on line G5, Subawards.

In the **Supplementary Documentation** section, include the following:

1. List of **key personnel involved** (maximum one page), with a succinct description of what each person uniquely brings to

the project and how they are integrated to produce positive synergies; and
2. A list, in a single alphabetized table, with the full names and institutional affiliations of all people with **conflicts of interest** for all senior personnel (PI and co-PI's) and any named personnel whose salary is requested in the project budget. Conflicts to be identified are (1) PhD thesis advisors or advisees, (2) collaborators or co-authors, including postdoctoral researchers, for the past 48 months, and (3) any other individuals with whom or institutions with which the PIs have financial ties (please specify type).

In addition to the FastLane instructions, the proposers must send the following two documents via email immediately after submission of their proposal. After receipt of the proposal number from FastLane, send an email to: efri2015@nsf.gov. The subject heading of the email should note the proposal number and the lead institution. Attach the following documents prepared on templates that will be available at http://www.nsf.gov/eng/efri:

1. An Excel spreadsheet containing two lists: one lists the last names, first names and institutional affiliations of all senior personnel (PI and co-PI's) and any named personnel whose salary is requested in the project budget; the second one lists the full names and institutional affiliations of all people having **conflicts of interest** with any senior personnel (PI and co-PI's) or named personnel whose salary is requested in the project budget. These lists will be used by NSF to check for conflicts of interest in assembling the review community.
2. A single **PowerPoint slide** summarizing the vision of the EFRI proposal. This will be used during review panel discussions.

Remember to email these two documents to: efri2015@nsf.gov; do not use FastLane.

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

- Full proposals submitted via FastLane: Proposals submitted in response to this program solicitation should be prepared and submitted in accordance with the general guidelines contained in the NSF Grant Proposal Guide (GPG). The complete text of the GPG is available electronically on the NSF website at: http://www.nsf.gov/publications/pub_summ.jsp?ods_key=gpg. Paper copies of the GPG may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-7827 or by e-mail from nsfpubs@nsf.gov. Proposers are reminded to identify this program solicitation number in the program solicitation block on the NSF Cover Sheet For Proposal to the National Science Foundation. Compliance with this requirement is critical to determining the relevant proposal processing guidelines. Failure to submit this information may delay processing.

- Full proposals submitted via Grants.gov: Proposals submitted in response to this program solicitation via Grants.gov should be prepared and submitted in accordance with the NSF Grants.gov Application Guide: A Guide for the Preparation and Submission of NSF Applications via Grants.gov. The complete text of the NSF Grants.gov Application Guide is available on the Grants.gov website and on the NSF website at: (http://www.nsf.gov/publications/pub_summ.jsp?ods_key=grantsgovguide). To obtain copies of the Application Guide and Application Forms Package, click on the Apply tab on the Grants.gov site, then click on the Apply Step 1: Download a Grant Application Package and Application Instructions link and enter the funding opportunity number, (the program solicitation number without the NSF prefix) and press the Download Package button. Paper copies of the Grants.gov Application Guide also may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-7827 or by e-mail from nsfpubs@nsf.gov.

Based on the review of preliminary proposals, a limited number of PIs will be invited to submit a full proposal. If multiple universities are involved in an invited full proposal, it must be submitted as a single full proposal with subawards, and not as separately submitted collaborative proposals.

The review of invited full proposals will include both *ad hoc* and panel reviews. The following exceptions and additions to the GPG or NSF Grants.gov Application Guide apply to full proposals submitted to this Program:

Full proposals will be accepted only from PIs who have submitted preliminary proposals in the current review cycle. Submission of full proposals by PIs whose preliminary proposals received a review recommendation of 'Not Invited' will be returned without review.

Cover Sheet: Select the EFRI program solicitation number from the pull down list. Check the box indicated for full proposal. Entries on the cover sheet are limited to the principal investigator and a maximum of four co-principal investigators. Additional project leaders or senior personnel should be listed on the project summary page and entered into FastLane as senior investigators.

Title of Proposed Project: The title for the proposed EFRI project must begin with "**EFRI 2-DARE:"**. The title must state clearly and succinctly the major emerging frontier in research and innovation that is the focus for the project.

Project Summary (one-page limit): The Project Summary consists of an overview, a statement on the intellectual merit of the proposed activity, and a statement on the broader impacts of the proposed activity. Provide the following information:

1. In the Overview section provide the title of the project, the name of the PI and the lead institution or organization, and a list of co-PIs and senior personnel along with their institutions and organization or both;
2. A succinct summary of the **intellectual merit** of the proposed project. This should include the transformative nature of the proposed research, and the significant leap or paradigm shift in fundamental engineering knowledge; and
3. The **broader impacts** of the proposed work, including the potential long-term impact on national needs and a grand challenge or both. Include a summary of your Broadening Participation Plan.

Proposals that do not contain the Project Summary, including an overview and separate statements on intellectual merit and broader impacts will not be accepted by FastLane or will be returned without review.

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

1. Results from **Prior Research**: Describe prior research of each PI or co-PIs funded by NSF that is directly relevant to the proposed project; and
2. **Proposed Research**: Describe the vision and goals of the proposed research, approaches and methodologies to attain the goals, and the expected outcomes.
3. The project description should end with a subsection labeled **"Impact"** that describes how the proposed project will lead to a significant shift in fundamental engineering knowledge and have strong long-term potential for significant impact on a national need or a grand challenge. The proposal should also discuss effective ways in which education and outreach are integrated within the research program to achieve societal impacts. Concisely articulate unifying and integrative aspects of the proposed research as well as the innovative ideas of the research. The **Impact** subsection must include a **Broadening Participation Plan**. The plan must aim to broaden participation of underrepresented groups in engineering research. For more information see: Enhancing Diversity in Engineering at the end of Introduction, Section I. If needed, you may include additional information, up to five pages, about your Broadening Participation Plan in the Supplementary Documentation section.
4. Proposals to be considered by AFOSR for co-funding must include in the Project Description a brief explanation of the

aspects of the proposal reflecting the Air Force interests and an explicit statement indicating Air Force relevance.

References Cited: Indicate with an asterisk any cited publications that resulted from prior research funded by NSF for the PI, or co-PI(s).

Biographical Sketches for key personnel (PI, co-PIs, and each of the senior personnel listed on the Project Summary page). Use the standard format.

Current and Pending Support information must be provided for the PI and each of the co-PIs and Senior Personnel listed in the Project Summary page.

Budget: Develop a realistic project budget that is consistent with the proposed activities. Provide detailed budget justifications separately for the lead institution's budget (up to three pages of budget justification), and for each subawardee budget (up to three pages of budget justification for each subaward). Proposed budgets must include funds for travel by at least one PI and at least one graduate student to attend an annual EFRI grantees' meeting.

Facilities and Equipment: Provide a description of available facilities and priorities for its use, if applicable. For EFRI projects requiring additional equipment, justify the need for these resources in the context of the innovative work proposed.

In the **Supplementary Documentation** section, include the following:

1. Provide a **list of key personnel** involved (maximum three pages), with a description of what each person uniquely brings to the project and how they are integrated to produce positive synergies;
2. Provide a detailed **management plan** (maximum three pages) including means of communication, data tracking, management of personnel within the project group, management of intellectual property resulting from the project, and timeline of activities;
3. Proposals must include a **data management plan** (maximum one page). The contents of the data management plan should include: (1) the types of data to be produced, (2) the standards that would be applied for data format and metadata content, and (3) access policies and provision;
4. For proposals that include support for post-doctoral researchers, provide a **post-doc mentoring plan**;
5. **Means of sharing the outcome** of the research with the rest of the scientific community, *e.g.* publications, web sites, and significant data bases, *etc*. (maximum two pages). The description should be specific and describe what, how, and when the community would have access to the outcome of the project. This is particularly important for the projects that will produce tangible research tools and resources; and
6. A list, in a single alphabetized table, with the full names and institutional affiliations of all people with **conflicts of interest** for all senior personnel (PI and co-PI's) and any named personnel whose salary is requested in the project budget. Conflicts to be identified are (1) PhD thesis advisors or advisees, (2) collaborators or co-authors, including post-docs, for the past 48 months, and (3) any other individuals or institutions with which the investigator has financial ties (please specify type).

In addition, the proposers **must send the following two documents via email immediately after submission of their proposal**. After receipt of the proposal number from FastLane, send an email to: efri2015@nsf.gov. The subject heading of the email should note the proposal number and the lead institution. Attach the following documents prepared on templates that will be available at http://www.nsf.gov/eng/efri.

1. An Excel spreadsheet containing two lists: one lists the last names, first names and institutional affiliations of all senior personnel (PI and co-PI's) and any named personnel whose salary is requested in the project budget; the second one lists the full names and institutional affiliations of all people having **conflicts of interest** with any senior personnel (PI and co-PI's) or named personnel whose salary is requested in the project budget. These lists will be used by NSF to check for conflicts of interest in assembling the review community.
2. A single **PowerPoint slide** summarizing the vision of the EFRI proposal. This will be used during review panel discussions.

Remember to email these two documents to: efri2015@nsf.gov; do not use FastLane. Please submit these documents even if the information has not changed since submission of the preliminary proposal.

Pre-submission Check List:

- No principal investigator or co-principal investigator is listed as a principal investigator or co-principal investigator on any other EFRI proposal.
- The Lead PI must be at the faculty level, as determined by the submitting institution.
- If the proposal has multiple organizations, it is not submitted as a collaborative proposal but as a single proposal with subawards.
- Proposal has a minimum number of 3 PI/Co-PIs and a maximum of 5 PI/Co-PIs.
- Total budget does not exceed $2,000,000 and is spread over 4 years.
- **Broadening Participation Plan:** All proposals must describe a plan (both in Project Summary and Project Description) that promotes the participation of underrepresented groups in engineering.
- **Post-doctoral Researcher Mentoring Plan:** As a reminder, each proposal that requests funding to support postdoctoral researchers must include, as a supplementary document, a description of the mentoring activities that will be provided for such individuals.
- **Data Management Plan:** All proposals must describe plans for data management and sharing of the products of research, or assert the absence of the need for such plans.
- Immediately after submission, an E-mail is sent to: efri2015@nsf.gov with (a) the Excel spreadsheet that includes COI information and (b) a one-page project summary as PowerPoint slide. The subject heading of the email should note the proposal number and the lead institution.

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

B. Budgetary Information

Cost Sharing: Inclusion of voluntary committed cost sharing is prohibited.

C. Due Dates

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

November 07, 2014

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

  January 09, 2015

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

  April 13, 2015

  By Invitation Only

D. FastLane / Grants.gov Requirements

For Proposals Submitted Via FastLane:

To prepare and submit a proposal via FastLane, see detailed technical instructions available at: https://www.fastlane.nsf.gov/a1/newstan.htm. For FastLane user support, call the FastLane Help Desk at 1-800-673-6188 or e-mail fastlane@nsf.gov. The FastLane Help Desk answers general technical questions related to the use of the FastLane system. Specific questions related to this program solicitation should be referred to the NSF program staff contact(s) listed in Section VIII of this funding opportunity.

For Proposals Submitted Via Grants.gov:

Before using Grants.gov for the first time, each organization must register to create an institutional profile. Once registered, the applicant's organization can then apply for any federal grant on the Grants.gov website. Comprehensive information about using Grants.gov is available on the Grants.gov Applicant Resources webpage: http://www.grants.gov/web/grants/applicants.html. In addition, the NSF Grants.gov Application Guide (see link in Section V.A) provides instructions regarding the technical preparation of proposals via Grants.gov. For Grants.gov user support, contact the Grants.gov Contact Center at 1-800-518-4726 or by email: support@grants.gov. The Grants.gov Contact Center answers general technical questions related to the use of Grants.gov. Specific questions related to this program solicitation should be referred to the NSF program staff contact(s) listed in Section VIII of this solicitation.

Submitting the Proposal: Once all documents have been completed, the Authorized Organizational Representative (AOR) must submit the application to Grants.gov and verify the desired funding opportunity and agency to which the application is submitted. The AOR must then sign and submit the application to Grants.gov. The completed application will be transferred to the NSF FastLane system for further processing.

Proposers that submitted via FastLane are strongly encouraged to use FastLane to verify the status of their submission to NSF. For proposers that submitted via Grants.gov, until an application has been received and validated by NSF, the Authorized Organizational Representative may check the status of an application on Grants.gov. After proposers have received an e-mail notification from NSF, Research.gov should be used to check the status of an application.

VI. NSF PROPOSAL PROCESSING AND REVIEW PROCEDURES

Proposals received by NSF are assigned to the appropriate NSF program for acknowledgement and, if they meet NSF requirements, for review. All proposals are carefully reviewed by a scientist, engineer, or educator serving as an NSF Program Officer, and usually by three to ten other persons outside NSF either as *ad hoc* reviewers, panelists, or both, who are experts in the particular fields represented by the proposal. These reviewers are selected by Program Officers charged with oversight of the review process. Proposers are invited to suggest names of persons they believe are especially well qualified to review the proposal and/or persons they would prefer not review the proposal. These suggestions may serve as one source in the reviewer selection process at the Program Officer's discretion. Submission of such names, however, is optional. Care is taken to ensure that reviewers have no conflicts of interest with the proposal. In addition, Program Officers may obtain comments from site visits before recommending final action on proposals. Senior NSF staff further review recommendations for awards. A flowchart that depicts the entire NSF proposal and award process (and associated timeline) is included in the GPG as Exhibit III-1.

A comprehensive description of the Foundation's merit review process is available on the NSF website at: http://nsf.gov/bfa/dias/policy/merit_review/.

Proposers should also be aware of core strategies that are essential to the fulfillment of NSF's mission, as articulated in *Investing in Science, Engineering, and Education for the Nation's Future: NSF Strategic Plan for 2014-2018*. These strategies are integrated in the program planning and implementation process, of which proposal review is one part. NSF's mission is particularly well-implemented through the integration of research and education and broadening participation in NSF programs, projects, and activities.

One of the strategic objectives in support of NSF's mission is to foster integration of research and education through the programs, projects, and activities it supports at academic and research institutions. These institutions must recruit, train, and prepare a diverse STEM workforce to advance the frontiers of science and participate in the U.S. technology-based economy. NSF's contribution to the national innovation ecosystem is to provide cutting-edge research under the guidance of the Nation's most creative scientists and engineers. NSF also supports development of a strong science, technology, engineering, and mathematics (STEM) workforce by investing in building the knowledge that informs improvements in STEM teaching and learning.

NSF's mission calls for the broadening of opportunities and expanding participation of groups, institutions, and geographic regions that are underrepresented in STEM disciplines, which is essential to the health and vitality of science and engineering. NSF is committed to this principle of diversity and deems it central to the programs, projects, and activities it considers and supports.

A. Merit Review Principles and Criteria

The National Science Foundation strives to invest in a robust and diverse portfolio of projects that creates new knowledge and enables breakthroughs in understanding across all areas of science and engineering research and education. To identify which projects to support, NSF relies on a merit review process that incorporates consideration of both the technical aspects of a proposed project and its potential to contribute more broadly to advancing NSF's mission "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense; and for other purposes." NSF makes every effort to conduct a fair, competitive, transparent merit review process for the selection of projects.

1. Merit Review Principles

These principles are to be given due diligence by PIs and organizations when preparing proposals and managing projects, by reviewers when reading and evaluating proposals, and by NSF program staff when determining whether or not to recommend proposals for funding and while overseeing awards. Given that NSF is the primary federal agency charged with nurturing and supporting excellence in basic research and education, the following three principles apply:

- All NSF projects should be of the highest quality and have the potential to advance, if not transform, the frontiers of knowledge.
- NSF projects, in the aggregate, should contribute more broadly to achieving societal goals. These "Broader Impacts" may be accomplished through the research itself, through activities that are directly related to specific research projects, or through activities that are supported by, but are complementary to, the project. The project activities may be based on previously established and/or innovative methods and approaches, but in either case must be well justified.
- Meaningful assessment and evaluation of NSF funded projects should be based on appropriate metrics, keeping in mind the likely correlation between the effect of broader impacts and the resources provided to implement projects. If the size of the activity is limited, evaluation of that activity in isolation is not likely to be meaningful. Thus, assessing the effectiveness of these activities may best be done at a higher, more aggregated, level than the individual project.

With respect to the third principle, even if assessment of Broader Impacts outcomes for particular projects is done at an aggregated level, PIs are expected to be accountable for carrying out the activities described in the funded project. Thus, individual projects should include clearly stated goals, specific descriptions of the activities that the PI intends to do, and a plan in place to document the outputs of those activities.

These three merit review principles provide the basis for the merit review criteria, as well as a context within which the users of the criteria can better understand their intent.

2. Merit Review Criteria

All NSF proposals are evaluated through use of the two National Science Board approved merit review criteria. In some instances, however, NSF will employ additional criteria as required to highlight the specific objectives of certain programs and activities.

The two merit review criteria are listed below. **Both** criteria are to be given **full consideration** during the review and decision-making processes; each criterion is necessary but neither, by itself, is sufficient. Therefore, proposers must fully address both criteria. (GPG Chapter II.C.2.d.i. contains additional information for use by proposers in development of the Project Description section of the proposal.) Reviewers are strongly encouraged to review the criteria, including GPG Chapter II.C.2.d.i., prior to the review of a proposal.

When evaluating NSF proposals, reviewers will be asked to consider what the proposers want to do, why they want to do it, how they plan to do it, how they will know if they succeed, and what benefits could accrue if the project is successful. These issues apply both to the technical aspects of the proposal and the way in which the project may make broader contributions. To that end, reviewers will be asked to evaluate all proposals against two criteria:

- **Intellectual Merit:** The Intellectual Merit criterion encompasses the potential to advance knowledge; and
- **Broader Impacts:** The Broader Impacts criterion encompasses the potential to benefit society and contribute to the achievement of specific, desired societal outcomes.

The following elements should be considered in the review for both criteria:

1. What is the potential for the proposed activity to
    a. Advance knowledge and understanding within its own field or across different fields (Intellectual Merit); and
    b. Benefit society or advance desired societal outcomes (Broader Impacts)?
2. To what extent do the proposed activities suggest and explore creative, original, or potentially transformative concepts?
3. Is the plan for carrying out the proposed activities well-reasoned, well-organized, and based on a sound rationale? Does the plan incorporate a mechanism to assess success?
4. How well qualified is the individual, team, or organization to conduct the proposed activities?
5. Are there adequate resources available to the PI (either at the home organization or through collaborations) to carry out the proposed activities?

Broader impacts may be accomplished through the research itself, through the activities that are directly related to specific research projects, or through activities that are supported by, but are complementary to, the project. NSF values the advancement of scientific knowledge and activities that contribute to achievement of societally relevant outcomes. Such outcomes include, but are not limited to: full participation of women, persons with disabilities, and underrepresented minorities in science, technology, engineering, and mathematics (STEM); improved STEM education and educator development at any level; increased public scientific literacy and public engagement with science and technology; improved well-being of individuals in society; development of a diverse, globally competitive STEM workforce; increased partnerships between academia, industry, and others; improved national security; increased economic competitiveness of the United States; and enhanced infrastructure for research and education.

Proposers are reminded that reviewers will also be asked to review the Data Management Plan and the Postdoctoral Researcher Mentoring Plan, as appropriate.

Additional Solicitation Specific Review Criteria

In addition to the two NSF review criteria (intellectual merit and broader impacts), the following criteria will be used in the review of all EFRI proposals:

- ***TRANSFORMATIVE*** **-** Does the proposed research represent an opportunity for a significant leap or paradigm shift in fundamental engineering knowledge?
- ***NATIONAL NEED/GRAND CHALLENGE*** - Is there potential for making significant progress on a current national need or grand challenge?
- Responsiveness to "**Programmatic Considerations**" for **EFRI-2DARE** proposals as delineated in Section II. Program Description.

Broadening Participation Plan - Does the plan actively promote, increase, and enhance the participation of underrepresented groups in the field of engineering and in engineering research?
- Effectiveness of the proposed **management plan**.

B. Review and Selection Process

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

Reviewers will be asked to evaluate proposals using two National Science Board approved merit review criteria and, if applicable, additional program specific criteria. A summary rating and accompanying narrative will be completed and submitted by each reviewer. The Program Officer assigned to manage the proposal's review will consider the advice of reviewers and will formulate a recommendation.

After scientific, technical and programmatic review and consideration of appropriate factors, the NSF Program Officer recommends to the cognizant Division Director whether the proposal should be declined or recommended for award. NSF is striving to be able to tell applicants whether their proposals have been declined or recommended for funding within six months. The time interval begins on the date of receipt. The interval ends when the Division Director accepts the Program Officer's recommendation.

A summary rating and accompanying narrative will be completed and submitted by each reviewer. In all cases, reviews are treated as confidential documents. Verbatim copies of reviews, excluding the names of the reviewers, are sent to the Principal Investigator/Project Director by the Program Officer. In addition, the proposer will receive an explanation of the decision to award or decline funding.

In developing its recommendations for awards, review panels as well as NSF staff will consider: the relative merit of the EFRI proposals using the criteria listed above, the potential national impact of the proposed activity, the balance of awards among scientific fields, geographical distribution, and the combined ability of the proposals to meet the objectives of the EFRI Office. The EFRI Office will not normally award more than one proposal from any one lead institution in this competition.

In all cases, after programmatic approval has been obtained, the proposals recommended for funding will be forwarded to the Division of Grants and Agreements for review of business, financial, and policy implications and the processing and issuance of a grant or other agreement. Proposers are cautioned that only a Grants and Agreements Officer may make commitments, obligations or awards on behalf of NSF or authorize the expenditure of funds. No commitment on the part of NSF should be inferred from technical or budgetary discussions with a NSF Program Officer. A Principal Investigator or organization that makes financial or personnel commitments in the absence of a grant or cooperative agreement signed by the NSF Grants and Agreements Officer does so at their own risk.

VII. AWARD ADMINISTRATION INFORMATION

A. Notification of the Award

Notification of the award is made to *the submitting organization* by a Grants Officer in the Division of Grants and Agreements. Organizations whose proposals are declined will be advised as promptly as possible by the cognizant NSF Program administering the program. Verbatim copies of reviews, not including the identity of the reviewer, will be provided automatically to the Principal Investigator. (See Section VI.B. for additional information on the review process).

B. Award Conditions

An NSF award consists of: (1) the award notice, which includes any special provisions applicable to the award and any numbered amendments thereto; (2) the budget, which indicates the amounts, by categories of expense, on which NSF has based its support (or otherwise communicates any specific approvals or disapprovals of proposed expenditures); (3) the proposal referenced in the award notice; (4) the applicable award conditions, such as Grant General Conditions (GC-1)*; or Research Terms and Conditions* and (5) any announcement or other NSF issuance that may be incorporated by reference in the award notice. Cooperative agreements also are administered in accordance with NSF Cooperative Agreement Financial and Administrative Terms and Conditions (CA-FATC) and the applicable Programmatic Terms and Conditions. NSF awards are electronically signed by an NSF Grants and Agreements Officer and transmitted electronically to the organization via e-mail.

*These documents may be accessed electronically on NSF's Website at http://www.nsf.gov/awards/managing/award_conditions.jsp?org=NSF. Paper copies may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-7827 or by e-mail from nsfpubs@nsf.gov.

More comprehensive information on NSF Award Conditions and other important information on the administration of NSF awards is contained in the NSF *Award & Administration Guide* (AAG) Chapter II, available electronically on the NSF Website at http://www.nsf.gov/publications/pub_summ.jsp?ods_key=aag.

Special Award Conditions:

Awardees must include in the proposal budget funds for travel by PI and one researcher or a student to attend an annual EFRI grantees' meeting.

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 at least 90 days prior to the end of the current budget period. (Some programs or awards require submission of more frequent project reports). Within 90 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 *Award & Administration Guide* (AAG) Chapter II, available electronically on the NSF Website at http://www.nsf.gov/publications/pub_summ.jsp?ods_key=aag.

Awardees will be required to attend and present their research results and plans annually at an annual EFRI grantees' conference for the duration for their award.

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:

- Dimitris Pavlidis, (TOPIC COORDINATOR), ENG/ECCS, telephone: (703) 292-2216, email: dpavlidi@nsf.gov
- Sohi Rastegar, Director, ENG/EFRI, telephone: (703) 292-8305, email: srastega@nsf.gov
- Garie Fordyce, Program Manager, ENG/EFRI, telephone: (703) 292-4603, email: gfordyce@nsf.gov
- Bruce M. Kramer, Program Director, ENG/CMMI, telephone: (703) 292-5348, email: bkramer@nsf.gov
- Charles Ying, Program Director, MPS/DMR, telephone: (703) 292-8428, email: cying@nsf.gov
- Rosemarie Wesson, Program Director, ENG/CBET/EFRI, telephone: (703) 292-7070, email: rwesson@nsf.gov
- Keith Roper, Program Director, ENG/EEC, telephone: (703) 292-8769, email: kroper@nsf.gov
- Timothy Patten, Program Director, MPS/CHE, telephone: (703) 292-7196, email: tpatten@nsf.gov
- Rajesh Mehta, Program Director, ENG\IIP, telephone: (703) 292-2174, email: rmehta@nsf.gov
- William Olbricht, Program Director, ENG\CBET, telephone: (703) 292-2563, email: wolbrich@nsf.gov

For questions related to the use of FastLane, contact:

- FastLane Help Desk, telephone: 1-800-673-6188; e-mail: fastlane@nsf.gov.

For questions relating to Grants.gov contact:

- Grants.gov Contact Center: If the Authorized Organizational Representatives (AOR) has not received a confirmation message from Grants.gov within 48 hours of submission of application, please contact via telephone: 1-800-518-4726; e-mail: support@grants.gov.

The following Program Officers may also be contacted for content specific questions on the EFRI 2014 topic:

- Dimitris Pavlidis, (Topic Coordinator), NSF/ENG/ECCS, telephone: (703) 292-2216, email: dpavlidi@nsf.gov,
- Bruce M Kramer, Program Director, NSF/ENG/CMMI, telephone: (703) 292-5348, email: bkramer@nsf.gov
- Charles Ying, Program Director, NSF/MPS/DMR, telephone: (703) 292-8428, email: cying@nsf.gov
- Timothy Patten, Program Director, NSF/MPS/CHE, telephone: (703) 292-7196, email: ltolbert@nsf.gov
- Keith Roper, Program Director, ENG/EEC, telephone: (703) 292-8769, email: ltolbert@nsf.gov
- Rajesh Mehta, Program Director, NSF/ENG/IIP, telephone: (703) 292-2174, email: rmehta@nsf.gov
- William Olbricht, Program Director, NSF/ENG/CBET, telephone: (703) 292-2563, email: wolbrich@nsf.gov

***AFOSR CONTACTS*:**

- Kenneth C. Goretta Program Officer, USAF/AFOSR/GHz-THz Electronics, (703) 696-7349, email: kenneth.goretta@us.af.mil
- Joycelyn Harrison, Program Officer, USAF/AFOSR/Low Density Materials, (703) 696-6225, email: joycelyn.harrison@us.af.mil
- Misoon Y. Mah, Director, USAF/AFOSR/Asian Office of Aerospace Research & Development, +81 (3) 6385-3282, email: misoon.mah@us.af.mil
- Gernot Pomrenke, Program Officer, USAF/AFOSR/Optoelectronics and Photonics, (703) 696-8426, email: gernot.pomrenke@us.af.mil

IX. OTHER INFORMATION

The NSF website provides the most comprehensive source of information on NSF Directorates (including contact information), programs and funding opportunities. Use of this website by potential proposers is strongly encouraged. In addition, "NSF Update" is an information-delivery system designed to keep potential proposers and other interested parties apprised of new NSF funding opportunities and publications, important changes in proposal and award policies and procedures, and upcoming NSF Grants Conferences. Subscribers are informed through e-mail or the user's Web browser each time new publications are issued that match their identified interests. "NSF Update" also is available on NSF's website at https://public.govdelivery.com/accounts/USNSF/subscriber/new?topic_id=USNSF_179.

Grants.gov provides an additional electronic capability to search for Federal government-wide grant opportunities. NSF funding opportunities may be accessed via this mechanism. Further information on Grants.gov may be obtained at http://www.grants.gov.

ABOUT THE NATIONAL SCIENCE FOUNDATION

The National Science Foundation (NSF) is an independent Federal agency created by the National Science Foundation Act of 1950, as amended (42 USC 1861-75). The Act states the purpose of the NSF is "to promote the progress of science; [and] to advance the national health, prosperity, and welfare by supporting research and education in all fields of science and engineering."

NSF funds research and education in most fields of science and engineering. It does this through grants and cooperative agreements to more than 2,000 colleges, universities, K-12 school systems, businesses, informal science organizations and other research organizations throughout the US. The Foundation accounts for about one-fourth of Federal support to academic institutions for basic research.

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

Facilitation Awards for Scientists and Engineers with Disabilities provide funding for special assistance or equipment to enable persons with disabilities to work on NSF-supported projects. See Grant Proposal Guide Chapter II, Section D.2 for instructions regarding preparation of these types of proposals.

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

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

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

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

- **Location:** 4201 Wilson Blvd. Arlington, VA 22230
- **For General Information** (NSF Information Center)**:** (703) 292-5111
- **TDD (for the hearing-impaired):** (703) 292-5090
- **To Order Publications or Forms:**

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

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

PRIVACY ACT AND PUBLIC BURDEN STATEMENTS

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

NSF-51, "Reviewer/Proposal File and Associated Records," 69 Federal Register 26410 (May 12, 2004). Submission of the information is voluntary. Failure to provide full and complete information, however, may reduce the possibility of receiving an award.

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

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