

**Program Announcement
To DOE National Laboratories**

LAB 13-02

**Office of Science
Office of Advanced Scientific Computing Research (ASCR)**

2013 Exascale Operating and Runtime Systems

Revision #3 made 2/5/2013 – Change in proposal due date

From: February 18, 2013

To: February 25, 2013

Revision #2 1/24/2013

From (page 15) : “We anticipate that up to \$7,000,000 total will be available for a small number of awards to be made in FY2013, contingent on the availability of funds.”

To: “We anticipate that up to \$6,000,000 total will be available for a small number of awards to be made in FY2013, contingent on the availability of funds.”

From (page 16): “If more than one award is made, it is anticipated that award sizes will range from \$3,000,000 to \$3,500,000 per year.”

To: “If more than one award is made, it is anticipated that award sizes will range from \$2,500,000 to \$3,000,000 per year.”

Revised 1/4/2013 to correct URL

From: [2] Exascale Operating System and Runtime Software Report:

<http://cms1.sc.science.doe.gov/~media/ascr/pdf/research/cs/Exascale%20Workshop/ExaOSR-Report-Final.pdf>

To: <http://science.energy.gov/~media/ascr/pdf/research/cs/Exascale%20Workshop/ExaOSR-Report-Final.pdf>

GENERAL INQUIRIES ABOUT THIS PROGRAM ANNOUNCEMENT TO DOE NATIONAL LABORATORIES SHOULD BE DIRECTED TO:

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SUMMARY:

The Office of Advanced Scientific Computing Research (ASCR) of the Office of Science (SC), U.S. Department of Energy (DOE), hereby invites proposals for basic research that significantly advances operating and runtime systems (OS/R) software for exascale computing platforms and that leads to a prototype of a vendor-neutral operating and runtime system for exascale platforms.

The next-generation of scientific discovery will be enabled by research developments that can effectively harness significant or disruptive advances in computing technology. Exascale applications will generate results with orders of magnitude higher resolution and fidelity, achieving a time-to-solution significantly shorter than possible with today's high performance computing platforms. In order to deliver exascale computing in the next decade, significant research breakthroughs will be needed to address challenges in four key areas:

1. Energy efficient hardware and software design constrained to a power envelope of 20 Megawatts(MW);
2. Managing unprecedented parallelism, especially at the node level of exascale systems;
3. Managing deep memory hierarchies and multi-stage storage systems under severe energy constraints; and
4. Resilience in the presence of predicted high rates of hard and soft faults.

The heightened awareness of challenges to be addressed in the path to exascale has guided ASCR to invest in the research and development of new techniques, new designs, and advanced hardware and software architectures for next-generation systems. The recently funded exascale software stack program (X-Stack) will improve the programmability of these new systems. One of the objectives of the X-Stack program is to expand the community of computational scientists who can use leadership-class platforms.

This solicitation focuses on the next high priority research agenda for exascale systems. We are seeking collaborative proposals that address these key challenges, leading to platform-neutral prototypes of a complete exascale operating system and runtime software (OS/R).

The scale and complexity of exascale platforms require a radically new structure for operating systems and runtime software. Traditional OS/R functions and interfaces will need to be completely redesigned in order to incorporate breakthroughs in energy, power, parallelism, resilience, and management of

memory and storage hierarchies. Radically new functions and interfaces will be required for system control, management of resources, communications, thread management, synchronization, power management, recovery from faults, initialization, configuration, monitoring, load-balancing and for migration of work. OS/R software architecture will be very different from today's architectures, requiring coordinating dynamically adaptive services distributed across multiple layers of OS/R software components.

Figure 1 illustrates a reference OS/R software architecture. This architecture captures the requirement that exascale systems need agile and dynamic node OS/R software and an organization that is radically opposite to today's monolithic OS/R systems. The bottom layer includes the system's hardware (compute nodes, storage nodes, network, service processors, etc.). A Hardware Abstraction Layer defines the hardware/software interface. The *System-Global OS/R* layer includes all the system functions that are local to one system but can affect the entire system---they can affect multiple concurrent jobs---encompassing OS/R code that runs on compute nodes, I/O nodes, service processors, consoles, and so forth. An *enclave* (i.e., partition) is a set of resources dedicated to one application or one service. To the greatest possible extent, system functionality is encapsulated within enclaves. In particular, the failure of an enclave should not cause global system failure, and different enclaves can provide different implementations of the same function.

We refer you to the Exascale Operating System and Runtime Software Report [2] for the detailed description of this reference architecture, including software components, functions, services, and interfaces. The proposed research is expected to leverage the OS/R reference architecture. The use of alternative architectures is allowed, but proposals must contain extensive justifications for the proposed deviations.

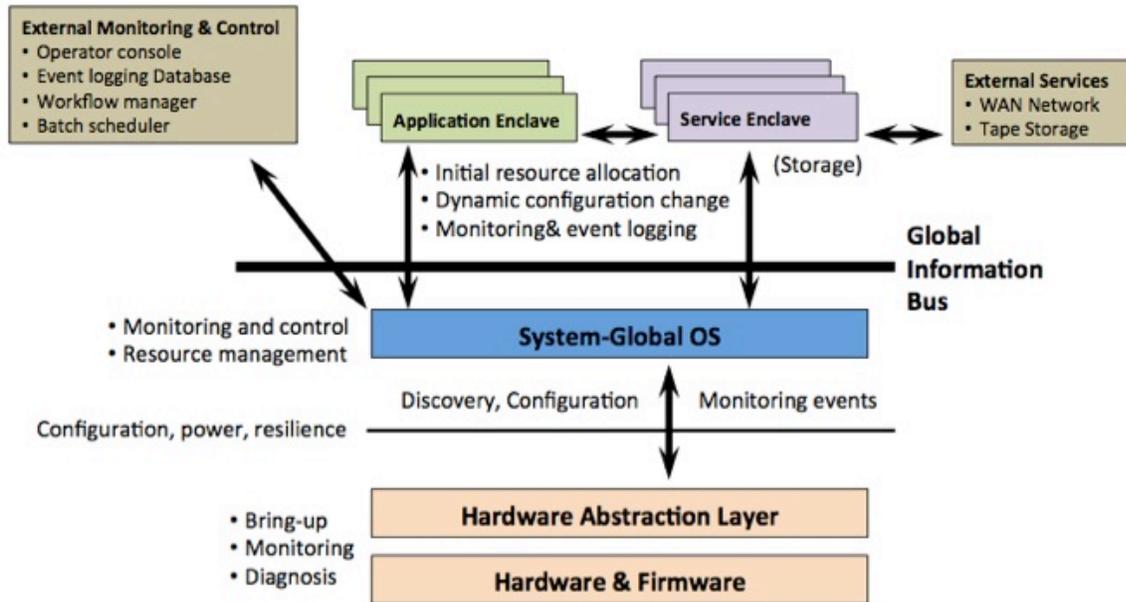


Figure 1: OS/R Reference Architecture

The proposed research must address all of the following seven classes of capabilities:

1. *Power management*: In order to keep exascale machines within a tight power budget of 20MW, we will need unprecedented techniques for global system monitoring, dynamic co-optimization of energy, resilience, and performance and goal-based control strategies for adaptive power management of system resources.
2. *Support for dynamic programming environments*. Managing billions of threads executing in the complex, energy constrained, heterogeneous, and energy-aware platforms will require new dynamic and adaptive mechanisms for thread activation, scheduling, placement, and message layers.
3. *Programmability and tuning support*: Exascale systems require low level mechanisms that support dynamic adaptation, debugging, and joint performance-power optimization. This will require innovation in extremely lightweight thread and task-based mechanisms that support correctness, debugging, and performance analysis tools as well as autonomic, real-time performance, power, and resilience tuning.
4. *Resilience*: Extremely high expected rates of error/faults are expected to impact the entire exascale system stack, from the hardware to the application level. Significant responsibility for resilience reside with the OS/R layer, demanding innovative, scalable mechanisms that independently and concurrently predict, detect, contain, and recover from faults at the different components of the system (nodes, group of nodes, domains, partitions, enclaves, etc.)
5. *Heterogeneity*: Handling the heterogeneous, hierarchical processor and memory systems of exascale platforms will require radically new OS/R mechanisms capable of dynamic goal-oriented management of heterogeneous resources, each with different power-performance-resilience characteristics.
6. *Memory management*: Achieving exascale requires the use of new, energy efficient memory technologies. Using these new memory systems requires lightweight OS/R mechanisms that support innovative, dynamic allocation management, movement, and placement of objects in memory; techniques to dynamically manage memory reliability; and adaptable mechanisms for sharing and protecting data across co-located, co-scheduled processes.
7. *Global optimization*: All execution components of an exascale platform must coordinate and execute as one whole system managing dynamic resources with a global view. This will require new strategies to enable the management of dynamic groups of interacting resources; scalable mechanisms for collecting, analyzing, and managing data globally; and global feedback loops for dynamic power management and performance optimization.

For more details on these classes of OS/R capabilities refer to the exascale Operating System and Runtime Software Report [2], which includes a summary of the input from the research community collected at the DOE OS/R Workshop [3].

More specific information is included under SUPPLEMENTARY INFORMATION below.

Letter of Intent (LOI)

A letter of intent is not required for this Program Announcement.

If your team wishes to submit an LOI, it **should be submitted by January 11, 2013, 5:00 PM Eastern Time**. It is important that the LOI be a single file with extension .pdf, .docx, or .doc. The LOI must be submitted electronically through the DOE Office of Science Portfolio Analysis and Management System (PAMS) website <https://pamspublic.science.energy.gov/>. Only the Lead PI needs to submit the LOI.

The lead Principal Investigator and anyone submitting on behalf of the lead Principal Investigator must register for an account in PAMS before it will be possible to submit a letter of intent. All PIs and those submitting LOIs on behalf of PIs are encouraged to establish PAMS accounts as soon as possible to avoid submission delays.

To access PAMS, you may use Internet Explorer, Firefox, Google Chrome, or Safari browsers.

Registering to PAMS is a two-step process; once you create an individual account, you must associate yourself with (“register to”) your institution. Detailed steps are listed below.

Create PAMS Account:

- To register, click the “Create New PAMS Account” link on the website <https://pamspublic.science.energy.gov/>.
- Click the “No, I have never had an account” link and then the “Create Account” button.
- You will be prompted to enter your name and email address, create a username and password, and select a security question and answer. Once you have done this, click the “Save and Continue” button.
- On the next page, enter the required information (at least one phone number and your mailing address) and any optional information you wish to provide (e.g., FAX number, website, mailstop code, additional email addresses or phone numbers, Division/Department). Click the “Create Account” button.
- Read the user agreement and click the “Accept” button to indicate that you understand your responsibilities and agree to comply with the rules of behavior for PAMS.
- PAMS will take you the “Having Trouble Logging In?” page.

Register to Your Institution:

- Click the link labeled “Option 2: I know my institution and I am here to register to the institution.” (Note: If you previously created a PAMS account but did not register to an institution at that time, you must click the Institutions tab and click the “Register to Institution” link.)
- PAMS will take you to the “Register to Institution” page.
- Type a word or phrase from your institution name in the field labeled, “Institution Name like,” choose the radio button next to the item that best describes your role in the system, and click the “Search” button. (Hint: If your laboratory has an acronym, e.g., ANL for Argonne National Laboratory or LBNL for Lawrence Berkeley National Laboratory, type the lab’s acronym under “Institution Name like.” All labs with acronyms are listed in PAMS with their acronyms in parentheses after their names.)

- Find your institution in the list that is returned by the search and click the “Actions” link in the Options column next to the institution name to obtain a dropdown list. Select “Add me to this institution” from the dropdown. PAMS will take you to the “Institutions – List” page.
- If you do not see your institution in the initial search results, you can search again by clicking the “Cancel” button, clicking the Option 2 link, and repeating the search.
- If, after searching, you think your institution is not currently in the database, click the “Cannot Find My Institution” button and enter the requested institution information into PAMS. Click the “Create Institution” button. PAMS will add the institution to the system, associate your profile with the new institution, and return you to the “Institutions – List” page when you are finished.

Submit Your Letter of Intent:

- Create your letter of intent outside the system and save it as a file with extension .docx, .doc, or .pdf. Make a note of the location of the file on your computer so you can browse for it later from within PAMS.
- Log into PAMS and click the Proposals tab. Click the “View / Respond to DOE National Laboratory Announcements” link and find the current announcement in the list. Click the “Actions/Views” link in the Options column next to this announcement to obtain a dropdown menu. Select “Submit Letter of Intent” from the dropdown.
- On the Submit Letter of Intent page, select the institution from which you are submitting this LOI from the Institution dropdown. If you are associated with only one institution in the system, there will only be one institution in the dropdown.
- Note that you must select one and only one Principal Investigator (PI) per LOI; to do so, click the “Select PI” button on the far right side of the screen. Find the appropriate PI from the list of all registered users from your institution returned by PAMS. (Hint: You may have to sort, filter, or search through the list if it has multiple pages.) Click the “Actions” link in the Options column next to the appropriate PI to obtain a dropdown menu. From the dropdown, choose “Select PI.”
- If the PI for whom you are submitting does not appear on the list, it means he or she has not yet registered in PAMS. For your convenience, you may have PAMS send an email invitation to the PI to register in PAMS. To do so, click the “Invite PI” link at the top left of the “Select PI” screen. You can enter an optional personal message to the PI in the “Comments” box, and it will be included in the email sent by PAMS to the PI. You must wait until the PI registers before you can submit the LOI. Save the LOI for later work by clicking the “Save” button at the bottom of the screen. It will be stored in “My Letters of Intent” for later editing.
- Enter a title for your letter of intent.
- Select the appropriate technical contact from the Program Manager dropdown.
- To upload the LOI file into PAMS, click the “Attach File” button at the far right side of the screen. Click the “Browse” (or “Choose File” depending on your browser) button to search for your file. You may enter an optional description of the file you are attaching. Click the “Attach” button to upload the file.
- At the bottom of the screen, click the “Submit to DOE” button to save and submit the LOI to DOE.
- Upon submission, the PI will receive an email from the PAMS system acknowledging receipt of the LOI.

You are encouraged to register for an account in PAMS at least a week in advance of the LOI submission deadline so that there will be no delays with your submission.

For help with PAMS, click the “External User Guide” link on the PAMS website, <https://pamspublic.science.energy.gov/>. You may also contact the PAMS Help Desk, which can be reached Monday through Friday, 9:00 AM – 5:30 PM Eastern Time. Telephone: (855) 818-1846 (toll free number) or (301) 903-9610, Email: sc.pams-helpdesk@science.doe.gov. All submission and inquiries about this Program Announcement should reference **LAB 13-02**.

The LOI is helpful in planning the review and the selection of potential reviewers for the proposal. For this purpose, the LOI must include: (1) identification of relevant research areas of interest from among those identified in this Program Announcement; (2) one-page abstract of the proposed research; (3) list of names and institutional affiliations of all participating investigators, including collaborators and consultants on the proposed project; and (4) for each funded investigator, a list of collaborative co-investigators including co-authors of past 48 months, co-editors of past 24 months, graduate and postdoctoral advisors/advisees, and close associations. For publications with more than 10 authors or participants, list only those individuals in the core group with whom the Principal Investigator interacted on a regular basis while the research was being done. For proposed investigations requiring access to experimental user facilities, confirmation of communication with the facility’s point-of-contact should be indicated in the LOI.

PROPOSAL DUE DATE: February 25, 2013, 5:00 PM Eastern Time

Formal proposals submitted in response to this Program Announcement must be received by **February 25, 2013, 5:00 PM Eastern Time**, to permit timely consideration of awards in Fiscal Year 2013. **You are encouraged to transmit your proposal well before the deadline. PROPOSALS RECEIVED AFTER THE DEADLINE WILL NOT BE REVIEWED OR CONSIDERED FOR AWARD.**

IMPORTANT SUBMISSION INFORMATION:

Full proposals must be submitted into the DOE Office of Science Portfolio Analysis and Management System (PAMS). For help with PAMS, click the “External User Guide” link on the PAMS website, <https://pamspublic.science.energy.gov/>. You may also contact the PAMS Help Desk, which can be reached Monday through Friday, 9:00 AM – 5:30 PM Eastern Time. Telephone: (855) 818-1846 (toll free number) or (301) 903-9610, Email: sc.pams-helpdesk@science.doe.gov. All submission and inquiries about this Program Announcement should reference **LAB 13-02**. Full proposals submitted in response to this Program Announcement must be submitted into PAMS no later than **February 25, 2013, 5:00 PM Eastern Time**.

All PIs and those submitting on behalf of PIs are encouraged to establish PAMS accounts as soon as possible to ensure timely submissions. To register, click “Create New PAMS Account” on the website <https://pamspublic.science.energy.gov/> and follow the instructions for creating an account.

The following information is provided to help with proposal submission. Detailed instructions and screen shots can be found in the user guide. To find the user guide, click the “External User Guide” link on the PAMS home page. Onscreen instructions are available within PAMS.

- Log into PAMS. From the proposals tab, click the “View DOE National Laboratory Announcements” link and find the current announcement in the list. Click the “Actions/Views” link in the Options column next to this announcement to obtain a dropdown menu. Select “Submit Proposal” from the dropdown.
- Note that you must select one and only one Principal Investigator (PI) per proposal; to do so, click the “Select PI” button on the far right side of the screen. Find the appropriate PI from the list of all registered users from your institution returned by PAMS. (Hint: You may have to sort, filter, or search through the list if it has multiple pages.) Click the “Actions” link in the Options column next to the appropriate PI to obtain a dropdown menu. From the dropdown, choose “Select PI.”
- If the PI for whom you are submitting does not appear on the list, it means he or she has not yet registered in PAMS. For your convenience, you may have PAMS send an email invitation to the PI to register in PAMS. To do so, click the “Invite PI” link at the top left of the “Select PI” screen. You can enter an optional personal message to the PI in the “Comments” box, and it will be included in the email sent by PAMS to the PI. You must wait until the PI registers before you can submit the proposal. Save the proposal for later work by selecting “Save” from the dropdown at the bottom of the screen and then clicking the “Go” button. It will be stored in “My Proposals” for later editing. As a minimum, you must complete all the required fields on the PAMS cover page before you can save the proposal for the first time.
- The cover page, budget, and attachments sections of the lab proposal are required by PAMS before it can be submitted to DOE.
- Complete the sections in PAMS one at a time, starting with the cover page and following the instructions for each section.
- Click the “+View More” link at the top of each section to expand the onscreen instructions. On the budget section, click the “Budget Tab Instructions” link to obtain detailed guidance on completing the budget form.
- Save each section by selecting either “Save” (to stay in the same section) or “Save... and Continue to the Next Section” (to move to the next section) from the dropdown menu at the bottom of the screen, followed by clicking the “Go” button.
- If you save the proposal and navigate away from it, you may return later to edit the proposal by clicking the “View My Existing Proposals” or “My Proposals” links within PAMS.
- You must enter a budget for each annual budget period.
- You must also enter a budget for each proposed subaward. The subaward section can be completed using the same steps used for the budget section.
- In the attachments section of the lab proposal, the budget justification and the proposal narrative are required and must be submitted as separate files.
- You must bundle everything other than the budget and budget justification into one single PDF file to be attached under “Proposal Attachment.”
- Do not attach anything under “Other Attachments.”
- To upload a file into PAMS, click the “Attach File” button at the far right side of the screen. Click the “Browse” (or "Choose File" depending on your browser) button to search for your

file. You may enter an optional description of the file you are attaching. Click the “Attach” button to upload the file.

- Once you have saved all of the sections, the “Submit to DOE” option will appear in the dropdown menu at the bottom of the screen.
- To submit the proposal, select “Submit to DOE” from the dropdown menu and then click the “Go” button.
- Upon submission, the PI will receive an email from the PAMS system acknowledging receipt of the proposal.
- The proposal will also appear under My Proposals with a Proposal Status of “Submitted to DOE.”

Please only submit a PAMS lab technical proposal in response to this announcement; do not submit a DOE Field Work Proposal (FWP) at this time. The Office of Advanced Scientific Computing Research will request FWPs later from those who are selected for funding under this announcement.

For help with PAMS, click the “External User Guide” link on the PAMS website, <https://pamspublic.science.energy.gov/>. You may also contact the PAMS Help Desk, which can be reached Monday through Friday, 9:00 AM – 5:30 PM Eastern Time. Telephone: (855) 818-1846 (toll free number) or (301) 903-9610, Email: sc.pams-helpdesk@science.doe.gov. All submission and inquiries about this Program Announcement should reference **LAB 13-02**.

SUPPLEMENTARY INFORMATION:

The complexity of exascale systems stems from new, energy-constrained, highly concurrent, heterogeneous and resilience-aware processor, memory, and system architectures. The complexity of these future platforms, particularly at the node level, is significantly increased from previous machine generations. The operating system and runtime software (OS/R) touches the hardware at its lowest level, both taking advantage of new hardware features and exposing them to user-level programming environments. Programming exascale class computers will require new operating and runtime systems that handle the significant increase in complexity of exascale platforms.

Power has been identified as the leading design constraint for future HPC systems. In order to keep exascale machines within a tight power budget of 20MW, new approaches in power management will be needed to complement fundamental breakthroughs in hardware components and architectures. Global optimization of power management will be needed at the operating system level, with some decisions delegated to runtime systems, and even to the application level. Exascale operating and runtime systems must include mechanisms for remapping software dynamically to adjust to changing resource availability, with fine-grained controls to maximize dynamic energy saving opportunities.

Exascale systems will support at least 3 orders of magnitude more parallelism than current systems, requiring the management of up to a billion separate threads. Unprecedented parallelism is a consequence of a reformulated Dennard’s scaling law for exascale computing. Progress of the last 2-3 decades in high performance computing were based on Dennard’s scaling rules for obtaining simultaneous improvements in transistor density, switching speed and power dissipation. Voltage scaling has been an extremely important element for achieving the rate of doubling performance and density of semiconductor devices about every 2 years. However, voltage scaling has reached its lower

limits due to more than three orders of magnitude increase of transistor sub-threshold leakage on overall chip power. A reformulated Dennard's law for exascale is based on minimizing power for an exponentially growing number of processing elements per chip and growing hardware threading per core. Rather than doubling devices, the reformulated law predicts doubling the number of parallel processing elements on a chip to occur every 18-24 months [4].

This increase in parallelism represents a challenge for operating and runtime systems, requiring efficient synchronization mechanisms, scheduling of an unprecedented number of computing resources, challenging control and coordination of resource management that supports fair access and global consistency. The operating and runtime system at each node will be required to be highly parallel, with minimal synchronization, configurable to single or multiple applications, supporting tight interaction across sets of nodes, right-sized to meet application needs while minimizing overheads.

Exascale OS/R software will require low-level mechanisms in order to support debugging, dynamic adaptation, and performance-resilience-power optimization. New concepts and approaches are needed to enable extremely lightweight performance data collection; thread and task-based performance attribution and debugging controls; low-overhead asynchronous event handling for shared-control tools; whole-system collection and synthesis; and feedback loops that enable autonomic real-time performance, resilience, and power tuning.

Error/fault rates of exascale systems are estimated to be high enough to rule out resilience via current checkpoint/restart methods. A number of studies (see, for example, [5]), and a recent DOE Workshop report on Fault Management [6] assures us that due to the high component counts and large application states, checkpoint/restart methods are not feasible for Exascale computing, as they would require applications to be in a near-constant state of recovery, unable to accomplish useful work. Expected high rates of error/faults and the requirement that full applications tolerate permanent, transient, and even silent errors in order to generate correct results demand radically new operating systems and runtime resilience mechanisms. The OS/R software must survive faults itself and provide dynamically adaptive notification and recovery capabilities to affected applications. Fault prediction, detection, containment and recovery needs to be designed independently and concurrently for every system component (node, group of nodes, partitions, enclaves, etc.), while avoiding and limiting fault propagation to neighboring areas of the system. New methods must also dynamically trade off resilience with energy efficiency and performance.

Exascale systems will rely on heterogeneous, hierarchical memory systems, which will make use of novel power efficient technologies. New programming models and *in situ* analysis approaches will further ensure that power consumed to move data intra- and inter-node be minimized. The new technologies, programming models, and *in situ* analysis methods will require new operating system organization and innovative mechanisms, such as lightweight memory management and low overhead memory access.

The multi-level, multi-function OS/R software components of an exascale platform must coordinate and execute as one whole system, such that dynamic resources are managed with a global view. New concepts and implementations are needed to enable collective tuning of dynamic groups of interacting resources; scalable infrastructure for collecting, analyzing, and responding to whole-system

data such as fault events, power consumption, and performance; reusable and scalable publish/subscribe infrastructures; distributed and resilient RAS (reliability, availability, and serviceability) subsystems; feedback loops for tuning and optimization; and dynamic power management.

We have identified two classes of runtime system software: application-facing and machine-facing. Application-facing runtime systems support the different programming models and libraries needed for programming Exascale systems. The mechanisms---including semantics---for application-facing runtime systems are part of the existing 2012 X-Stack Program [1]. This solicitation addresses mechanisms, including semantics, for machine-facing runtime software. Services to be performed by machine-facing runtimes are referred to as common runtime services in the OS/R report [2]. It will be essential that the proposed research on machine-facing runtime software includes a plan to closely coordinate with the runtime systems research of the existing X-Stack program, and a plan to develop standard runtime interfaces.

A business challenge identified for OS/R software is the sustainability of research results by an active community of vendors. This will be a new territory both for the research and the vendor community, as successful research results from this program must be integrated into future software stacks of future HPC platforms. Our expectation is that the vendor community will provide sustainable support for research results, while ongoing research in OS/R software influences and is influenced by the vendor community. A related challenge that is shared among hardware and OS/R technologies is that of generating results that exhibit the potential for technology adoption by broader segments of the market outside of DOE HPC machines. OS/R research components supported by this program must scale down to smaller scale systems, possibly as small as desktop-class systems.

We expect that the proposed platform-neutral prototype of a complete Exascale operating system and runtime software (OS/R) will include alternative high impact, high risk research component that offer breakthroughs in one or more of the seven capabilities areas described above. The description of high impact, high risk research components and the benefits of each one of these components to the OS/R software prototype must be clearly articulated in a section of the proposal titled High Impact, High Risk Research. Peer review and ASCR program analysis will ultimately decide which high impact, high risk research components will be included in the projects selected for funding.

The proposed OS/R prototype must be vendor neutral, i.e., it cannot be targeted to a particular vendor platform. In addition, collaboration with a particular vendor team will not be considered for funding.

We expect to make research investments that not only address fundamental exascale operating system and runtime software challenges and capabilities, but also offer:

1. a path to support a wide range of computing platforms, scaling down from exascale to server class machines;
2. a path to integrate with a broad ecosystem of computing system vendors;
3. a migration path from current OS/R environments to the proposed one, and
4. a plan to connect with future extreme-scale systems supported by the HPC industry.

Portability and adoption across multiple platforms and programming environments will be paramount to the success of the proposed research. Therefore, proposals must clearly articulate a plan for identifying, publishing, and sharing interfaces to their prototypes. It is expected that prototypes will include clearly specified interfaces to manage low-level hardware resources, to control power, to ensure resilience, to manage messaging, synchronization, scheduling, memory, and threads as well as higher-level global OS features such as collections of nodes, dynamic resizing of resources, and interfaces to tools. Prototypes must be delivered under an open source license that enables significant leveraging by vendors. It is also expected that the proposed research will include plans for transitioning the prototype into production-quality code.

Proposals must include an evaluation plan of the OS/R prototype. The evaluation of correctness and performance of early prototypes of OS and runtime features and mechanisms is very important for the success of this program. Evaluation plans for the proposed prototype should leverage workload characterizations used to develop proxy-apps for the DOE/SC co-design centers [7], [8], [9], and other science proxy-apps [16], [17], [18]. Proposed evaluation should also be coordinated with the evaluation plans of the X-Stack projects, and other relevant ASCR programs (see the ASCR Research website at <http://science.energy.gov/ascr/research/>).

We expect that the development of prototypes of the OS/R research artifacts will influence and be influenced by the co-evolution of interfaces to DOE-funded exascale simulators [10], [11], [12], and [13]. Proposals must include a plan for the co-evolution of interfaces to these simulators. In order to guarantee that OS/R research artifacts will be adopted and deployed at scale, extensive scalability studies of novel operating system and runtime software will be needed. Proposals must include plans for scalability studies, which may include plans for the submission of compelling INCITE [14] or ALCC [15] proposals.

We anticipate forming a technical panel from industry to engage in standardization of operating system components and interfaces. We will rely on this panel to monitor functionalities and interfaces of research artifacts delivered, so that we can ensure that the technology to be delivered ties into the vendor space. Proposals must include a plan to coordinate with this panel, flexibly adjusting research directions in response to panel recommendations.

Applicants must organize themselves into a coordinated team that includes one or more high impact/high risk component with a clearly articulated management structure. We will refer to these collaborative structures as OS/R galaxies¹. Proposals will be evaluated on an extensive and specific list of review criteria that are listed in section Guide for Preparation of Scientific/Technical Proposals.

We anticipate that the teams developing OS/R prototypes under this program will be funded for a second three year program to create, refine, and further develop **one** OS/R software prototype for exascale computing. We cannot emphasize enough the need to collaborate across the selected OS/R galaxies to ensure that common functions and interfaces coded into the delivered prototypes are standardized. Functions and interfaces particular to only one OS/R prototype delivered under this program must

¹ Merriam-Webster definition of Galaxy, 2 a: an assemblage of brilliant or notable persons or things.

seamlessly integrate with prototypes delivered by other OS/R galaxies. In particular, programming interfaces must be fully specified, including their exact semantics.

SUMMARY OF APPLICATION REQUIREMENTS:

We expect OS/R galaxy proposals to include multiple collaborations. Collaborative applications must carefully consider the fact that we will give priority to applications that have a lean budget, in which overheads are minimized and in which every senior/key person has a significant technical contribution to the proposed research.

Each Application must include the following:

- Description of basic research that:
 - a. significantly advances operating and runtime systems (OS/R) software for exascale computing platforms;
 - b. addresses the four key challenges and the seven classes of OS/R capabilities; and
 - c. that leads to vendor-neutral prototypes;
- Description of high impact, high risk components, clearly articulating their benefits to the OS/R prototype;
- Plans for developing open source prototypes of the proposed OS/R software;
- Plans for identifying, publishing, and sharing interfaces to the proposed prototype;
- Plans to extend the proposed prototype to multiple scales of computing platforms (from desktop to large scale systems);
- Integration/evaluation plans coordinated with X-Stack projects, co-design centers, and other relevant ASCR programs; Plan to coordinate with technical panel of vendors;
- Plan for the co-evolution of interfaces to the DOE-funded exascale simulators;
- Plans to integrate with a broad ecosystem of computing system vendors;
- Management plan for the OS/R galaxy.

Applicants must detail the management structure that will enable an effective collaboration among the participants. The structure and management must be sufficiently flexible to adapt quickly to changing technical challenges and scientific needs. To that end, the proposers must identify a Lead Principal Investigator, Principal Investigator(s), and Senior/Key Personnel. Typical duties, responsibilities and authorities for each category are provided below:

- **Lead Principal Investigator** - The Lead Principal Investigator must be employed by the Lead institution and will serve as the primary contact responsible for communications with DOE Program Officials on behalf of all of the Principal Investigators in the team.
- **Principal Investigator** - A Principal Investigator (PI) is the individual designated by each collaborating institution and empowered with the appropriate level of authority and responsibility for the proper conduct of the research within that organization. These authorities and responsibilities include the appropriate use of funds and administrative requirements such as the submission of scientific progress reports to DOE.
- **Senior/Key Personnel** - A senior/key person is an individual who contributes in a substantive, measurable way to the scientific or technical development or execution of the project.

COLLABORATIONS:

Collaborative proposals submitted from different DOE National Laboratories should clearly indicate they are part of a collaborative project/group. Every partner laboratory must submit a proposal through its own business office that has distinct scope of work and a qualified principal investigator who is responsible for the research effort being performed at his or her institution. Each proposal within the collaborative group, **including the title, narrative and all required appendices and attachments, should be identical with one exception:** each proposal should contain unique budget and budget justification documents corresponding to the expenditures for that proposal’s submitting institution only. Our intent is to create a single document for merit review that consists of the common, identical general narrative, appendices and attachments combined with a set of detailed budgets from the partner institutions. Thus, it is very important that every application in the collaboration be exactly identical (including the title) with the exception of the budget, and budget justification.

A collaborative project can have only one lead institution, which should be identified in the common narrative. The title of a Lead application **must include the project title with the addition of “LEAD” at the end.** The title of a collaborative application **must be identical to the lead application with the addition of “COLLABORATION” at the end.**

The Lead application must include a **summary table describing the budget breakdown by institution** for all participants, as exemplified below:

2013 OS/R	Year 1	Year 2	Year 3	Total
Name of the Principal Investigator and Institution	\$	\$	\$	\$
Collaborating Institutions				Total
Name of Co-PI and Institution	\$	\$	\$	\$
Name of Co-PI and Institution	\$	\$	\$	\$
Name of Co-PI and Institution	\$	\$	\$	\$
TOTALS	\$	\$	\$	\$

Multi-institutional collaborative applications will be reviewed as a single project and subsequently awarded or declined as a single project. Further information on preparation of collaborative applications may be accessed via the Internet at: <http://www.science.doe.gov/grants/colab.asp>.

REFERENCES:

- [1] X-Stack Portfolio: <http://science.energy.gov/ascr/research/computer-science/ascr-x-stack-portfolio/>
- [2] Exascale Operating System and Runtime Software Report:
<http://science.energy.gov/~media/ascr/pdf/research/cs/Exascale%20Workshop/ExaOSR-Report-Final.pdf>
- [3] DOE Workshop on Exascale Operating System and Runtime Software, October 4-5, 2012, American Geophysical Union, Washington, DC.,
<https://collab.mcs.anl.gov/pages/viewpage.action?pageId=3211285>
- [4] DOE ASCR 2011 Exascale Programming Challenges Workshop Report:
<http://science.energy.gov/~media/ascr/pdf/programdocuments/docs/ProgrammingChallengesWorkshopReport.pdf>
- [5] Peter Kogge, Keren Bergman, Shekhar Borkar, Dan Campbell, William Carlson, William Dally, Monty Denneau, Paul Franzon, William Harrod, Jon Hiller, Sherman Karp, Stephen Keckler, Dean Klein, Robert Lucas, Mark Richards, Al Scarpelli, Steven Scott, Allan Snavely, Thomas Sterling, R. Stanley Williams, and Katherine Yelick. Exascale computing study: Technology challenges in achieving exascale systems, 2008.
- [6] Al Geist, et al., “Fault Management Workshop Final Report,” August 13, 2012,
<http://science.energy.gov/~media/ascr/pdf/program-documents/docs/FaultManagement-wrkshpRpt-v4-final.pdf>
- [7] Center for Exascale Simulation of Advanced Reactors (CESAR) co-design center:
<https://cesar.mcs.anl.gov>
- [8] Exascale Co-Design Center for Materials in Extreme Environments (ExMatEx) co-design center:
<http://codesign.lanl.gov/projects/exmatex/index.html>
- [9] Center for Exascale Simulation of Combustion in Turbulence (ExaCT): <http://exactcodesign.org>
- [10] SST: Structural Simulation Toolkit, <http://code.google.com/p/sst-simulator/>
- [11] CoDEX: <http://sites.google.com/a/lbl.gov/codex/>
- [12] AFL: <https://sites.google.com/site/traleikaglacierxstack/afl>
- [13] FSIM: <https://sites.google.com/site/traleikaglacierxstack/fsim>
- [14] Innovative and Novel Computational Impact on Theory and Experiment (INCITE),
<http://science.energy.gov/ascr/facilities/incite/>
- [15] ASCR Leadership Computing Challenge (ALCC), <http://science.energy.gov/ascr/facilities/alcc/>

[16] Mantevo mini-apps, <https://software.sandia.gov/mantevo/>

[17] C. L. Janssen, H. Adalsteinsson, S. Cranford, J. P. Kenny, A. Pinar, D. A. Evensky, and J. Mayo, "A simulator for large-scale parallel computer architectures", International Journal of Distributed Systems and Technology (IJ DST), 1, pp. 57-73, 2010.

[18] Erich Strohmaier et al., "TORCH Computational Reference Kernels: A Testbed for Computer Science Research, University of California, Berkeley, Technical Report, <http://www.eecs.berkeley.edu/Pubs/TechRpts/2010/EECS-2010-144.html>

PROGRAM FUNDING:

We anticipate that up to \$6,000,000 total will be available for a small number of awards to be made in FY2013, contingent on the availability of funds. Awards are expected to be made for a period of three years at a funding level appropriate for the proposed scope, with a fourth year support contingent on the availability of funds, satisfactory progress, and continuing program needs. One or more awards may be made depending on the number and quality of the proposals that are received and favorably reviewed. If more than one award is made, it is anticipated that award sizes will range from \$2,500,000 to \$3,000,000 per year. Programmatic relevance is a factor in evaluating all grant proposals.

DOE is under no obligation to pay for any costs associated with the preparation or submission of a proposal. The ASCR Program reserves the right to fund, in whole or in part, any, all, or none of the proposals submitted in response to this Program Announcement, depending on the suitable scientific quality or relevance to the program described here. DOE is under no obligation to pay for any costs associated with the preparation or submission of a proposal.

TYPE OF PROPOSAL:

DOE will accept only new proposals under the Program Announcement.

ELIGIBILITY

This is a DOE Lab-only Announcement. FFRDCs from other Federal agencies are not eligible to submit in response to this Program Announcement.

For official postings see the Office of Science Grants and Contracts web site, <http://www.science.doe.gov/grants>.

The instructions and format described below should be followed. You must reference Program Announcement LAB 13-02 on all submissions and inquiries about this program.

OFFICE OF SCIENCE
GUIDE FOR PREPARATION OF SCIENTIFIC/TECHNICAL PROPOSALS TO
BE SUBMITTED BY NATIONAL LABORATORIES

The following guidelines for content and format are intended to facilitate an understanding of the requirements necessary for SC to conduct a merit review of a proposal. Please follow the guidelines carefully, as deviations could be cause for declination of a proposal without merit review.

1. Evaluation Criteria

Proposals will be subjected to scientific merit review (peer review) and will be evaluated against the following evaluation criteria which are listed in descending order of importance. Included within each criterion are specific questions that the merit reviewers will be asked to consider:

a) Scientific and/or Technical Merit of the Proposed Research

- Comment on the scientific objectives of the proposed research in terms of an achievable plan. Comment on the competence of the investigators, the institutionally available infrastructure, and proposed resources for achieving this plan.
- Comment on the likelihood that the specific project will lead to fundamental advances or discovery in its field within the proposed project period.
- Comment on whether or not the proposed research will significantly advance the state-of-the-art in operating systems and runtime software for Exascale computing.
- Comment on how comprehensive the proposed solution is and how well it addresses all identified challenges in this area.
- Comment on how well the proposed research deals with a dynamic environment resulting from adaptive hardware and software mechanisms as well as from transient faults.
- What is the likelihood that the applicant can overcome the key challenges and, as warranted, shift research directions in response to promising advances in basic research?
- *Assess strengths and weaknesses of each high impact, high risk research component proposed.*
- *Comment on the required plans, listed in the Summary of Proposal Requirements section.*

b) Appropriateness of the Proposed Method or Approach

- How logical and feasible are the proposed research approaches?
- Does the proposed research employ innovative concepts or methods?
- Are the conceptual framework, methods, and analyses well justified, adequately developed, and likely to lead to scientifically valid conclusions?
- To what extent does the applicant recognize significant potential problems and consider alternative strategies?
- Does the proposed research leverage the nominal architecture? If no, comment on the presented justifications for creating a new one.
- Comment on the effectiveness of the proposed research effort in addressing the scientific issues and/or objectives of the proposed research.

- *Provide separate assessment on the method and approach for each high impact, high risk research component proposed.*
- *Are details of the proposed OS/R prototype clearly presented?*
- Comment on the proposed coordinating activities with X-Stack projects, Co-Design Centers, and other ASCR-funded projects.
- Does the research plan contain appropriate performance metrics that will allow progress and contributions to be measured?
- If this is a collaborative proposal, does it include a management plan that addresses the organization, communications, and coordination of the collaborating teams? Does it include mitigation strategies for foreseeable risks and explain how the project will have sufficient flexibility to adapt to changing priorities, challenges, and resources.

c) Competency of Applicant's Personnel and Adequacy of Proposed Resources

- How well qualified are the applicant's personnel to carry out the proposed research?
- Comment on the applicants proven record of success in research and development in the disciplines needed for the proposed work.
- Comment on the applicants' proven record of delivering OS/R results for advanced computational science research.
- Are the roles and intellectual contributions of the Principal Investigator(s), and each senior/key personnel adequately described? Do you consider the contributions of each senior/key personnel of significant value for the project?
- Comment on the applicant's research environment and resources.
- Does the proposed work take advantage of unique facilities and capabilities and/or make good use of collaborative arrangements?
- How well versed are applicants on legacy scientific codes and OS/R issues?
- How well connected are applicants to the exascale ecosystem?
- Do applicants have sufficient connections with the vendor community in order to influence their support for research artifacts generated by the proposed work?

d) Reasonableness and Appropriateness of the Proposed Budget

- Are the proposed budget and staffing levels adequate to carry out the proposed research?
- Is the budget as lean as it can be to deliver the promised results? Are budget overheads minimized?
- Does the requested budget support the applicant's specified management structure in a meaningful way?
- Is travel budget appropriate? Are video conferencing technologies proposed to reduce the travel budget?
- Is the requested budget appropriate to support the evaluation plan?

e) Other Appropriate Factors

- If applicable, please comment on the educational benefits of the proposed activity.
- What are the overall strengths and weaknesses of the proposal?

2. Summary of Proposal Contents

- Proposal Cover Page
- Table of Contents
- Budget (as entered into PAMS)
- Abstract (one page)
- Narrative (main technical portion of the proposal, including background/introduction, proposed research and methods, timetable of activities, management plan and responsibilities of key project personnel – 25 page limit)
- Literature Cited
- Biographical Sketch(es)
- Description of Facilities and Resources
- Other Support of Investigator(s)
- Appendix (optional)

2.1 Submission Instructions

Full proposals must be submitted into the DOE Office of Science Portfolio Analysis and Management System (PAMS). For help with PAMS, click the “External User Guide” link on the PAMS website, <https://pamspublic.science.energy.gov/>. You may also contact the PAMS Help Desk, which can be reached Monday through Friday, 9:00 AM – 5:30 PM Eastern Time. Telephone: (855) 818-1846 (toll free number) or (301) 903-9610, Email: sc.pams-helpdesk@science.doe.gov. All submission and inquiries about this Program Announcement should reference **LAB 13-02**. Full proposals submitted in response to this Program Announcement must be submitted PAMS no later than **February 25, 2013, 5:00 PM Eastern Time**.

3. Detailed Contents of the Proposal

Adherence to font size and line spacing requirements is necessary. Font size must be at least 11 point. Line spacing is at the discretion of the researcher but there must be no more than 6 lines per vertical inch of text. Pages should be standard 8 1/2" x 11" (or metric A4, i.e., 210 mm x 297 mm).

3.1 Proposal Cover Page

The following proposal cover page information may be placed on plain paper. No form is required.

Title of proposed project:

SC Program Announcement title: **2013 Exascale Operating and Runtime Systems – LAB 13-02**

Name of laboratory:

Name of principal investigator (PI):

Position title of PI:

Mailing address of PI:

Telephone of PI:

Fax number of PI:

Electronic mail address of PI:
Name of official approving for laboratory:
Title of official:
Fax number of official:
Telephone of official:
Electronic mail address of official:
Requested funding for each year; total request:

3.2 Budget and Budget Explanation

The budget must be submitted into PAMS using the PAMS budget form. Research proposed under this announcement should have three annual budget periods. Please enter the following budget period start and end dates into PAMS for proposals submitted to this announcement:

- Budget Period 1: 7/1/2013 – 6/30/2014
- Budget Period 2: 7/1/2014 – 6/30/2015
- Budget Period 3: 7/1/2015 – 6/30/2016

PAMS will calculate the cumulative budget totals for you.

A written justification of each budget item is to follow the budget pages. For personnel this should take the form of a one-sentence statement of the role of the person in the project. Provide a detailed justification of the need for each item of permanent equipment. Explain each of the other direct costs in sufficient detail for reviewers to be able to judge the appropriateness of the amount requested.

Further instructions regarding the budget and justification are given below and in the PAMS software.

3.3 Abstract

Summarize the proposal in one page. Give the project objectives (in broad scientific terms), the approach to be used, and what the research is intended to accomplish. State the hypotheses to be tested (if any). At the top of the abstract give the lead DOE national Laboratory, project title, names of all the investigators and their institutions, and contact information for the principal investigator, including e-mail address.

3.4 Narrative (main technical portion of the proposal, including background/introduction, proposed research and methods, timetable of activities, and responsibilities of key project personnel).

The narrative comprises the research plan for the project and is limited to **25 pages (maximum)**. It should contain enough background material in the Introduction, including review of the relevant literature, to demonstrate sufficient knowledge of the state of the science. The major part of the narrative should be devoted to a description and justification of the proposed project, including details of the methods to be used. It should also include a timeline for the major activities of the proposed project, and should indicate which project personnel will be responsible for which activities. It is important that the 25-page technical information section provide a complete description of the proposed work, because reviewers are not obliged to read the Appendices. Proposals exceeding these page limits may be rejected without review or the first 25 pages may be reviewed without regard to the remainder.

The page count of 25 does not include the Face Page and Budget Pages, the Title Page, the biographical material and publication information, or any Appendices. Letters of endorsement from unfunded collaborators should also be included, if applicable. Please do not submit general letters of support as these are not used in making funding decisions and can interfere with the selection of peer reviewers.

Background

Background – explanation of the importance and relevance of the proposed work.

Proposed Research and Tasks

In addition to the technical description of the proposed work and tasks, include a discussion of the following:

- impact of the proposed research on other fields of science, if appropriate.
- project schedule, milestones, and deliverables.

If any portion of the project is to be done in **collaboration** with another institution (or institutions), provide information on the institution(s) and what part of the project it will carry out. Further information on any such arrangements is to be given in the sections "Budget and Budget Explanation," "Biographical Sketches," and "Description of Facilities and Resources."

3.5 Literature Cited

Give full bibliographic entries for each publication cited in the narrative. Each reference must include the names of all authors (in the same sequence in which they appear in the publication), the article and journal title, book title, volume number, page numbers, and year of publication. Include only bibliographic citations. Principal investigators should be especially careful to follow scholarly practices in providing citations for source materials relied upon when preparing any section of the proposal.

3.6 Biographical Sketches

This information is required for senior personnel at the institution submitting the proposal and at all subcontracting institutions (if any). The biographical sketch is limited to a maximum of two pages for each investigator and must include:

Education and Training. Undergraduate, graduate and postdoctoral training, provide institution, major/area, degree and year.

Research and Professional Experience. Beginning with the current position list, in chronological order, professional/academic positions with a brief description.

Publications. Provide a list of up to 10 publications most closely related to the proposed project. For each publication, identify the names of all authors (in the same sequence in which they appear in the publication), the article title, book or journal title, volume number, page numbers, year of publication, and website address if available electronically. Patents, copyrights and software systems developed may be provided in addition to or substituted for publications.

Synergistic Activities. List no more than five professional and scholarly activities related to the effort proposed.

To assist in the identification of potential conflicts of interest or bias in the selection of reviewers, the following information must also be provided in each biographical sketch.

Collaborators and Co-editors: A list of all persons in alphabetical order (including their current organizational affiliations) who are currently, or who have been, collaborators or co- authors with the investigator on a research project, book or book article, report, abstract, or paper during the 48 months preceding the submission of the proposal. For publications or collaborations with more than 10 authors or participants, only list those individuals in the core group with whom the Principal Investigator interacted on a regular basis while the research was being done. Also, include those individuals who are currently or have been co- editors of a special issue of a journal, compendium, or conference proceedings during the 24 months preceding the submission of the proposal. Finally, list any individuals who are not listed in the previous categories with whom you are discussing future collaborations. If there are no collaborators or co-editors to report, this should be so indicated.

Graduate and Postdoctoral Advisors and Advisees: A list of the names of the individual's own graduate advisor(s) and principal postdoctoral sponsor(s), and their current organizational affiliations. A list of the names of the individual's graduate students and postdoctoral associates during the past five years, and their current organizational affiliations.

3.7 Description of Facilities and Resources

Facilities to be used for the conduct of the proposed research should be briefly described. Indicate the pertinent capabilities of the institution, including support facilities (such as machine shops), that will be used during the project. List the most important equipment items already available for the project and their pertinent capabilities. Include this information for each subcontracting institution (if any).

3.8 Other Support of Investigators

Other support is defined as all financial resources, whether Federal, non-Federal, commercial, or institutional, available in direct support of an individual's research endeavors. Information on active and pending other support is required for all senior personnel, including investigators at collaborating institutions to be funded by a subcontract. For each item of other support, give the organization or agency, inclusive dates of the project or proposed project, annual funding, and level of effort (months per year or percentage of the year) devoted to the project.

3.9 Appendix

Information not easily accessible to a reviewer may be included in an appendix, but **do not use the appendix to circumvent the page limitations of the proposal**. Reviewers are not required to consider information in an appendix, and reviewers may not have time to read extensive appendix materials with the same care they would use with the proposal proper.

The appendix may contain the following items: up to five publications, manuscripts accepted for publication, abstracts, patents, or other printed materials directly relevant to this project, but not generally available to the scientific community; and letters from investigators at other institutions stating their agreement to participate in the project (do not include letters of endorsement of the project).

4. Detailed Instructions for the Budget

Budgets are required for the entire project period. A budget form should be completed for each budget period of the award, and a cumulative budget form for the entire project period will be populated by PAMS. A detailed budget justification narrative should be included after the budget pages. The justification should cover labor, domestic and foreign travel, equipment, materials and supplies, and anything else that will be covered with project funds.

To edit a section on the budget, click the edit icon () for each section on the page. Remember to save all budget periods before moving on to the next section.

A. Senior/Key Person (Required)

For each Senior/Key Person, enter the appropriate information. List personnel, salary funds, and the number of months that person will be allocated to the project. Also include a written narrative in the budget justification that fully justifies the need for requested personnel.

B. Other Personnel

List personnel, salary funds, and the number of months that person will be allocated to the project. Also include a written narrative in the budget justification that fully justifies the need for requested personnel.

C. Equipment Description

For the purpose of this budget, equipment is designated as an item of property that has an acquisition cost of \$5,000 or more and an expected service life of more than one year. (Note that this designation applies for proposal budgeting only and differs from the DOE definition of capital equipment.) List each item of equipment separately and justify each in the budget justification section. Allowable items ordinarily will be limited to research equipment and apparatus not already available for the conduct of the work. General-purpose office equipment, such as a personal computer, is not eligible for support unless primarily or exclusively used in the actual conduct of scientific research.

D. Travel

In the budget justification, list each trip's destination, dates, estimated costs including transportation and subsistence, number of staff traveling, the purpose of the travel, and how it relates to the project. Indicate whether travel cost estimates are based upon quotes from travel agencies; upon past experience of similar number of trips to similar travel destinations; or something else (describe). To qualify for support, attendance at meetings or conferences must enhance the investigator's capability to perform the research, plan extensions of it, or disseminate its results.

Do not include international travel costs.

E. Participant/Trainee Support Costs:

If applicable, submit training support costs. Educational projects that intend to support trainees (precollege, college, graduate and post graduate) must list each trainee cost that includes stipend levels and amounts, cost of tuition for each trainee, cost of any travel (provide the same information as needed under the regular travel category), and costs for any related training expenses. Participant costs are those costs associated with conferences, workshops, symposia or institutes and breakout

items should indicate the number of participants, cost for each participant, purpose of the conference, dates and places of meetings and any related administrative expenses. In the budget justification, indicate whether trainee cost estimates are based upon past experience of support of similar number of trainees on similar projects; past experience of support of similar number of participants attending similar conferences/workshops/symposia; or something else (describe).

F. Other Direct Costs:

Enter Other Direct Costs information for each item listed.

- **Materials and Supplies:** Enter total funds requested for materials and supplies in the appropriate fields. In the budget justification, indicate general categories such as glassware, and chemicals, including an amount for each category (items not identified under “Equipment”). Categories less than \$1,000 are not required to be itemized. In the budget justification, indicate whether cost estimates are based upon past experience of purchase of similar or like items; quotes/catalog prices of similar or like items; or something else (describe).
- **Publication Costs:** Enter the total publication funds requested. The proposal budget may request funds for the costs of documenting, preparing, publishing or otherwise making available to others the findings and products of the work conducted under the award. In the budget justification, include supporting information. In the budget justification, indicate whether cost estimates are based upon past experience of purchase of similar or like items; vendor quotes of similar publication services; or something else (describe).
- **Consultant Services:** Enter total funds requested for all consultant services. In the budget justification, identify each consultant, the services he/she will perform, total number of days, travel costs, and total estimated costs. In the budget justification, indicate whether consultant cost estimate is based upon previous experience/quotes for similar or like services; or something else (describe).
- **ADP/Computer Services:** Enter total funds requested for ADP/Computer Services. The cost of computer services, including computer-based retrieval of scientific, technical and education information may be requested. In the budget justification, include the established computer service rates at the proposing organization if applicable. In the budget justification, indicate whether cost estimates are based upon quotes/past experience of purchase of similar computer services; established computer service rates at the proposing institution; or something else (describe).
- **Subawards/Consortium/Contractual Costs:** Enter total costs for all subawards/consortium organizations and other contractual costs proposed for the project. In the budget justification, justify the details.
- **Equipment or Facility Rental/User Fees:** Enter total funds requested for Equipment or Facility Rental/User Fees. In the budget justification, identify each rental/user fee and justify. In the budget justification, indicate whether cost estimates are based upon past experience with similar or like items; vendor quotes of similar items; or something else (describe).
- **Alterations and Renovations:** Enter total funds requested for Alterations and Renovations. In the budget justification, itemize by category and justify the costs of alterations and renovations, including repairs, painting, removal or installation of partitions, shielding, or air conditioning. Where applicable, provide the square footage and costs.
- **Other:** Add text to describe any other Direct Costs not requested above. Enter costs associated with “Other” item(s). Use the budget justification to further itemize and justify.

G. Direct Costs

This represents Total Direct Costs (Sections A thru F) and will be calculated by PAMS.

H. Other Indirect Costs

Enter the Indirect Cost information for each field. Only four general categories of indirect costs are allowed/requested on this form, so please consolidate if needed.

I. Total Direct and Indirect Costs

This amount will be calculated by PAMS (Sections G + H)