

NSF/VMware Partnership on the Next Generation of Sustainable Digital Infrastructure (NGSDI)

PROGRAM SOLICITATION NSF 20-594



National Science Foundation

Directorate for Computer and Information Science and Engineering
Division of Computer and Network Systems



VMware, Inc.

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

November 04, 2020

IMPORTANT INFORMATION AND REVISION NOTES

NSF will hold an informational webinar to discuss the solicitation, submission requirements, and will include a question and answer session. Please check the program page for updates.

Any proposal submitted in response to this solicitation should be submitted in accordance with the revised *NSF Proposal & Award Policies & Procedures Guide* (PAPPG) (NSF 20-1), which is effective for proposals submitted, or due, on or after June 1, 2020.

SUMMARY OF PROGRAM REQUIREMENTS

General Information

Program Title:

NSF/VMware Partnership on The Next Generation of Sustainable Digital Infrastructure (NGSDI)

Synopsis of Program:

The goal of this joint solicitation between NSF and VMware is to foster novel, transformative research in fundamental and systematic approaches that bring dramatic increases in the environmental sustainability of the Digital Infrastructure leading to practical methodologies and tools. The Digital Infrastructure is broadly defined as the totality of software, hardware, and the methods for managing them for the purpose of efficient computation. This research includes, but is not limited to, computer software and systems; management of distributed software, the Digital Infrastructure, and data center power sourcing; and resource allocation and scheduling. Critical to initiating such research is to set its objectives through the definition of novel metrics and benchmarks that capture the sustainability challenges of all components in the entire computation chain.

The program also aims to support a research community committed to advancing research and education at the confluence of management technologies for software, hardware and power for Sustainable Digital Infrastructure, and to transition research findings into practice. A new generation of innovation would build on many recent advances such as passive and active measurements, statistical analysis and inference, learning for automated control and complex optimization, workload isolation and management, agile development, convergence of development and production environments, and architecture-optimized language translation.

In recent years, along with the rapid expansion of data centers and cloud computing, there has been an increased interest in making this expansion environmentally sustainable. According to a recent report, compute workload has grown six-fold between 2010 and 2018 [https://datacenters.lbl.gov/sites/default/files/Masanet_et_al_Science_2020.full_.pdf] with tremendous consumer and societal benefits. While some cloud-based applications increased overall sustainability (such as reduced emissions from cloud-enabled telecommuting, including VMware's Virtual Desktop Infrastructure, VDI [<https://www.vmware.com/topics/glossary/content/virtual-desktop-infrastructure-vgdi>]), there has been a high interest and effort in increasing the sustainability of data center operations. The *LBNL US Data Center Energy Report* [<https://eta.lbl.gov/publications/united-states-data-center-energy>] finds that the annual growth of data center power consumption decreased from 90% in 2000-2005 to 4% in 2010-2014 and is forecasted to remain at 4% for 2015-2020. The report mainly attributes this reduction in growth rate to industry adoption of server virtualization and hardware improvements. For example, VMware's advances in virtualization and resource management technologies resulted in customer server consolidation, reducing power consumption by 120 million MWh and saving 67 million Metric Tons of CO₂ in 2015 alone [<https://www.vmware.com/content/dam/digitalmarketing/vmware/en/pdf/sustainability/vmware->

[greenit-virtualization-delivers-energy-carbon-emissions.pdf](#)].

The next generation of innovation in sustainability of Digital Infrastructure will consider the full range of research areas, including 1) metrics, benchmarks and measurement methods to capture the wide variety of applications; 2) infrastructure architectures and approaches to incorporate sustainability concerns across the full Development and Operations (DevOps) lifecycle; and 3) methods to manage the aggregate Digital Infrastructure environment and workloads.

NSF and VMware will support multiple projects with funding of up to \$3,000,000 each over three years, and it is intended that NSF and VMware will co-fund each project.

This NSF/VMware partnership combines CISE's experience in developing and managing successful large, diverse research portfolios with VMware's significant expertise in management of virtualized workloads, virtualization technology, distributed systems, cloud computing, and other aspects of large-scale software infrastructure and infrastructure management.

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.

- Erik Brunvand, Program Director, CISE/CNS, telephone: (703) 292-2767, email: ebrunvan@nsf.gov
- Darleen Fisher, Program Director, CISE/CNS, telephone: (703) 292-4547, email: dlfisher@nsf.gov
- Matt Mutka, Program Director, CISE/CNS, telephone: (703) 292-7344, email: mmutka@nsf.gov
- Ann Von Lehman, Program Director, CISE/CNS, telephone: (703) 292-4756, email: avonlehm@nsf.gov
- Victor Firoiu, VMware, telephone: (650) 427-4542, email: vfiroiu@vmware.com
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Applicable Catalog of Federal Domestic Assistance (CFDA) Number(s):

- 47.070 --- Computer and Information Science and Engineering

Award Information

Anticipated Type of Award:

Standard Grant or Continuing Grant or VMware Agreement (Contract or Grant) through VMware or its Vanguard-managed University Research Fund

Estimated Number of Awards: 2

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

Anticipated Funding Amount: \$6,000,000

Subject to the quality of proposals received and availability of funds.

Eligibility Information

Who May Submit Proposals:

Proposals may only be submitted by the following:

- Institutions of Higher Education (IHEs) - Two- and four-year IHEs (including community colleges) accredited in, and having a campus located in the US, acting on behalf of their faculty members. Special Instructions for International Branch Campuses of US IHEs: If the proposal includes funding to be provided to an international branch campus of a US institution of higher education (including through use of subawards and consultant arrangements), the proposer must explain the benefit(s) to the project of performance at the international branch campus, and justify why the project activities cannot be performed at the US campus.

Who May Serve as PI:

There are no restrictions or limits.

Limit on Number of Proposals per Organization:

There are no restrictions or limits.

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

An individual may participate as PI, co-PI, or senior personnel in **no more than one proposal** submitted in response to this solicitation. In the event that an individual exceeds this limit, the first proposal received within the limit will be accepted based on the earliest date and time of proposal submission (i.e., the first proposal received will be accepted and the remainder will be returned without review). **No exceptions will be made.**

This limit on the number of proposals per PI, co-PI, or senior personnel applies only to this NSF/VMware NGSDI program solicitation.

Proposal Preparation and Submission Instructions

A. Proposal Preparation Instructions

- **Letters of Intent:** Not required
- **Preliminary Proposal Submission:** Not required
- **Full Proposals:**
 - Full Proposals submitted via FastLane: *NSF Proposal and Award Policies and Procedures Guide* (PAPPG) guidelines apply. The complete text of the PAPPG is available electronically on the NSF website at: https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg.
 - Full Proposals submitted via Grants.gov: *NSF Grants.gov Application Guide: A Guide for the Preparation and Submission of NSF Applications via Grants.gov* guidelines apply (Note: The *NSF Grants.gov Application Guide* is available on the Grants.gov website and on the NSF website at: https://www.nsf.gov/publications/pub_summ.jsp?ods_key=grantsgovguide).

B. Budgetary Information

- **Cost Sharing Requirements:**

Inclusion of voluntary committed cost sharing is prohibited.
- **Indirect Cost (F&A) Limitations:**

Not Applicable
- **Other Budgetary Limitations:**

Not Applicable

C. Due Dates

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

November 04, 2020

Proposal Review Information Criteria

Merit Review Criteria:

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

Award Administration Information

Award Conditions:

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

Reporting Requirements:

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

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I. INTRODUCTION

In recent years, along with the rapid expansion of data centers and cloud computing, there has been an increased interest in making this expansion sustainable. According to a recent report [https://datacenters.lbl.gov/sites/default/files/Masanet_et_al_Science_2020.full_.pdf], compute workload has grown six-fold between 2010 and 2018, or 25% annually. While this growth brought a wide range of benefits for consumers and society, it has also enabled applications that themselves increase overall sustainability. For example, cloud-enabled telecommuting (such as VMware's Virtual Desktop Infrastructure, VDI [<https://www.vmware.com/topics/glossary/content/virtual-desktop-infrastructure-vgdi>]), e-learning, and virtual conferencing are reducing transportation and carbon emissions [http://smarter2030.gesi.org/downloads/Full_report.pdf].

The high growth rate in computation demand poses significant sustainability problems including energy and material consumption and carbon footprint. The *LBNL US Data Center Energy Report* [<https://eta.lbl.gov/publications/united-states-data-center-energy>] found that the growth rate of data center energy consumption was 90% annually during the period between 2000 and 2005. The same report shows that significant progress has been made since 2005, reducing the growth rate to 4% in 2010-2014 and forecasted to remain at 4% in 2015-2020. The report attributes this reduction in growth rate primarily to industry adoption of server virtualization and hardware improvements. For example, VMware's advances in virtualization and resource management technologies resulted in customer server consolidation, reducing power consumption by 120 million MWh and saving 67 million Metric Tons of CO₂ in 2015 alone [<https://www.vmware.com/content/dam/digitalmarketing/vmware/en/pdf/sustainability/vmware-greenit-virtualization-delivers-energy-carbon-emissions.pdf>].

While reducing the growth rate of data center power consumption has been a very important achievement toward sustainability, it is not sufficient to attain the long-term goals of carbon-neutrality and carbon-freedom. The 2015 report of the NSF Workshop on Sustainable Data Centers [<http://vhosts.eecs.umich.edu/wsdc/NSF-SDC-FinalReport.pdf>] finds that the "first generation of improvement has plateaued" and that "it is time for a second, holistic, clean-slate redesign of the data center". The emerging consensus at the time was that the current generation of innovation (increased density of workloads per computing unit via virtualization, redesign of computing systems power management, and redesign of the data center electrical and mechanical architectures) has realized the bulk of its potential for increased efficiency. Moreover, the scope of workload and infrastructure optimization now comprises a larger domain of managed computing environments, including on-premise and hosted private cloud, public cloud, hybrid cloud and multi-cloud.

While the first generation of data center improvements achieved a high level of server efficiency, sustainability requires efficiency of the entire computation chain, starting from the consumption of power and material, and ending with the desired computation results. In this context, the Digital Infrastructure is broadly defined as the totality of the software, hardware, and the methods for managing them for the purpose of efficient computation.

In order to set the objectives for the second generation of research in Sustainable Digital Infrastructure, it is critical that new metrics and benchmarks be defined first. These metrics and benchmarks would capture the sustainability challenges of the entire computation chain, going well beyond the scope of the first-generation metrics, where the Power Usage Effectiveness (PUE) focused on maximizing server efficiency.

In summary, the next generation of innovation for increased sustainability of Digital Infrastructure should include broader considerations, such as:

- Metrics and benchmarks for systemic computational efficiency;
- Software bloat and inefficiency;
- Distributed resource allocation;
- Capacity planning and provisioning;
- Compute-storage-networking tradeoffs and placement;
- Hardware-software co-optimization;
- Service level agreement (SLA) trade space;
- Renewable energy source optimization;
- Hardware lifetime optimization; and
- Renewable-energy driven workload shifting.

II. PROGRAM DESCRIPTION

The central question to be addressed in this research program is as follows:

What fundamental and systematic approaches in measurement, design, development and management of the Digital Infrastructure resources and workloads will enable significant progress toward maximizing sustainability of the Digital Infrastructure with minimal impact on traditional concerns such as programmer productivity and Digital Infrastructure performance and scalability?

Researchers must consider the fundamental nature of this problem, the multiple aspects of sustainability, and the multitude of competing goals of Digital Infrastructure management (including economics, performance, efficiency, and sustainability).

Of particular interest are 1) metrics and benchmarks that capture the multiple aspects of sustainability, plus methods to measure these metrics for a wide variety of applications and infrastructure architectures; 2) approaches to incorporate sustainability concerns across the full Development and Operations (DevOps) lifecycle; and 3) methods to manage the aggregate Digital Infrastructure ecosystem and workloads with the goal of maximizing the sustainability metrics.

The research vectors noted below are illustrative of potential key areas of research, but are not meant to be prescriptive or to limit the nature and scope of proposed approaches. Researchers should feel free to propose solutions that address broader Digital Infrastructure sustainability challenges in novel and innovative ways.

Vector 1: Sustainability Metrics: Systemic Computational Efficiency, Instrumentation and Benchmarks

- **Sustainability Metrics and Instrumentation.** The cost of energy, cooling and system resources do not fully characterize sustainability, nor is sustainability data incorporated into software development or management planes. Research is needed in methods and tools to quantify the *end-to-end efficiency of computation (Systemic Computational Efficiency)*. Arguably new metrics would account for total energy consumption at a functional level in full consideration of distributed storage/compute/networking energy costs. These new metrics might also reflect unaccounted externalities such as energy source, lifecycle costs of equipment, CO₂, water, and e-waste. In addition to defining new system-level metrics, research may be needed to operationalize such metrics.
- **Sustainability Benchmarks and Service-Level Objectives (SLO).** While metrics can be defined in a controlled setting, practical methods are needed for standardized assessment of applications and infrastructure in a real data center setting. Research is needed to define benchmarking methods such as standardized workloads for evaluation and comparison of sustainability metrics of dimensioning, configuration, control and management of execution environments and app implementations. Research is also needed for defining SLO that convey customer and provider sustainability objectives and priorities.

Vector 2: Sustainable Workload Design and Development

- **DevOps Divide.** DevOps has brought modern application development through seamless collaboration between software development and Information Technology (IT) operation. One of its benefits is an increased development productivity by focusing on a platform-independent application deployment format (containerization) that abstracts run-time platform resource consumption. But this abstraction, in turn, tends to obscure inefficiency issues of app execution on IT infrastructure. Research is needed into methods to provide software developers with visibility into energy implications. This visibility in turn can enable efficient coding and architectures of modern applications that minimize the resources required for a given workload. Software development tools have been focusing on agility and productivity of development. Research is needed in software development tools and best practices that help developers optimize the combined goals of sustainability, agility and productivity.
- **Full-stack Visibility and Optimization.** Traditionally, performance optimization has focused within individual layers of the workload-infrastructure stack. New research is needed to address inefficiencies between software layers, and between applications and infrastructure, which span all environments and platforms: on-premise and hosted private cloud, public cloud, hybrid private-public cloud and multi-cloud. In addition, research is needed on methods to coordinate and adapt tenant incentives for optimizing aggregate sustainability metrics in multi-tenant data centers.
- **Distributed Applications.** Migration of applications to the cloud have provided significant efficiencies of infrastructure utilization. While apps are distributed into single-, multi- or hybrid cloud, increasing amounts of data need to be moved between increased number of locations. Past research has focused on efficient placement of application on physical systems [<https://www.sciencedirect.com/science/article/pii/S1877050916000958>]. Research is needed into energy-efficient methods for combined app and data mobility and distribution in hybrid and multi-cloud. Research is also needed in the design of distributed apps for aggregate efficiency, as well as dynamic allocation of resources.

Vector 3: Sustainable Workload and Digital Infrastructure Management

- **IT/Operational Technology (OT) Divide.** The separation between IT concerns of information integrity and security and OT concerns of maximizing uptime can result in Digital Infrastructure inefficiencies. Research in IT/OT convergence with a sustainability focus can include improved efficiency from OT decisions informed by IT data, and IT overhead reduced by using inputs from operational assets and processes.
- **Automation.** The recent explosion of automation at all stages of the application lifecycle provided significant savings in development and management costs, but the evolution of aggregate sustainability costs is not well understood. Novel research is needed to quantify inefficiencies brought by software lifecycle automation and to develop mitigation of the inefficiencies. Another aspect of automation is the management and control of the increasingly complex Digital Infrastructure. Research is needed in the application of statistical analysis and learning techniques for management and control to optimize sustainability of the Digital Infrastructure.
- **Full Digital Infrastructure Optimization.** The first generation of sustainability has focused on efficient computation. As processing efficiency has increased, a recent trend is that an increasingly large fraction of energy is consumed by high-performance storage and network elements. Research is needed in optimizing total energy consumption of the Digital Infrastructure, taking advantage of recent advances in second generation of software-defined storage, smartNICs and network data transformation. Similarly, traditional sustainability efforts have focused primarily on the physical infrastructure. Research is needed in increasing efficiency and sustainability in the aggregate operation of vertical industries, such as the combined management of infrastructure resources, Internet of Things (IoT) devices, workloads and services in the Telecommunication or Cloud Computing verticals.
- **Power-sensitive Execution.** Recent advances in processor hardware created low-power alternatives to run many operational aspects of data centers. For example, hypervisors can run on low power, while compute-intensive workloads can run on high-power processors. Research is needed on power-aware workload placement on multi-tier processing resources.
- **Renewable power sources.** Recent developments in power generation and distribution have made it practical to have real-time information on the origin and type of power provided to data centers. Similarly, data center environmental data such as energy required for cooling may also be available in real time. Research is needed in the area of power- and environment-aware control and management of workload and infrastructure (such as workload scheduling and placement) for maximizing sustainability goals. This would enable, for example, integrating availability of renewable electric

power and consumptions needs with energy sourcing and pricing, in the context of Transactive Energy Systems (TES), where value is exchanged between parties but within parameter ranges that keep the power grid stable.

A wealth of emerging techniques could be harnessed to address these challenges. Examples of such techniques include:

- Passive and active measurements at system, local and wide area levels;
- Metrics aggregation services, statistical analysis and inference;
- Modeling and learning techniques to assist automated control, complex resource management and optimization;
- Process and system isolation (virtual machines, containers, functions-as-a-service) to enable control at a wide range of parameters and scale to include sustainability objectives; and
- Technologies for agile development and convergence of development and production environments.

While the above are just examples of emerging techniques that may be relevant to solving sustainability challenges, these should not be considered as preferred or an exclusive set. Proposers are encouraged to consider any combination of techniques to support approaches that fundamentally increase the understanding of and solutions for Digital Infrastructure sustainability challenges.

Scope and Expectations

This solicitation is looking for proposals of disruptive innovative approaches and ideas that have the potential to significantly advance the state of the art. Specifically excluded is research that primarily results in evolutionary improvements to the existing state of practice.

This solicitation seeks proposals that tackle game-changing sustainability opportunities. Proposers are encouraged to design a research plan with the potential for significant impact in terms of meaningful sustainability metrics. This solicitation focuses on software-layer sustainability, whereas proposals with a narrow focus on non-software components and disciplines are out of scope (e.g., strictly hardware architectures, water, power, cooling).

While fundamental, theoretical results have the potential for wide-ranging impact, such research should be substantiated with proof-of-concept experimental research.

Researchers are expected to develop prototypes of their proposed approaches to explore implementation aspects of their designs and to demonstrate the effectiveness of their approaches empirically. Prototypes should leverage existing software tools and frameworks where possible and avoid unnecessary re-invention.

Researchers are encouraged to use existing infrastructures for deploying and testing prototypes of their work, and for collecting data to demonstrate the effectiveness of their approach. Such infrastructures include but are not limited to the NSF FutureCloud projects [https://nsf.gov/news/news_summ.jsp?cntn_id=132377], Chameleon [www.chameleoncloud.org] and CloudLab [<https://cloudlab.us>], and NSF-funded CloudBank [<https://CloudBank.org/>], which provides NSF/CISE-funded researchers and educators with access to commercial cloud computing resources [https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=505591].

Where appropriate, proposers should be clear as to how they plan to navigate broader policy, economic, and social considerations that may influence, drive, or limit the impact of their research.

Expectation for Broader Impacts

Proposers should strive to be concrete about their plans to achieve broader industry impacts with any foundational results. Of particular interest are plans for disseminating research results including open source software, production and publication of datasets, and activities leading to real-world experimentation, measurements, and deployments.

III. AWARD INFORMATION

Anticipated Type of Award:

Continuing Grant or Standard Grant or VMware Agreement (Contract or Grant) through VMware or its Vanguard-managed University Research Fund

Estimated Number of Awards: 2

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

Anticipated Funding Amount: \$6,000,000

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

IV. ELIGIBILITY INFORMATION

Who May Submit Proposals:

Proposals may only be submitted by the following:

- Institutions of Higher Education (IHEs) - Two- and four-year IHEs (including community colleges) accredited in, and having a campus located in the US, acting on behalf of their faculty members. Special Instructions for International Branch Campuses of US IHEs: If the proposal includes funding to be provided to an international branch campus of a US institution of higher education (including through use of subawards and consultant arrangements), the proposer must explain the benefit(s) to the project of performance at the international branch campus, and justify why the project activities cannot be performed at the US campus.

Who May Serve as PI:

There are no restrictions or limits.

Limit on Number of Proposals per Organization:

There are no restrictions or limits.

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

An individual may participate as PI, co-PI, or senior personnel in **no more than one proposal** submitted in response to this solicitation. In the event that an individual exceeds this limit, the first proposal received within the limit will be accepted based on the earliest date and time of proposal submission (i.e., the first proposal received will be accepted and the remainder will be returned without review). **No exceptions will be made.**

This limit on the number of proposals per PI, co-PI, or senior personnel applies only to this NSF/VMware NGSDI program solicitation.

Additional Eligibility Info:

Subawardees may only include two-and four-year IHEs (including community colleges) accredited in, and having a campus located in, the US acting on behalf of their faculty members.

V. PROPOSAL PREPARATION AND SUBMISSION INSTRUCTIONS

A. Proposal Preparation Instructions

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

- Full proposals submitted via FastLane: Proposals submitted in response to this program solicitation should be prepared and submitted in accordance with the general guidelines contained in the *NSF Proposal & Award Policies & Procedures Guide* (PAPPG). The complete text of the PAPPG is available electronically on the NSF website at: https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg. Paper copies of the PAPPG may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-8134 or by e-mail from nsfpubs@nsf.gov. Proposers are reminded to identify this program solicitation number in the program solicitation block on the NSF Cover Sheet For Proposal to the National Science Foundation. Compliance with this requirement is critical to determining the relevant proposal processing guidelines. Failure to submit this information may delay processing.
- Full proposals submitted via Grants.gov: Proposals submitted in response to this program solicitation via Grants.gov should be prepared and submitted in accordance with the *NSF Grants.gov Application Guide: A Guide for the Preparation and Submission of NSF Applications via Grants.gov*. The complete text of the *NSF Grants.gov Application Guide* is available on the Grants.gov website and on the NSF website at: (https://www.nsf.gov/publications/pub_summ.jsp?ods_key=grantsgovguide). To obtain copies of the Application Guide and Application Forms Package, click on the Apply tab on the Grants.gov site, then click on the Apply Step 1: Download a Grant Application Package and Application Instructions link and enter the funding opportunity number, (the program solicitation number without the NSF prefix) and press the Download Package button. Paper copies of the Grants.gov Application Guide also may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-8134 or by e-mail from nsfpubs@nsf.gov.

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

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

See PAPPG Chapter II.C.2 for guidance on the required sections of a full research proposal submitted to NSF. Please note that the proposal preparation instructions provided in this program solicitation may deviate from the PAPPG instructions.

Proposal Titles:

A proposal title must begin with "NGSDI:". For example, titles should take the form **NGSDI: Title**. If a proposal is submitted as part of a set of collaborative proposals, the title of the proposal should begin with "Collaborative Research:", followed by "NGSDI:", followed by the title. For example, if you are submitting a collaborative set of proposals, the title of each would be **Collaborative Research: NSDI: Title**.

Project Description:

Describe the research and education activities to be undertaken in **up to 20 pages**. Note that additional documents listed under the Single Copy Documents and Supplementary Documents sections below do not count towards this page limit. All proposals are expected to:

- Describe how the project goals and research outcomes have the potential to fundamentally improve the sustainability of Digital Infrastructure;
- Clearly explain the research component(s) of the project;
- Explain how research outcomes can be generalized to other areas of application;
- Explain how the proposed research aligns with the Program Description;

- Include a plan for validation of the research by experimentation and prototyping;
- Present a plan to integrate research outcomes into education and more broadly advance education in the field;
- Provide plans for disseminating the research and education outcomes in a manner that enables the research community to use the results in ways that go beyond traditional academic publications. These plans should include:
 - Creating and maintaining a web site that acknowledges funding by NSF and VMware, and includes description, publications, results, demonstrations and presentations; and
 - Preprints provided to NSF and VMware after papers have been accepted for publication, with published papers acknowledging funding by NSF and VMware.
- If the proposal involves a collaboration spanning multiple institutions, provide a compelling rationale for the multi-institution structure of the project and an explanation of how effective collaboration will be assured; and
- Present a research plan including a **Gantt chart** with major tasks, milestones, and interdependencies.

For all collaborative projects, Project Descriptions must be comprehensive and well-integrated, and should make a convincing case that the collaborative contributions of the project team will be greater than the sum of each of their individual contributions.

Supplementary Documents:

In the Supplementary Documents section, upload the following information where relevant or required.

1. *A list of Project Personnel and Partner Institutions (required):*

Note: In collaborative proposals, the lead institution should provide this information for all participants):

Provide current, accurate information for all personnel and institutions involved in the project. NSF staff will use this information in the merit review process to manage reviewer selection. The list **must** include all PIs, co-PIs, Senior Personnel, paid/unpaid Consultants or Collaborators, Subawardees, Postdocs, and project-level advisory committee members. This list should be numbered and include (in this order) Full name, Organization(s), and Role in the project, with each item separated by a semi-colon. Each person listed should start a new numbered line. For example:

- Mary Smith; XYZ University; PI
- John Jones; University of PQR; Senior Personnel
- Jane Brown; XYZ University; Postdoc
- Bob Adams; ABC Community College; Paid Consultant
- Susan White; Welldone Institution; Unpaid Collaborator
- Tim Green; ZZZ University; Subawardee

2. *Collaboration Plan (if applicable):*

Since the success of collaborative research efforts are known to depend on thoughtful coordination mechanisms that regularly bring together the various participants of the project, a substantive Collaboration Plan is required for all proposals with more than one investigator. Up to 2 pages are allowed for Collaboration Plans. The length of and level of detail provided in the Collaboration Plan should be commensurate with the complexity of the proposed project. The appropriateness of the research team's composition and expertise should be justified with respect to the focused goals of the project, and will be a factor in the merit review. Where appropriate, the Collaboration Plan should include: 1) the specific roles of the project participants in all organizations involved; 2) information on how the project will be managed across all the investigators, institutions, and/or disciplines; 3) identification of the specific coordination mechanisms that will enable cross-investigator, cross-institution, and/or cross-discipline scientific integration (e.g., monthly leadership meetings, yearly workshops, graduate student exchange, project meetings at conferences, use of video-conferences, software repositories, etc.); and 4) specific references to the budget line items that support collaboration and coordination mechanisms. The Collaboration Plan should reference and support the project research plan, including key interdependencies between tasks for different PIs, outlined in the Project Description. However, note that the Collaboration Plan should not be used to expand discussions on proposed research activities; all research activities should reside within the Project Description section.

If a proposal with more than one investigator does not include a Collaboration Plan of at most 2 pages, that proposal will be returned without review.

3. *Postdoctoral Researcher Mentoring Plan (if applicable):*

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. In no more than one page, the mentoring plan must describe the mentoring that will be provided to all postdoctoral researchers supported by the project, irrespective of whether they reside at the submitting organization, any subawardee organization, or at any organization participating in a simultaneously submitted collaborative project. Please be advised that, if required, FastLane will not permit submission of a proposal that is missing a Postdoctoral Researcher Mentoring Plan. See Chapter II.C.2.j of the PAPPG for further information about the implementation of this requirement.

4. *Data Management Plan (required):*

Proposals must include a supplementary document of no more than two pages labeled "Data Management Plan." This supplementary document should describe how the proposal will conform to NSF policy on the dissemination and sharing of research results and the intellectual property, publishing, and licensing requirements outlined under the Special Award Conditions section below.

See Chapter II.C.2.j of the PAPPG for full policy implementation.

For additional information see: <https://www.nsf.gov/bfa/dias/policy/dmp.jsp>.

For specific guidance for proposals submitted to the Directorate for Computer and Information Science and Engineering (CISE) see: https://www.nsf.gov/cise/cise_dmp.jsp.

Single Copy Documents:

Collaborators and Other Affiliations Information: Proposers should follow the guidance specified in Chapter II.C.1.e of the NSF PAPPG. Grants.gov Users: The

COA information must be provided through use of the COA template and uploaded as a PDF attachment.

Note the distinction to the list of Project Personnel and Partner Institutions specified above under Supplementary Documents: the listing of all project participants is collected by the project lead and entered as a Supplementary Document, which is then automatically included with all proposals in a project. The Collaborators and Other Affiliations are entered for each participant within each proposal and, as Single Copy Documents, are available only to NSF staff.

B. Budgetary Information

Cost Sharing:

Inclusion of voluntary committed cost sharing is prohibited.

Budget Preparation Instructions:

Budgets for projects should include funding for one or more project representatives (PI/co-PI/senior researcher or NSF-approved replacement and key students or postdocs) to attend a kickoff meeting as well as annual retreats held during the proposed lifetime of the award. For budget preparation purposes, PIs should assume these meetings will be held each year at VMware's corporate headquarters in Palo Alto, CA.

The budget submitted with the proposal should include all necessary project funds without regard to the two funding organizations; NSF and VMware will inform selected PIs of the breakdown in funding between the two organizations, and will request revised budgets at that point.

C. Due Dates

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

November 04, 2020

D. FastLane/Research.gov/Grants.gov Requirements

For Proposals Submitted Via FastLane or Research.gov:

To prepare and submit a proposal via FastLane, see detailed technical instructions available at: <https://www.fastlane.nsf.gov/a1/newstan.htm>. To prepare and submit a proposal via Research.gov, see detailed technical instructions available at: https://www.research.gov/research-portal/appmanager/base/desktop?_nfpb=true&_pageLabel=research_node_display&_nodePath=/researchGov/Service/Desktop/ProposalPreparationandSubmission.html. For FastLane or Research.gov user support, call the FastLane and Research.gov Help Desk at 1-800-673-6188 or e-mail fastlane@nsf.gov or rgov@nsf.gov. The FastLane and Research.gov Help Desk answers general technical questions related to the use of the FastLane and Research.gov systems. Specific questions related to this program solicitation should be referred to the NSF program staff contact(s) listed in Section VIII of this funding opportunity.

For Proposals Submitted Via Grants.gov:

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

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

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

VI. NSF PROPOSAL PROCESSING AND REVIEW PROCEDURES

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

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

Proposers should also be aware of core strategies that are essential to the fulfillment of NSF's mission, as articulated in *Building the Future: Investing in Discovery and Innovation - NSF Strategic Plan for Fiscal Years (FY) 2018 – 2022*. These strategies are integrated in the program planning and implementation process, of which proposal review is one part. NSF's mission is particularly well-implemented through the integration of research and education and broadening participation in NSF programs, projects, and activities.

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

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

A. Merit Review Principles and Criteria

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

1. Merit Review Principles

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

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

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

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

2. Merit Review Criteria

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

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

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

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

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

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

Broader impacts may be accomplished through the research itself, through the activities that are directly related to specific research projects, or through activities that are supported by, but are complementary to, the project. NSF values the advancement of scientific knowledge and activities that contribute to achievement of societally relevant outcomes. Such outcomes include, but are not limited to: full participation of women, persons with disabilities, and

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

NSF engages in partnership programs with companies in order to increase the potential for research discoveries to translate into innovations with societal impact through market mechanisms. It also seeks to foster insights that arise at disciplinary boundaries. While all aspects of Intellectual Merit and Broader Impacts described above will be considered, special attention will be placed on the degree to which:

- Project plans pursue both the development of a systems perspective as well as the creation, deployment, and evaluation of demonstrations or prototypes at the component and eventually the system levels;
- Proposals include lean, well-integrated teams of researchers with expertise in critical area(s) necessary to conduct the proposed work;
- Convincingly frames meaningful system-level sustainability metrics and argues that successful results will have a meaningful impact in terms of those metrics;
- Projects demonstrate concrete plans to impact and influence the broader industry; and
- Researchers use existing components and infrastructure such as the NSF FutureCloud projects, Chameleon and CloudLab, and NSF-funded CloudBank which provides NSF/CISE-funded researchers and educators with access to commercial cloud computing resources, and provide justification for their choices. Note: if proposing to build a new infrastructure, justification is needed for why the existing infrastructures do not suffice.

B. Review and Selection Process

Proposals submitted in response to this program solicitation will be reviewed by

Ad hoc Review and/or Panel Review, or Reverse Site Review.

A uniform review process will be conducted by NSF for all proposals received responding to this program solicitation. VMware may, through designated VMware Program Directors, provide input on the selection of reviewers and attend any review panels, including Reverse Site Visits, as observers. Upon conclusion of the review, award recommendations will be coordinated by a Joint NSF and VMware Working Group (hereafter referred to as JWG) comprising Program Directors from both NSF and VMware. Review materials from the NSF merit review process (i.e., proposals, unattributed reviews, and panel summaries) will be shared with appropriate VMware personnel for purposes of their review, as well as for subsequent discussion by the JWG. Additionally, if a given partnership award is deemed to fit the characteristics of a charitable contribution, VMware may recommend that its donor-advised fund at Vanguard Charitable make the award. In this case, the same review materials for the recommended proposal may be shared with Vanguard Charitable personnel for the purposes of performing their due diligence. All such information shared between NSF, VMware, and Vanguard Charitable will be kept confidential.

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

After scientific, technical and programmatic review and consideration of appropriate factors, the NSF Program Officer recommends to the cognizant Division Director whether the proposal should be declined or recommended for award. NSF strives to be able to tell applicants whether their proposals have been declined or recommended for funding within six months. Large or particularly complex proposals or proposals from new awardees may require additional review and processing time. The time interval begins on the deadline or target date, or receipt date, whichever is later. The interval ends when the Division Director acts upon the Program Officer's recommendation.

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

Once an award or declination decision has been made, Principal Investigators are provided feedback about their proposals. In all cases, reviews are treated as confidential documents. Verbatim copies of reviews, excluding the names of the reviewers or any reviewer-identifying information, are sent to the Principal Investigator/Project Director by the Program Officer. In addition, the proposer will receive an explanation of the decision to award or decline funding.

VII. AWARD ADMINISTRATION INFORMATION

A. Notification of the Award

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

B. Award Conditions

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

*These documents may be accessed electronically on NSF's Website at https://www.nsf.gov/awards/managing/award_conditions.jsp?org=NSF. Paper copies may be obtained from the NSF Publications Clearinghouse, telephone (703) 292-8134 or by e-mail from nsfpubs@nsf.gov.

More comprehensive information on NSF Award Conditions and other important information on the administration of NSF awards is contained in the NSF *Proposal & Award Policies & Procedures Guide* (PAPPG) Chapter VII, available electronically on the NSF Website at https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg.

Special Award Conditions:

Award Conditions:

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

1. Site visits, meetings, and annual retreats

VMware and NSF will organize annual retreats for awardees that will bring together the academic community involved in a specific NSF/VMware Partnership program, along with NSF and VMware personnel who have interest in that program. VMware and NSF will work with academic leadership to organize these events. VMware will provide space for such meetings at its corporate headquarters in Palo Alto, CA. They will involve reviews of the research underway in each project along with presentations from NSF and VMware on technical areas of interest related to each awarded project. Ample time will be provided for face-to-face interaction between participants in these retreats. NSF views these meetings as fundamentally valuable opportunities for faculty and students to learn about industry trends and context, and thereby to increase the potential for transitioning research results to practice.

2. Intellectual property, publishing, and licensing

NSF/VMware Partnership awardees will agree to dedicate to the public all intellectual property resulting from the research funded as part of this program, and further:

- The awardees will, with respect to software, offer such software through an open source license under an Apache 2.0 license found at: <https://opensource.org/licenses/apache2.0> or other similar open source license; in the event the software already contains code licensed under GNU's General Public License (GPL), then the open source shall be through GPL version 3 found at <http://www.gnu.org/licenses/gpl.html>;
- The awardees will submit for publication in openly available literature any results of the research funded as part of this program that are deemed to meet the standards for research publications in the field of study; and
- The awardees will deposit all published manuscripts and juried conference papers in a public access-compliant repository in accordance with the guidelines set forth in NSF's Public Access Policy (see NSF Public Access Frequently Asked Questions at https://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf18041&org=NSF) no later than 12 months after initial publication

Awardees will be required to include appropriate acknowledgment of NSF and VMware support in reports and/or publications on work performed under the award. An example of such an acknowledgement would be: "This material is based upon work supported by the NSF/VMware Partnership on The Next Generation of Sustainable Digital Infrastructure (NGSDI) program under Award Title and No. [Recipient enters project title and awards number(s)]." If VMware recommends funding through its donor-advised fund at Vanguard Charitable and such funding is granted, awardees will provide recognition to the VMware University Research Fund.

3. VMware participation in research

Upon request from the award recipient, or from NSF with the recipient's consent, VMware will share industry context, insights, and experience with the award recipient in order to support the success of the funded academic researchers. VMware may separately fund its own personnel to directly support the NSF/VMware Partnership research, part-time or full-time, with the institutions awarded NSF/VMware Partnership projects. Proposals do not need to budget for the cost of such personnel. At the request of an award recipient, or at the request of NSF with the recipient's consent, VMware researchers may work alongside the academic researchers on related projects, may be involved with the projects as advisors, and may be in a position to host student interns who wish to gain further industry experience. Further, at the request of an award recipient, or of NSF with the recipient's consent, VMware may designate one of its more senior, separately-funded researchers or engineers to work alongside NSF/VMware Partnership academic lead PIs to help identify promising directions for increased industrial and societal impact.

Such personnel will be available to the academic researchers solely for the benefit of the academic researchers and will not attempt to control or direct the research. To the extent that VMware personnel provide expertise at the request of an award recipient, such expertise should be understood as advice to the award recipients and the PIs, and shall not be understood either as advice to NSF or as compulsory for the award recipients and PIs. VMware will not seek any information that the researchers do not intend to share widely with other parties. VMware may provide the researchers with software (prototypes or products), computing infrastructure, or other support related to its products or internal research; however, in no case will any researcher be required to use VMware's offered contributions.

4. Program management

NSF and VMware will each designate a Program Director for each NSF/VMware Partnership award who will jointly oversee the execution of the project. The VMware Program Director may become a member of the NSF/VMware Partnership Project Management Team. Upon the request of an award recipient, or of NSF with the consent of the recipient, in order to help advise researchers on technical issues and industry context, VMware will be granted access to any reports or meetings normally required by NSF.

Annual on-site reviews may be conducted jointly by NSF and VMware. VMware will not be expected to share proprietary information, and neither will VMware presentations be published more broadly without explicit consent. Materials presented by the academic researchers at these meetings will be public material, as allowed by law. In order to support the NSF's vision of industry-academic interaction leading to greater impact for NSF-funded

research, at the request of an award recipient, or of NSF with the recipient's consent, VMware may lead the organization of biannual or more frequent phone calls with project teams in which NSF will also participate at its discretion. NSF may request visits to the research institutions or may ask PIs to visit NSF or VMware. Institutions may request site visits to VMware or invite site visits from VMware. VMware may invite academic faculty and students to visit VMware and may visit research institutions upon request.

5. Funding support and budget revisions

Each awarded project will be jointly funded by NSF and VMware through separate NSF and VMware funding instruments. NSF awards will be made as continuing or standard grants. VMware awards will be made as VMware agreements (Contracts, Grants, or Gifts). If a given partnership award is deemed to fit the characteristics of a charitable contribution, VMware may recommend that Vanguard Charitable make the award. NSF and VMware will manage their respective awards/agreements in accordance with their own guidelines and regulations. Either organization may supplement a project without requiring the other party to provide any additional funds.

The budget submitted with the proposal should include all necessary project funds without regard to the two funding organizations; NSF and VMware will inform selected PIs of the breakdown in funding between the two organizations, and will request revised budgets at that point.

C. Reporting Requirements

For all multi-year grants (including both standard and continuing grants), the Principal Investigator must submit an annual project report to the cognizant Program Officer no later than 90 days prior to the end of the current budget period. (Some programs or awards require submission of more frequent project reports). No later than 120 days following expiration of a grant, the PI also is required to submit a final project report, and a project outcomes report for the general public.

Failure to provide the required annual or final project reports, or the project outcomes report, will delay NSF review and processing of any future funding increments as well as any pending proposals for all identified PIs and co-PIs on a given award. PIs should examine the formats of the required reports in advance to assure availability of required data.

PIs are required to use NSF's electronic project-reporting system, available through Research.gov, for preparation and submission of annual and final project reports. Such reports provide information on accomplishments, project participants (individual and organizational), publications, and other specific products and impacts of the project. Submission of the report via Research.gov constitutes certification by the PI that the contents of the report are accurate and complete. The project outcomes report also must be prepared and submitted using Research.gov. This report serves as a brief summary, prepared specifically for the public, of the nature and outcomes of the project. This report will be posted on the NSF website exactly as it is submitted by the PI.

More comprehensive information on NSF Reporting Requirements and other important information on the administration of NSF awards is contained in the *NSF Proposal & Award Policies & Procedures Guide (PAPPG)* Chapter VII, available electronically on the NSF Website at https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg.

C. Reporting Requirements

For all multi-year grants (including both standard and continuing grants), the Principal Investigator must submit an annual project report to the cognizant Program Officer no later than 90 days prior to the end of the current budget period. (Some programs or awards require submission of more frequent project reports). No later than 120 days following expiration of a grant, the PI also is required to submit a final project report, and a project outcomes report for the general public.

Failure to provide the required annual or final project reports, or the project outcomes report, will delay NSF review and processing of any future funding increments as well as any pending proposals for all identified PIs and co-PIs on a given award. PIs should examine the formats of the required reports in advance to assure availability of required data.

PIs are required to use NSF's electronic project-reporting system, available through Research.gov, for preparation and submission of annual and final project reports. Such reports provide information on accomplishments, project participants (individual and organizational), publications, and other specific products and impacts of the project. Submission of the report via Research.gov constitutes certification by the PI that the contents of the report are accurate and complete. The project outcomes report also must be prepared and submitted using Research.gov. This report serves as a brief summary, prepared specifically for the public, of the nature and outcomes of the project. This report will be posted on the NSF website exactly as it is submitted by the PI.

More comprehensive information on NSF Reporting Requirements and other important information on the administration of NSF awards is contained in the *NSF Proposal & Award Policies & Procedures Guide (PAPPG)* Chapter VII, available electronically on the NSF Website at https://www.nsf.gov/publications/pub_summ.jsp?ods_key=pappg.

PIs are not required to submit reports to VMware. However, PIs acknowledge that VMware will be granted confidential access to any such reports required by NSF.

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:

- Erik Brunvand, Program Director, CISE/CNS, telephone: (703) 292-2767, email: ebunvan@nsf.gov
- Darleen Fisher, Program Director, CISE/CNS, telephone: (703) 292-4547, email: dlfisher@nsf.gov
- Matt Mutka, Program Director, CISE/CNS, telephone: (703) 292-7344, email: mmutka@nsf.gov
- Ann Von Lehman, Program Director, CISE/CNS, telephone: (703) 292-4756, email: avonlehm@nsf.gov

- Victor Firoiu, VMware, telephone: (650) 427-4542, email: vfiroiu@vmware.com
- J. Christopher Ramming, VMware, telephone: (650) 427-5000, email: chrisramming@vmware.com
- David Ott, VMware, telephone: (650) 427-5816, email: dott@vmware.com
- Sujata Banerjee, VMware, telephone: (650) 427-1066, email: sujatab@vmware.com

For questions related to the use of FastLane or Research.gov, contact:

- FastLane and Research.gov Help Desk: 1-800-673-6188
- FastLane Help Desk e-mail: fastlane@nsf.gov.
- Research.gov Help Desk e-mail: rgov@nsf.gov

For questions relating to Grants.gov contact:

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

IX. OTHER INFORMATION

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

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

ABOUT VMware Research & Innovation

VMware Research & Innovation delivers breakthrough technologies to fuel the growth and productivity of the computing industry as well as VMware's technology leadership. VMware focuses its research in the areas of software and distributed systems, with particular emphasis on virtualization in all aspects (e.g., compute, storage, and network) as well as systems management. VMware comprises R&D centers in many countries.

VMware Research & Innovation works with industry partners, government, and academia throughout the world to advance the state of the art in computing. VMware also supports groundbreaking university research projects through the VMware University Research Fund.

ABOUT THE NATIONAL SCIENCE FOUNDATION

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

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

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

Facilitation Awards for Scientists and Engineers with Disabilities (FASSED) provide funding for special assistance or equipment to enable persons with disabilities to work on NSF-supported projects. See the *NSF Proposal & Award Policies & Procedures Guide* Chapter II.E.6 for instructions regarding preparation of these types of proposals.

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

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

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

To get the latest information about program deadlines, to download copies of NSF publications, and to access abstracts of awards,

visit the NSF Website at <https://www.nsf.gov>

- **Location:** 2415 Eisenhower Avenue, Alexandria, VA 22314
- **For General Information** (NSF Information Center): (703) 292-5111
- **TDD (for the hearing-impaired):** (703) 292-5090
- **To Order Publications or Forms:**
Send an e-mail to: nsfpubs@nsf.gov
or telephone: (703) 292-8569
- **To Locate NSF Employees:** (703) 292-5111

PRIVACY ACT AND PUBLIC BURDEN STATEMENTS

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