FY 2021 – 2023 PROGRESS REPORT ON PIONEERING THE FUTURE ADVANCED COMPUTING ECOSYSTEM: A STRATEGIC PLAN

A Report by the

SUBCOMMITTEE ON FUTURE ADVANCED COMPUTING ECOSYSTEM

COMMITTEE ON TECHNOLOGY

and the

HIGH END COMPUTING INTERAGENCY WORKING GROUP

SUBCOMMITTEE ON NETWORKING AND INFORMATION TECHNOLOGY RESEARCH AND DEVELOPMENT

COMMITTEE ON SCIENCE AND TECHNOLOGY ENTERPRISE

of the

NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

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The NSTC Subcommittee on Future Advanced Computing Ecosystem (FACE) coordinates the Federal agencies to pioneer, sustain, and enhance the advanced computing ecosystem necessary for U.S. scientific, technological, and economic leadership. It is guided by the objectives, priorities, and recommendations outlined in the 2019 report, National Strategic Computing Initiative: Pioneering the Future of Computing, in alignment with the Networking and Information Technology Research and Development (NITRD) Subcommittee and other subcommittees as appropriate.

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The Networking and Information Technology Research and Development (NITRD) Program has been the Nation's primary source of federally funded work on pioneering information technologies (IT) in computing, networking, and software since it was first established as the High-Performance Computing and Communications program following passage of the High-Performance Computing Act of 1991. The NITRD Subcommittee of the NSTC guides the multiagency NITRD Program in its work to provide the R&D foundations for ensuring continued U.S. technological leadership and for meeting the Nation's needs for advanced IT. The National Coordination Office (NCO) supports the NITRD Subcommittee and its Interagency Working Groups (IWGs) (https://www.nitrd.gov/about/).

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The NITRD High End Computing Interagency Working Group (HEC IWG) coordinates Federal R&D to enhance U.S. advanced computing capabilities and explore fundamentally new approaches to computing, focused on bolstering U.S. dominance in high-capability computing (HCC). In addition, the HEC IWG coordinates Federal activities to provide HCC systems and infrastructure (including expertise necessary to use the HCC systems effectively) and develop algorithms and applications to support agency missions and accelerate scientific discoveries and technological innovations.

About This Document

This progress report summarizes investments and activities under each of the FACE strategic objectives and the sub-objectives, as listed in the 2020 Pioneering the Future Advanced Computing Ecosystem: A Strategic Plan. The report also highlights outcomes of selected investments and activities from across the federal agencies.

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Table of Contents

Executive Summary

The national advanced computing ecosystem (comprised of computing systems, data storage systems, advanced instruments and data repositories, visualization environments, and people, with high-speed networks to link them together) supports the national research and development enterprise. This ecosystem is a strategic asset for ensuring a robust U.S. economy and safeguarding the security of the nation. The 2020 NSTC report, *Pioneering the Future Advanced Computing Ecosystem: A Strategic Plan*[2], laid out a vision for a Future Advanced Computing Ecosystem (FACE). The document outlined a federal strategic plan for a whole-of-nation approach to pioneering the future national advanced computing ecosystem. Since its publication, federal agencies have worked to realize the vision laid out in the strategic plan through significant investments in computing, storage, data, software, and workforce development, that lays the foundations for a national FACE asset that provides a production quality computing infrastructure to support critical applications. At the same time, significant investments have been made to support foundational, applied, and translational research and development to drive the future of advanced computing and its application; and to integrate future technologies and foster strategic partnerships across the government, academia, and industry.

The FY 2021 – 2023 Progress Report on Future Advanced Computing Ecosystem (FACE) Strategic Plan summarizes the important progress that agencies are making to achieve the following national FACE objectives as listed in the 2020 NSTC report, *Pioneering the Future Advanced Computing Ecosystem: A Strategic Plan*:

Strategic Objective 1: Advanced Computing Ecosystem as a Strategic National Asset

Strategic Objective 2: Robust, Sustainable Software and Data Ecosystem

Strategic Objective 3: Foundational, Applied, and Translational R&D

Strategic Objective 4: Fostering a Diverse, Capable, and Flexible Workforce

This progress report summarizes investments and activities under each strategic objective and the sub-objectives, as listed in the 2020 strategic plan. The report also highlights outcomes of selected investments and activities from across the federal agencies.

At a high level, the progress report also conveys the following key messages:

- The federal government has made strategic investments and developed key partnerships with industry and academia to realize the FACE objectives and made significant progress towards creating a robust FACE national asset.
- The United States benefits significantly from the current FACE assets in science and engineering, economic competitiveness, and national security.
- Continued support is needed to ensure that the national asset continues to keep pace with the rapidly evolving computing technology landscape and supports the growing national demands for advanced computing.

[2] https://www.nitrd.gov/pubs/Future-Advanced-Computing-Ecosystem-Strategic-Plan-Nov-2020.pdf

Introduction

The national advanced computing ecosystem is an essential strategic asset for our nation's economy and security as well as for implementing solutions to current and future challenges in areas such as national security, sustainability, healthcare, and addressing climate change. The *Pioneering the Future Advanced Computing Ecosystem: A Strategic Plan* outlines a comprehensive vision of a future advanced computing ecosystem (FACE) that will serve as the foundation for American leadership in science and engineering, economic competitiveness, and national security. Since the publication of this strategic plan, federal agencies have worked to advance the goals of the FACE strategic plan towards this future advanced computing ecosystem.

The subsequent sections of this report provide an overview of federal efforts and highlight the accomplishments and notable developments by the federal agencies supporting the objectives identified in the strategic plan. This report is not a comprehensive listing of federal efforts but showcases select highlights for each of the FACE objectives, covering fiscal years (FYs) 2021-2023. Reference materials used to develop this report are available under Table 1 – Table 4.

Strategic Objective 1. Advanced Computing Ecosystem as a Strategic National Asset

Utilize the future advanced computing ecosystem as a strategic resource spanning government, academia, nonprofits, and industry.

A world-class computing infrastructure is paramount for addressing the current and future challenges faced by the nation. With the continuous introduction of new and potentially disruptive computing technologies and paradigms, along with the rapid evolution of the application requirements from the different sectors, in terms of scale, fidelity, usage modes, and constraints, it is critical that this strategic asset is at the forefront of technological innovation to meet the nation's computing needs. In recent years, several strategic investments across the federal agencies have been made to ensure a balance between the availability of stable, production-level computing capabilities and exploration of innovative computing paradigms that will eventually be transitioned to general availability to meet the rapidly evolving and increasing computing needs of the nation.

Since the release of Pioneering the Future Advanced Computing Ecosystem: A Strategic Plan, agencies have been working towards the goal of a nationwide interoperable computing ecosystem. A rapidly evolving computing technology frontier and the heterogeneous needs across the agencies have posed challenges in the realization of such an ecosystem. However, significant efforts have been made in acquiring and deploying key computing, networking, and storage capabilities, establishing mechanisms to coordinate access to these resources, and developing a robust middleware of tools (including portals, gateways, and workflow tools). At the same time, there have been significant investments in emerging technologies such as quantum and neuromorphic computing. There have been several coordination efforts across the agencies to establish standards and move the current loosely federated computing ecosystem into a tightly coupled interoperable entity. This will require additional efforts across the agencies to build upon the current progress through strategic activities as outlined in the following subsections.

Federate a spectrum of capabilities and capacities that can be used collectively as a strategic national asset.

Federal agencies have acquired and deployed a diverse set of computing, storage, networking, and security assets. Current investments from multiple agencies such as DOD, DOE/SC, DOE/NNSA, DHS, NASA, NIH, NSF have led to the development of a diverse set of capabilities and capacities, including data, software, networking, and security, that form a strategic national asset. This includes federated systems for data sharing and analysis supported by NIH; the High End Computing (HEC) program at NASA; DOE/SC's Integrated Research Infrastructure Program; DOE/NNSA's Advanced Computing and Simulation (ASC) program's enterprise-wide data infrastructure for nuclear security; DOD's High Performance Computing Modernization Program (HPCMP); and NSF's Advanced Computing Systems and Services Program, the Leadership-Class Computing Facility (LCCF), and other related infrastructure programs at NSF.

A key achievement is the development of a hybrid computing ecosystem that combines on-premises systems listed above with commercial clouds, including the CloudBank program at NSF and the NIH STRIDES Initiative. In the area of knowledge integration, agencies have developed publicly accessible data repositories and associated knowledge graphs to enable data-driven solutions for a variety of problems faced by the various agencies. One such multi-agency effort is building the Prototype Open Knowledge Network (Proto-OKN) involving NSF, NIH, NOAA, and USGS which follows the investments through NSF's Convergence Accelerator program on Open Knowledge Networks, among other related activities.

Highlighted Examples 1.1
• DOE/SC's Integrated Research Infrastructure (IRI) was established in 2023 to address the unique challenges of near real-time computing needed to support the explosion of scientific data from SC's 28 Scientific User Facilities. IRI will enable researchers to seamlessly and securely meld DOE's unique data, user facilities, and computing resources utilizing the DOE/SC Energy Sciences Network (ESNet). ESNet features over 15,000 miles of links, with backbones ranging from 400 Gigabit per second to 1 Terabit per second. The SC IRI Blueprint Activity, a convening of over 160 DOE laboratory subject matter experts, identified the need for new high performance data infrastructure to advance these goals, resulted in a first-of-a-kind report, published in July 2023, documenting integration requirements and future vision. • The NIH Science and Technology Research Infrastructure for Discovery, Experimentation, and Sustainability (STRIDES) Initiative modernizes the biomedical research ecosystem by reducing economic and process barriers to accessing commercial cloud services. The STRIDES Initiative partnership with commercial vendors was established in July 2018 and subsequently expanded upon with additional partnerships in September 2018 and July 2021. The STRIDES investment enables access to over 253 PB of data, more than 506 million compute hours and supports over 1785 research programs. • NSF's current leadership-class computing investment supports the Frontera project at the Texas Advanced Computing Center at The University of Texas at Austin. Frontera, and its successor system, Horizon, form the core of the NSF LCCF, and provides a unique HPC capability to the U.S. research community. Frontera serves as the leading capability system available to the research community within the FACE computing ecosystem, intended for large applications that require thousands of compute nodes. In 2023, the Frontera system had delivered more than 72 million node hours and completed over one million jobs, with a cumulative completion of more than 5.8 million jobs over its four years of life.

Address the needs of emerging application workflows that have diverse advanced computing requirements as well as natural affinities to specific innovative technologies, system architectures, and usage modes.

Multiple agencies, such as DOD, DOE/NNSA, DOE/SC, DHS, NASA, and NSF, develop and release workflow tools that are tailored to the needs of the corresponding communities that they serve. Prominent activities include the NASA HEC program that supports all the technical mission directorates at NASA, the DOD's Defense Innovation Unit's interface development to enable users to access DOD computing and cloud-based assets, DHS/S&T's Data Analytic Technology Center, DOE/NNSA ASC program providing simulation support for the NNSA production complex, and NSF investments in developing scientific workflow infrastructure, such as the Pegasus project. All federally supported high performance computing systems now support containerization of application workloads for enhancing productivity, portability, and performance, and is an important step towards a unified computing ecosystem.

Highlighted Examples 1.2
• NSF's "Pegasus: Automating Compute and Data Intensive Science" project sustains and enhances the Pegasus Workflow Management System, which enables scientists to orchestrate and run data- and compute-intensive computations on diverse distributed computational resources. Enhancements focus on the automation capabilities provided by Pegasus to support workflows handling large data sets, as well as the usability of Pegasus, which lowers the barrier of its adoption. This effort expands the reach of the advanced capabilities provided by Pegasus to researchers from a broader spectrum of disciplines, ranging from gravitational-wave physics to bioinformatics and from earth science to material science. Pegasus Workflow Management System has been designed, implemented, and supported to provide abstractions that enable scientists to focus on structuring their computations without worrying about the details of the target CI. To support these workflow abstractions. Pegasus has been adopted by researchers from a broad spectrum of disciplines. It provides and enhances access to national CI such as Open Science Grid and Extreme Science and Engineering Discovery Environment, and as part of this work, it will be deployed within Chameleon and Jetstream to provide broader access to NSF's CI investments. Through usability improvements, and engagement with CI and community platform providers such as HubZero and Cyverse, combined with educational, training, and tutorial activities, this project broadens the set of researchers that leverage automation for their work. Collaboration with the Gateways Institute assures that Pegasus interfaces are suitable for vertical integration within science gateways and seamlessly support new scientific communities. • In 2023, DOE/SC instantiated a new research portfolio in Distributed Resilient Systems, starting a $40M, five-year effort to tackle challenges associated with scientific workflows processing astounding amounts of data generated by geographically distributed instruments. Five collaborative projects involving DOE National Laboratories and university research teams are utilizing approaches, including novel methods in swarm intelligence to distributed resource allocation and improving our understanding of scalable, federated, privacy-preserving machine learning. This portfolio complements projects at DOE/SC computational user facilities to provide programmatic access to system resources to enable automated scientific workflows. These projects include INTERSECT at the Oak Ridge Leadership Computing Facility (OLCF), Superfacility at the National Energy Research Scientific Computing Center (NERSC), and Nexus at the Argonne Leadership Computing Facility (ALCF). For example, by 2020, the Superfacility has already enabled many significant science efforts to automate their workflows, including the Dark Energy Spectroscopic Instrument, the Linac Coherent Light Source, the Lux-Zeplin experiment, and the National Center for Electron Microscopy's 4D scanning transmission electron microscope camera.

Promote and support the availability, integrity, and security of critical advanced computing components in the international software and hardware supply chains.

Security is paramount for the computing ecosystem and spans multiple scales and architectures. Many agencies such as DOD and NSF support efforts that ensure the availability, integrity, and security of the deployed systems as well as critical advanced computing components of global supply chains. The growing competition from the private sector for advanced computing hardware such as high-end graphics processing units (GPUs), has resulted in an increasing focus on how the international supply chains can be leveraged to meet the cross-agency demands. Bilateral efforts such as the DOD's US-Australia project agreement for scientific computing technologies have laid the groundwork for international collaborations. At the same time, agencies have also focused on ensuring that the software infrastructure is secure, with investments from agencies such as NSF through its Secure and Trustworthy Cyberspace (SaTC) and the Cybersecurity Innovation for Cyberinfrastructure programs that fund development of solutions to secure scientific data, workflows, and infrastructure.

Highlighted Examples 1.3
• The SaTC program from NSF supports research addressing cybersecurity and privacy, drawing on expertise in one or more of these areas: computing, communication, and information sciences; engineering; economics; education; mathematics; statistics; and social and behavioral sciences. The goals of the SaTC program are aligned with the NSTC's Federal Cybersecurity Research and Development Strategic Plan and National Privacy Research Strategy to protect and preserve the growing social and economic benefits of cyber systems while ensuring security and privacy. NSF has made over $200 million investments in this critical area through the SaTC program from FY21 to FY23. Additionally, the Knowledge Graph for Software Supply Chain Security project, funded by NSF as part of the Proto-OKN, is developing a unified knowledge graph to continually collect and track software dependencies and vulnerabilities discussed and revealed in various online security forums and documents. Working in close collaboration with industry partners, the project is developing a unified knowledge graph to capture rich, up to date information on software components in heterogenous software ecosystems. A neural knowledge acquisition pipeline extracts software information from a variety of online information sources including but not limited to official documentation, software release notes, bug reports, common vulnerabilities and exposures, and online discussions; consolidates the extracted information using various quality control and fact-checking mechanisms; and constantly updates the knowledge graph. • DOE/SC and DOE/NNSA invested, from 2017 through 2021, through the Exascale Computing Project's PathForward program, in technologies from six prime vendors to enhance the ecosystem of high-performance, robust computational hardware appropriate for exascale supercomputers and beyond. The total portfolio was $258M in Federal expenditures complemented by a 40% industry cost share. For example, when the PathForward project started, the number of GPU compute nodes in an exascale system was estimated to be many tens of thousands. At that time, they estimated that silent data corruption (SDC) failures in time (FIT) would be sufficiently high that the resulting mean-time-to-failure would be inadequate to meet exascale system requirements. The PathForward program funded the development and implementation of a number of enhancements to vendor's methodology and hardware that are expected to reduce the SDC FIT rate and to improve availability by a large factor (and to meet exascale system requirements) over current generation of products, while only incurring a small silicon area overhead. • DOD/AFRL's Secure Extreme Embedded Exploitation and Processing On-board program enables integration of advanced commercial and government-owned processing and exploitation technologies into a secure edge compute system (including the T-CORE cyber-hardened processor to enhance cybersecurity and prevent data exfiltration in the highly contested environment, and a rugged distributed computing platform to deliver high performance within a size, weight and power-constrained system). The T-CORE processor provides several cybersecurity guarantees at the hardware level regardless of software execution, including byte-level security tagging protection that prevents unsigned or unverified code modifications, in-line memory encryption, and a specialized instruction set architecture that prevents the creation of new or arbitrary instructions.

Accelerate access to innovative computing paradigms, technologies, and capabilities, while integrating and sustaining existing advanced computing systems critical to agency mission.

Agencies have made strategic investments in new areas of computing and are creating a robust coordination framework to provide access to these capabilities. Two key technologies are quantum and neuromorphic computing, that multiple agencies such as DOD, DOE/NNSA, DOE/SC, NASA, NIST, and NSF have invested in, including the development of testbeds such as the Advanced Quantum Testbed at the Lawrence Berkeley Laboratory/DOE/SC and the acquisition of a neural computer at Sandia National Laboratory/DOE/NNSA. Facilitating access to such testbeds will require coordination platforms, building on existing setups such as the DOE/SC HPC facilities and the network user facility (ESnet), NSF Leadership-class Computing and the Advanced Cyberinfrastructure Coordination Ecosystem (ACCESS), and the NASA HEC program.

Highlighted Examples 1.4

- DOE/SC supports two quantum computing testbeds, the Quantum Scientific Computing Open User Testbed at Sandia National Laboratories, and the Advanced Quantum Testbed at Lawrence Berkeley National Laboratory. The testbeds have been available to external collaborators on a competitive basis since 2020. In 2023, DOE/SC announced an additional $11.7M in funding for six collaborative projects to improve our understanding of whether, when, and how quantum computing might advance the frontiers of computational science. The projects explore the limitations of the noisy, intermediate-scale quantum processors available today and aim to develop tools for assessing whether a particular quantum processor may be able to advance the frontiers of computational science even in the absence of formal error correction on the device.
- The NASA Quantum Artificial Intelligence Laboratory (QuAIL) is the agency's hub for assessing the potential of quantum computers to impact future computational challenges faced by NASA. Located at Ames, the lab conducts research on quantum applications and algorithms, develops tools for quantum computing, and investigates the fundamental physics behind quantum computing. The lab also partners with other quantum labs across the country, such as those at Oak Ridge National Laboratory; and Department of Energy's Co-design Center for Quantum Advantage and Superconducting Quantum Materials and Systems Center.
- The Advanced Cyberinfrastructure Coordination Ecosystem: Services & Support (ACCESS) program was created by NSF to improve the accessibility of national cyberinfrastructure centers and increase integration with systems and research communities on campuses across the nation and is an exemplar of agency efforts to enable access to advanced computing systems within FACE. With ACCESS, the NSF has awarded $52 million over five years to five lead institutions and their sub-awardees to facilitate the program. Each project within ACCESS is independently managed yet highly cooperative; additionally, the ACCESS Coordination Office supports the collective operation of the ACCESS projects, endeavoring to provide seamless experiences across a high-performance, innovative array of national computational resources.

Leverage crosscutting synergies and efficiencies across governments, academia, non-profits, and industry, and with like-minded international counterparts.

Agencies have been setting up and engaging in coordination efforts to bring together various stakeholders. Establishing a robust computing ecosystem will not only require close coordination among the federal agencies, but also partnerships with industry and academic researchers within the US and with international research communities. Many federal agencies routinely collaborate through participation in working groups such as the NITRD HEC IWG, as well other initiatives such as the National Quantum Initiative (DARPA, DHS, DOC, DOD, DOE, DOJ/FBI, IARPA, NASA, NIH, NSA, NSF, ODNI, OSTP, USGS, and USPTO), the National AI Research Resource (NAIRR) Pilot program, and other efforts to engage with academia, nonprofits, and industry, both nationally and internationally.

Highlighted Examples 1.5
• In April 2022, the U.S. National Science Foundation announced a new investment of over $37 million, aimed at the development of intelligent, resilient, and reliable next generation (NextG) networks. The investment called RINGS (Resilient and Intelligent Next-Generation Systems) is a public-private partnership that focuses on accelerating research to increase the competitiveness of the U.S. in NextG networking and computing technologies and ensures the security and resilience of NextG technologies and infrastructure. This public-private partnership brings unique experience, insight, and resources to research efforts to accelerate the translation of fundamental research findings into new technologies that can transform the telecommunication and information technology sectors of the U.S. economy. The RINGS program is NSF's single largest effort to date to engage public and private partners to jointly support a research program, including several private sector and government partners - the U.S. Department of Defense's Office of the Under Secretary of Defense for Research and Engineering and the National Institute of Standards and Technology. • The COVID-19 HPC Consortium brought together the federal government, industry, and academic leaders coming together to provide access to the key computing resources within FACE to support urgently needed research on COVID-19. The consortium was rapidly formed through the joint effort of OSTP, NSF, DOE, and industry to create a unique public-private partnership between government, industry, and academic leaders and consisted of 43 members from US and around the world, enabling access to over 600 petaflops of supercomputing systems, over 165,000 compute nodes, more than 6.8 million compute processor cores, and over 50,000 GPUs. Over 115 projects were supported by the consortium and contributed significantly to topics such as the scientific understanding of the virus, optimizing medical supply chains and improving resource allocations. The National Strategic Computing Reserve was envisioned to provide a similar capability for future emergencies and the report National Strategic Computing Reserve: A Blueprint outlines the key role of public-private partnership to realize this vision. • The Exascale Computing Project (ECP) Industry and Agency Council (ECP-IAC) is an advisory committee to the ECP comprised of senior HEC leadership in government agencies and from strategic industry partners working together to advance awareness and promote adoption of exascale computing. The five agencies (DOD, NASA, NSF, NIH, NOAA) in conjunction with the seventeen industry partners meet several times each year for technical exchange, updates from ECP leadership, and to provide feedback to the ECP director.

Strategic Objective 2. Robust, Sustainable Software and Data Ecosystem

Establish an innovative, trusted, verified, usable, and sustainable software and data ecosystem.

Software challenges abound in the current environment of rapidly changing hardware advances. It is critical that the US maintain a software ecosystem that can respond to the scientific challenges posed by the need to simulate larger and more complex systems, and to ensure a robust and agile data ecosystem. The rapid advances in the use of artificial intelligence (AI) and machine learning (ML) have only exacerbated the situation. In recent years, projects such as the DOE ECP have led to the creation of a robust, software ecosystem that is delivering mission critical applications that scale on modern hardware platforms. These developments need to be extended to other applications and sustained to keep up with new hardware developments.

Considerable progress has been made toward the objectives of this strategy, but, in part due to the accelerating pace of technological advancement, additional efforts will be needed to maintain and build upon that progress. The execution for this strategy is supported by the subobjectives as outlined in the following subsections.

Ensure a robust and sustainable software ecosystem that will translate technology innovations into national S&E leadership.

Ensuring a robust and sustainable software ecosystem requires novel software development as well as modernizing legacy application codes, libraries, and software tools. While the evolution of both hardware technology, the software ecosystem, and development best practices make this a moving target, notable progress has been achieved through the creation of standard interfaces and portability frameworks that allow decoupling programming at the application level from many of the lower-level system details. Multiple agencies such as DHS, DOD, DOE/NNSA, DOE/SC, NASA, NIH, and NIST develop and release software that takes advantage of the latest hardware and software innovations and enables a sustainable software ecosystem. ECP, supported by DOE/SC and DOE/NNSA, is the most prominent of these efforts in its scope and contributions. ECP utilized the creation and adoption of portability frameworks including Kokkos, RAJA, and OpenMP to provide the ability to quickly adapt applications to different platforms. While some applications have begun to use machine learning models, and initial exploration of artificial intelligence-driven software development tools is underway, recognizing the full advantage of AI for the software ecosystem remains an opportunity for future endeavors.

Highlighted Examples 2.1
• DOE/SC's and DOE/NNSA's investments in the ECP built a comprehensive software ecosystem consisting of more than 20 applications and 80 software packages that use more than 10 compilers and 10 programming models on a range of target hardware architectures (from laptops to exascale). The legacy of these efforts will be a computational ecosystem that accelerates U.S. capabilities in scientific simulation and AI, unlocking the potential of exascale computers and preparing us for future systems that will build on our legacy. The complexity of this ecosystem, with over one million combinations, is being managed and simplified for the entire scientific and AI user community through the creation of ECP's Extreme-Scale Scientific Software Stack (E4S). E4S is lowering the barrier to entry for users and developers in the DOE and other U.S. government agencies, industries, and universities. The E4S has aggressively evolved, providing 80 distinct turn-key HPC and AI products grouped into thematic software development kits. Application codes that build on top of E4S benefit from guaranteed version compatibility, access to the latest stable features integrated into each quarterly release, and advanced build environment features that can improve build times by a factor of ten. E4S contains support for GPU architectures and is installed on DOE and NSF pre-exascale and exascale systems, as well as systems from other government agencies and industry, enabling the portability promise that is central to the success of future U.S. supercomputing. Applications building on E4S can use portability frameworks including Kokkos, RAJA, and OpenMP to quickly adapt applications to different platforms, including pre-exascale, exascale, and cloud-computing systems. • The DOD HPCMP provides a diverse computational ecosystem, including hardware, software, network, and other service, that blends computational assets for traditional HPC workloads as well as assets designed to leverage emerging interests and needs in AI and ML. These assets are made available across the DOD, the Defense Industrial Base, and with key mission partners in NASA and DHS and can accommodate changing classification levels, multiple caveats, and balance the needs of code developers and users. The program provides access to over 86 petaflops of computing to DOD scientists. HPCMP also has a collaborative data lake ecosystem (collection, storage, curation, and data management) to assist real-time processing across DOD hardware platforms, networks, and geographic locations. These investments have enabled advancements in AI/ML applications for weapons system maintenance and inventory management. Additionally, HPCMP initiative Cybersecurity Environment for Detection, Analysis, and Reporting (CEDAR) allows for the design, testing, building, and continuous evaluation of a defensive cyberspace operations (DCO) platform. CEDAR incorporates a variety of sensors and a robust data processing pipeline (i.e. 100 Gbps+) to detect anomalous and malicious network traffic that may pose a threat to the security posture of the Defense Research and Engineering Network and its Research, Development, Test, and Evaluation (RDT&E) community in real-time. CEDAR allows cybersecurity analysts to collect, enrich, correlate, index, and alert a variety of data sources with strong scaling (100k+ events/sec) to meet the security requirements of the DOD RDT&E community.

Support needs for novel software development.

Novel software development needs are driven by emerging technologies and computing paradigms and their unique requirements. Multiple agencies such as DOE/NNSA, DOE/SC, NASA, NIH, and NSF, support new software development approaches. The multitude of platforms relevant for exploring new algorithms and maturing software has been increasing. Relevant platforms now often include those featuring GPUs, which are increasingly common on high-end HPC systems and edge platforms, and state-of-the-art AI accelerators. Access to small systems and testbeds are increasingly common, while access to large-scale systems for development and testing remains a challenge because such usage competes with large-scale production tasks. Multiple agencies have made progress on adapting industry best practices, such as the use of continuous integration and version control, to high-end computing platforms covering both production platforms and testbeds. Ongoing adoption work is needed by agencies as software-development tools and best practices continue to evolve. Additionally, new AI-driven tools for software development and AI-driven software interfaces provide potentially transformative opportunities to increase developer and user productivity assuming that correctness, provenance, reproducibility, robustness, and many other challenge areas can be adequately addressed.

Highlighted Examples 2.2
In 2022, DOE/SC's ALCF deployed the Polaris supercomputer to give scientists and application developers a platform to test and optimize codes for Aurora, ALCF's then-upcoming exascale supercomputer. This proved to be an essential steppingstone for many as they prepared their applications and libraries for Aurora because Aurora features a different software stack than previous ALCF systems. Developers were able to test and develop code for GPUs using programming models, such as OpenMP and SYCL, that are now available on Aurora. Polaris also provided an opportunity for the facility to test out new system-management software many months before it was deployed on Aurora. Polaris also supports several projects focused on using AI for science and the integration of large-scale research instruments with high performance computing. With Aurora deployed, Polaris will transition in 2024 to be ALCF's primary production resource for visualization and analysis. In addition, DOE/SC is looking beyond exascale and supporting basic research on programming techniques and tools that will enable high-performance, trusted application development and porting to new systems through the Software Stack for Extreme HPC Heterogeneity program. • The DOD HPCMP established a reimagined software development initiative in FY23 called HPCMP Institutes to meet the specialized HEC needs of the DOD Acquisition Engineering, S&T and Analysis stakeholders. These three-year efforts are intended to produce a software deliverable that will transition to the DOD community of users for deployment on HPCMP resources. While scientists and engineers from government, industry, and academia may participate in a funded Institute, a DOD sponsor is required for each development effort. When fully established in FY25, three Institutes will operate simultaneously to address emerging DOD mission-critical requirements. • NSF has continued to invest in development of software to enable scientific discovery through the Cyberinfrastructure for Sustained Scientific Impact (CSSI) program, which is an integral part of the overall NSF Data and Software strategy through long-term investments that focus on catalyzing new thinking paradigms, and practices in developing and using data and software services to understand natural, human and engineered systems. CSSI FY21-23 investments include over $198M funding for over 200 projects that focus on development of software and data cyberinfrastructure across all scientific disciplines. Funded projects address urgent needs in these disciplines through innovative solutions and contribute to the software and data ecosystem that is complemented by other NSF investments in the foundational areas. Since 2022, CSSI program has included a track called Transition to Sustainability, that funds innovative ideas for sustaining the investments beyond the years of funding.

Ensure a robust data ecosystem that includes collaborative data management platforms for real-time processing, curation, analysis, and sharing of data across hardware platforms and geographic locations; increased availability of data across government, academia, nonprofits, industry, and the public; and an accelerated pace of discovery.

Several agencies such as DOD, DOE/SC, NASA, NIH, NIST, and USGS have data-focused efforts and make data and tools available to the public. Some of these tools are deployed in the form of "gateways" allowing tools and data to be accessed through a website, thus enhancing provenance-tracking capabilities, and increasing accessibility to students and researchers beyond those with computer-programming skills. Nevertheless, substantial challenges remain due to policy, legal, and technical data-sharing impediments; the increasing size and update frequency of many key data sets; and the largely manual process of curation and quality control needed in many areas. Opportunities to use emerging AI technologies to reduce manual data curation steps and enable federated and privacy-preserving modeling promise to substantially address many of these challenges in the future.

Highlighted Examples 2.3
• NIH has continued to expand its The STRIDES (Science and Technology Research Infrastructure for Discovery, Experimentation, and Sustainability) Initiative, adding another major cloud vendor as a service provider in 2021, joining other partners. A central tenet of STRIDES is that data made available through these partnerships will incorporate standards endorsed by the biomedical research community to make data findable, accessible, interoperable, and reusable. NIH's initial efforts focuse on making NIH high-value datasets more accessible through the cloud, leveraging partnerships to take advantage of data-related innovations such as machine learning and artificial intelligence, and experimenting with new ways to optimize technology-intensive research. The STRIDES Initiative has expanded access to critical infrastructure and cutting-edge cloud resources for NIH researchers, as well as NIH-funded researchers at more than 2,500 academic institutions across the nation. As of 2021, STRIDES investment enables access to over 253 PB of data, more than 506 million compute hours and supports over 1785 research programs. • The NSF program on Harnessing the Data Revolution (HDR): Institutes for Data-Intensive Research in Science and Engineering was started in FY21 to establish a group of HDR Institutes for data-intensive research in science and engineering and lead innovation by harnessing diverse data sources and developing and applying new methodologies, technologies, and infrastructure for data management and analysis. The program funded five multi-disciplinary institutes with a total budget of over $70 million that form an integral part of the robust data ecosystem within FACE. These include the Imageomics Institute at Ohio State University to enable discovery from biological images, the High-frequency Active Auroral Research Program Institute that develops data science solutions for the most important priorities and challenges for navigating the Arctic, climate change and sea level rise, the Institute for Data Driven Dynamical Design to enable materials discoveries, the Institute on Accelerated AI algorithms for data-driven discovery in fields of High-energy Physics, multi-messenger Astronomy and neuroscience, and the Institute for Geospatial Understanding to enhance community resilience and environmental sustainability. Another NSF initiative, the Open Knowledge Network (OKN), links trusted information using state-of-the-art knowledge representation. The NSF Convergence Accelerator Track A supported five projects in Phase 2, for a total of $25M, to create the OKN. Following an OKN Innovation Sprint sponsored by OSTP and NSF that brought together a multi-sector community, NSF launched the Prototype OKN program which now supports 18 projects, at a total of $26.7 million—all working together as a single cohort—to create the Proto-OKN, in collaboration with NIH, NASA, NOAA, USGS, and NIJ.

Develop, deploy, operate, and promote trusted services and capabilities that ensure secure and effective management and high utilization of resources.

Multiple agencies such as DOE/HPCMP, DOE/NNSA, DOD/SC, NASA, and NIH provide trusted services or resources to their customer basis. These services and capabilities range from DOE's exascale supercomputers through high-end edge capabilities across the world, both at fixed locations and on mobile platforms. Research into techniques for scheduling and resource allocation continues to help high resource utilization as systems become larger, more geographically distributed, and use more-heterogeneous hardware. While numerous advances have been made, ensuring security, resilience, longevity, and efficiency of systems and applications remains an ongoing challenge.

Highlighted Examples 2.4
• DOE/SC's OLCF introduced, in 2021, CITADEL, a new framework of security protocols that will enable researchers to harness protected health information, personally identifiable information, data protected under International Traffic in Arms Regulations, and other types of data that require privacy to be securely used on the Summit supercomputer, the Frontier exascale system, and some other systems managed by the laboratory. For example, using medical records that include handwritten doctor's notes could generally not be used on the supercomputers before CITADEL; although names and addresses could be automatically stripped out of structured medical records, freeform notes were not as simple. In 2022, the CITADEL security framework was used to securely transfer and analyze veterans' health records on OLCF's Summit as part of Improve Outcomes Now. In 2023, a new algorithm was developed under a Cancer Moonshot program as part of a partnership between DOE and NIH's National Cancer Institute that classifies US cancer reports 18 times faster than traditional methods. The new Case-Level Multi-Task Hierarchical Self Attention Network uses natural language processing to autocode cancer pathology reports that are submitted to Surveillance, Epidemiology and End Results registries across the United States. • The NSF Cybersecurity Center of Excellence, Trusted Cyberinfrastructure (CI), was established in 2020 to bring together experts in cybersecurity, to provide NSF community with leadership and support necessary to tackle the cybersecurity challenges in NSF research ecosystem. Trusted CI directly supports individual NSF cyberinfrastructure projects and Major Facilities through collaborative engagements that address specific project needs. Trusted CI engagement activities include (but are not limited to) security reviews, security architecture design, identity and access management, and software assurance. Trusted CI performs outreach and dissemination of best practices via the Trusted CI website, blog posts, email lists, and online chats, as well as providing cybersecurity training in person and via online courses. In 2023, Trusted CI published the Trusted CI Operational Technology Procurement Vendor Matrix to provide organizational understanding of risks involved with incorporating new operational technology into their security apparatus. Additionally, NSF has created programs in Pathways to Open Source Ecosystems, FAIR (Findable Accessible Interoperable Reusable) Open Science Research Coordination Networks (RCN)and Geosciences Open Science Ecosystem to help create trusted, open systems. For example, the FAIR in ML, AI Readiness and Reproducibility RCN is helping to develop an understanding of the relationship between FAIR data and ML accuracy and performance; the reproducibility of ML output and how this varies between software stacks, hardware processor types, and environmental effects; and how data facilities can make it easier to use ML on their collections so that those running high-end compute facilities and data repositories, and the researchers using these resources can keep pace with ML adoption.

Explore innovative models for PPP aimed at developing models for software and data innovation and sustainability.

Multiple agencies such as DOE/NNSA, DOE/SC, NASA, and NIH are partnering with other agencies or the private sector to provide continuing support for mission-critical software packages. For example, several small and large businesses offer, or are developing offerings/support for software developed under ECP, including E4S. Opportunities for public-private partnerships (PPPs) will grow as the use of HPC in industry grows, which is happening for many reasons, including the diffusion of capabilities for using high-end computing, the synergy between HPC and AI capabilities, and the need for ever-more-precise analysis of ever-larger and more-dynamic data sets.

Highlighted Examples 2.5
• DOE/SC, through its investments for Aurora at the ALCF, and DOE/SC and DOE/NNSA, through ECP, has

partnered with industry to develop an innovative open-source HPC data-management framework called Distributed Asynchronous Object Storage (DAOS). This framework is optimized for next-generation non-volatile memory technologies and DAOS powers the storage system on Aurora exascale supercomputer at ALCF. DAOS provides high bandwidth, low latency, and high I/O operations per second, taking advantage of its object storage paradigm to eliminate performance bottlenecks that plague more-traditional storage systems. Investment started in 2016, and by 2020, a DAOS-powered storage system was #1 on the IO 500 system benchmark, with DAOS powering 8 of the top 17 systems on that list.

- The NSF Technology, Innovation and Partnership (TIP) directorate was established in 2022 to advance use-inspired and translational research in all fields of science and engineering, giving rise to new industries and engaging all Americans. A core component of TIP mission is to accelerate research to impact through programs that accelerate breakthroughs in critical and emerging technologies, such as advanced manufacturing, advanced materials, advanced wireless, artificial intelligence, biotechnology, quantum information science, and semiconductors and microelectronics, to sustain long-term U.S. competitiveness. At the same time, TIP aims at accelerating the translation of research results to practical use through its Lab-to-Market Platform. Programs such as Partnerships for Innovation, Innovation Corps, America's Seed Fund (also known as the Small Business Innovation Research/Small Business Technology Transfer Programs), Activate, and Pathways to Open-source Ecosystems provide pathways for researchers, startups, small businesses, and aspiring entrepreneurs to move their ideas from the lab to society while gaining access to a range of NSF resources. These programs support new pathways for translating research results to society as well, including new, open-source ecosystems, government services or at-scale educational innovations. From its inception in 2022, TIP has invested in five new i-Corps hubs and explored partnership models with industry to strengthen workforce development in critical areas relevant to FACE.

Strategic Objective 3. Foundational, Applied, and Translational R&D

Support foundational, applied, and translational research and development to drive the future of advanced computing and its applications.

The HEC community is faced with a significant challenge in moving from traditional von Neumann architectures and the dominance of the Moore's law mindset to an environment where neuromorphic, biological, quantum and other technologies will begin to play a major role. The challenge is significant and will only be met by a continued investment of resources into the research required to catalyze that transition. The realization of this transition is the major driver behind Objective 3 of the FACE initiative.

Significant progress continues toward the objectives of this strategy, with new computing methodologies being researched and matured, new AI and data-analytics methods being developed at an astounding rate, increasingly-large-scale computing being deployed, and a significant number of testbeds and prototypes being created and upgraded. However, significant work remains to develop and deploy efficient, intelligent, and scalable computing technologies. The execution for this strategy is supported by the subobjectives as outlined in the following subsections.

Ensure hardware leadership in a post-Moore/von Neumann era ensuring broad investments across diverse candidate technologies.

The end of Dennard scaling and the slowing of improvement in Moore's Law are motivating investigations of alternatives to traditional, von Neumann-based models of computing such as neuromorphic, bioinspired, quantum, analog, hybrid, and probabilistic computing. Moreover, novel materials and approaches such as DNA storage, and quantum technologies have been significant targets of agency investments, and while still in the basic-research regime, important advancements in understanding have been achieved. DOE/SC, NIST, NSF, and other agencies have invested in neuromorphic, bioinspired, and analog computing approaches, especially in the context of machine learning. Many of the same agencies are involved in quantum-oriented developments that have the potential of upstaging traditional computing hardware and software with Quantum Information Science being a focus of multiple activities. The transition to non-von Neumann-era computing will undoubtedly be disruptive to agencies as both hardware and software will need to be reimagined, resulting in a large number of challenges but countless opportunities for innovation and discovery. Current plans and methodologies for sustainability of software, for instance, will most likely not be appropriate in this new era of computing and will need to be reinvented. Fielding a workforce with skillsets in non-von-Neumann-era architectures will be extremely challenging (see Objective 4). Furthermore, these changes will have a direct impact on the innovation economy and on the larger economy through users of such technologies. Nevertheless, given the strategic importance of, growing demand for, and growing energy use of, computing and AI capabilities, advancement toward this objective is essential and the research accomplished provides confidence in further significant progress.

Highlighted Examples 3.1

- The National Quantum Initiative Act called for the NSF and DOE to establish new Centers focusing on quantum information science (QIS) research and discovery. In alignment with this goal, NSF announced the Quantum Leap Challenge Institutes first round of three awards in 2020, with two additional awards in 2021. DOE/SC announced the National QIS Research Centers funding opportunity awards in 2020. These Centers bring together multidisciplinary teams to tackle some of the most complex and urgent problems in quantum information science and engineering. With connections to universities, national laboratories and industry, these NQI Centers will explore quantum frontiers, stimulate QIS technology development, and expand QIS training opportunities. Quantum computing and networking technologies that promise enhanced performance and energy efficiency on key problems in science, medicine, industrial operations, and other areas are a core part of the focus for the Institutes and Centers, and the centers have made progress toward understanding the fundamental features and limitations of different kinds of qubits and quantum communications technologies.
- DOE/SC funded in 2019 multi-institutional teams as part of its Accelerated Research in Quantum Computing program to research innovative methods for quantum computing. Quantum computing requires new algorithms, system software, programming tools, and hardware techniques. For example, in 2022 researchers at Lawrence Berkeley National Laboratory developed a new approach to quantum error mitigation that could help make quantum computing's theoretical potential a reality: noise estimation circuits. When combined with three other error mitigation techniques, noise elimination circuits obtained reliable results for dynamic simulations of materials. The novel error mitigation approach will allow researchers to run longer, more realistic simulations and still obtain reliable results. This will broaden the potential impact of upcoming quantum computers on scientific discovery in a huge range of fields, from clean energy to artificial intelligence.

Advance software and software-hardware research to enhance the scale and resolution of important problems that are tractable.

Progress in high-end computing depends on both advancement in hardware as well as on advancement in software techniques and frameworks. This has become increasingly important as systems have become more heterogeneous, and in many cases, geographically distributed. This trend continues as new computing paradigms are developed, and additionally, new paradigms often require hardware and software capabilities to be co-designed – designed together in a cycle of iterative improvement – to enable realizing the promise of new computing technologies. Multiple agencies such as DOD, DOE/NNSA, DOE/SC, NASA, and NSF, support developing novel software algorithms and applications that leverage HPC at scale. For example, ECP, supported by DOE/NNSA and DOE/SC, prepared a number of applications for the nation's largest exascale supercomputers. As systems grow in size, new programming methodologies may be needed to exploit the full capabilities of the resources. Both the increasing complexity of heterogeneous hardware and the increasing complexity of modern software

are driving exploration of new programming approaches. For example, NIST is researching the use of software abstractions rooted in data flow graphs to develop HEC applications.

Highlighted Examples 3.2
• DOE/SC's Scientific Discovery Through Advanced Computing (SciDAC) program was created to bring together many of the nation's top researchers to develop new computational methods for tackling some of the most challenging scientific problems by leveraging expertise in applied mathematics and computer science. Established in 2001, SciDAC involves ASCR partnerships with other SC programs, other DOE program offices, and other federal agencies. Since its inception, the SciDAC model has accelerated the pace of scientific discovery. SciDAC continues to address mathematical and computational challenges related to predictive modeling and high-fidelity simulations and to the generation and management of large data sets, increased demand for scientific credibility, and expected disruptions in computer architectures. The two currently funded SciDAC institutes represent over $50 million investment through this program. The two teams, led respectively by Argonne and Lawrence Berkeley National Laboratories, are composed of leading experts in computer science, software development, applied mathematics, and related disciplines. The teams will provide expertise and develop tools to enable scientists to take full advantage of DOE's high-performance computing capabilities. • The NSF Software and Hardware Foundations program supports potentially transformative research in the design, verification, operation, utilization, and evaluation of computer software and hardware through novel approaches, robust theories, high-leverage tools, and lasting principles. Such advances may involve formal methods, languages, logics, novel software and/or hardware artifacts, or algorithms to enable new or enhanced functionality, verification, usability, and scale. The SHF program supports all aspects of the science and engineering of software, seeking transformative ideas that reformulate the relationships between requirements, design and evolution of software, and software-intensive systems. In the last three years, NSF has made investments of more than $140 million to support a variety of research projects through this program. This includes investments hardware-software co-design to achieve scalability and memory-efficiency, developing massively parallel server processors, formal methods for verification of concurrent software, and developing alternate computing models such as reversible computing. • The Computational Research and Engineering Acquisition Tools and Environments (CREATE) element of the DOD HPCMP programs represents investments for development, deployment, and maintenance of software in response to demands of the DOD. The software applications developed through the CREATE program enable prototyping and testing analysis for major Defense weapons programs by making the acquisition process efficient and by enhancing the capabilities of the weapon systems. Currently, CREATE develops and deploys 12 multi-fidelity software products for design, virtual test, and analysis. These include software for military aircraft design, meshing and geometry tool, ground vehicle design, radio frequency antenna design, and military ship design. Additionally, CREATE offers an educational software suite for computational fluid geometry, called Genesis, which is made available to undergraduate and graduate students.

Address challenges and opportunities related to growing data volumes and successful translation of data into insights.

High end computing is well into a transition period from localized, homogenous resources to geographically distributed, heterogeneous computing ecosystems. Multiple agencies such as DOD, DOE/NNSA, DOE/SC, NASA, and NSF, support developing novel software algorithms and applications that leverage HPC at scale. For example, ECP, supported by DOE/NNSA and DOE/SC, prepared a number of applications for the nation's largest exascale supercomputers. As systems grow in size, new programming methodologies may be needed to exploit the full capabilities of the resources. Both the increasing complexity of the heterogeneous hardware and the increasingly complexity of modern software are driving exploration of new programming approaches. For example, NIST is researching the use of software abstractions rooted in data flow graphs to develop HEC applications. It is not only individual systems that are increasing in scale, but rather, geographically distributed systems are being combined into distributed computing ecosystems. With the Spaceborne Computer-2 on the

International Space Station, NASA has even put HEC capabilities into space. While important progress has been made, the growing size of data sets, the changing workloads and the increasing impact of AI, and the complexity of scheduling and allocating distributed resources in an efficient and resilient way, continue to motivate research in large-scale systems.

Highlighted Examples 3.3
• In 2021, NASA launched the Spaceborne Computer-2 to the International Space Station (ISS). The Spaceborne Computer-2 is commercial, off-the-shelf computing hardware, much like the hardware that powers cloud computing on Earth, to enable experimenting with cloud computing in space. By April 2022, the computer had completed 24 experiments on the ISS. Experiments conducted to date have focused on a wide range of challenges from astronaut healthcare to 3D printing. For example, the computer can perform on-board DNA-sequence analysis in minutes that used to take hours to transmit back to Earth for analysis. • DOD, in collaboration with industry, developed an AI chip architecture for advanced computing ecosystem edge applications. This inferencing processor tightly integrates processing and memory, and thus allows data to move far more efficiently compared to conventional computer chip designs. Instant analysis of high-bandwidth data is demonstrated for various DOD AI inferencing applications. This processor provides DOD with significant technological advantages over the best commercial solutions, leading to superior DOD mission capabilities. • USGS curates and disseminates critical datasets to the public, providing not only raw data, but tools used to view and understand that data. For example, Landsat 9, a joint mission between the USGS and NASA, started releasing public data in 2022, and collects approximately 750 images of Earth each day. Updated software, including the LandsatLook 2.0 Viewer, will make it easier and faster to access earth imagery and simpler to analyze through the use of cloud-based systems. Other kinds of data and corresponding software have also been improved. As another example, the topoBuilder application is designed to assist recreationalists and the general public that use cartographic products in their work and daily lives as well as support resource management, natural hazard risk reduction, national health and security, and sustainable energy development.

Enhance AI capabilities including real-time, at-scale, and with attributes of fairness and explainability.

Today, state-of-the-art sensors and at-scale processes can generate petabytes of data every day. Maintaining U.S. leadership in extracting insights from this flood of data requires improvements in both hardware and computing techniques that address the storage, transmission, and processing of data. Multiple agencies such as DOD, DOE/SC, DHS/S&T, NASA, NIH and USGS are developing software that takes advantage of large data volumes and, in some instances, releasing such applications. Several agencies are also making large datasets available to the public. For example, DOE/SC's Public Reusable Research (PuRe) Data initiative establishes best practices for public data repositories and designates repositories following those practices, many of which hold data that is AI ready by virtue of being large, systematically curated, well-characterized collections of high-quality data suitable for use in AI training; and highlights a set of data repositories following those best practices. Moreover, large-scale data and AI modeling capabilities are transforming our computing ecosystem and impacting many facets of our daily lives. Multiple agencies such as DOE/SC, DOE/NNSA, DHS/S&T, NASA, NIH, NIST, NSF, and USGS report AI-related activities that leverage large datasets. For example, research supported by DOE/SC is exploring the reliability, robustness, explainability, and interpretability of AI approaches; NIST has developed a Trustworthy & Responsible AI Resource Center and has released the AI Risk Management Framework.

Highlighted Examples 3.4
• The NSF-led National Artificial Intelligence Research program, launched in 2020, has funded 25 institutes that connect over 500 funded and collaborative institutions across the U.S. and the world. Funded at about $20 million each over an initial five years, these 25 institutes represent a total investment of about $500 million,

making this one of the biggest single public investments to date in AI research and development. The program also brings in funding partners from other federal agencies including Department of Education, DHS, DOD, NIST, and USDA as well as industry partners. These institutes represent interdisciplinary collaborations among top AI researchers to tackle large-scale challenges in both foundational and use-inspired AI research, develop future AI workforce, and become national nexus points for addressing society's grand challenges. NSF and its partners are continuing such investments through the next round of funding for five more institutes that focus on Astronomical Sciences, investments through the next round of funding for five more institutes that focus on Astronomical Sciences, Materials Research and Strengthening AI with partnerships from DOD, NIST, and commercial and nonprofit entities. Additionally, NSF is currently planning a workshop to bring FAIR principles into the National AI Research Resources. The NAIRR Meets FAIR workshop will address the issue of creating trustworthy AI systems by introducing FAIR principles, including traceability, provenance, and transparency, from the very beginning. As mentioned earlier, NSF has created programs in Pathways to Open Source Ecosystems, FAIR Open Science Research Coordination Networks and Geosciences Open Science Ecosystem to help create trusted, open systems. For example, the FAIR in ML, AI Readiness and Reproducibility RCN is helping to develop an understanding of the relationship between FAIR data and ML accuracy and performance; the reproducibility of ML output and how this varies between software stacks, hardware processor types, and environmental effects; and how data facilities can make it easier to use ML on their collections so that those running high-end compute facilities and data repositories, and the researchers using these resources can keep pace with ML adoption.

- DOE/SC's Research Initiative on Artificial Intelligence and Machine Learning, over $165 million by FY23, covers exploratory and use-inspired basic research in AI and its application across SC's portfolio. The initiative includes investment in the co-design of new hardware and systems with U.S. technology vendors, including advanced memory technology, for AI applications. The initiative leverages that DOE's exascale supercomputers will be some of the most powerful resources in the world for scientific AI training and in addition, like all of DOE's computing facilities, support AI-coupled modeling-and-simulation workloads and digital twins. Work spans a multitude of awards, for example, a team from Argonne National Laboratory, California Institute of Technology, Harvard University, Northern Illinois University, Technical University of Munich, University of Chicago, University of Illinois Chicago, and hardware companies, developed an AI based on "large language model" techniques to understand the evolutionary dynamics of COVID – work that was awarded the 2022 Gordon Bell Special Prize for High Performance Computing-Based COVID-19 Research.

Expand availability of and access to testbeds, prototyping, and research infrastructure to encourage research, development, and sustainment of software tools needed to deploy applications onto increasingly complex systems.

Developing fundamental new approaches to computing, the system software that enables those approaches to be realized as usable systems, and the applications that fulfill the promise of new computing advancements, all require the development of testbeds and technology prototypes. As technology and approaches mature, application developers and others need access to testbeds that can be used to evaluate and build upon those technologies and approaches. NSF and DOE/SC are making testbeds available for prototyping and exploratory research. For example, DOE/SC's ALCF's AI Testbed features a variety of different AI accelerators and software stacks. Moreover, developing applications at scale requires testbeds of increasing size, and ALCF's Polaris computer has provided a large-scale resource for preparing applications for exascale computers. The NSF-funded SAGE testbed is a national research infrastructure of sensors that support AI research evaluating new approaches to AI-enabled scientific workflows, programming, and runtime environments, integrating data from diverse sources in context of a national-scale computing continuum spanning intelligent edge devices to centralized high-performance computing centers.

Highlighted Examples 3.5
• DARPA's Next-Generation Microelectronics Manufacturing (NGMM) program, launched in 2022, aims to create a novel, U.S.-based center for R&D and manufacturing three-dimensional heterogeneously integrated (3DHI) microsystems. The ability to perform onshore 3DHI R&D and prototyping for silicon-based components is hindered by the lack of integrated design tools and assembly/packaging/testing facilities. Additionally, there is extremely limited capability for non-silicon-based 3DHI. The first phase of NGMM, Phase 0, will inform planning for a domestic 3DHI manufacturing center. Later phases will leverage expertise in establishing the open-access center, qualifying and maturing processes, and operationalizing capabilities. • DOE/SC's ALCF's AI Testbed opened to users in 2022 and provides the global research community with access to the world's most advanced AI platforms. A major focus of the testbed is to help evaluate the usability and performance of machine learning-based high-performance computing applications on unique AI hardware. Testbed applications already range from COVID-19 research to multiphysics simulations of massive stars to predicting cancer treatments. The testbed combines a number of bleeding-edge components from vendors, and users can evaluate both novel hardware and software capabilities for advanced AI. Users can also evaluate how hardware designed for AI applications can be used for advanced AI. Users can also evaluate how hardware designed for AI applications can be used to perform other kinds of calculations, including some kinds of modeling-and-simulation applications. • SAGE, a software-defined sensor network, a project led by Northwestern University and leveraging open-source hardware and software developed by DOE/SC's Argonne National Laboratory, was funded by NSF to provide a national research infrastructure of sensors that support AI and other scientific research. SAGE will deploy sensor nodes that support machine learning frameworks in environmental testbeds in California, Colorado, and Kansas and in urban environments in Illinois and Texas. Partners will deploy Sage testbeds in Australia, Japan, UK, and Taiwan, providing scientists with even more data for analysis. The reusable cyber-infrastructure running on these testbeds will give climate, traffic, and ecosystem scientists new data for building models to study these coupled systems. • Several federal agencies in the Washington, DC area (AFRL, ARL, NIWC-P, NRL, USNO, NIST, NSA, and NIST) are deploying a regional quantum network known as the DC-QNet. It is being developed as a non-proprietary environment for testing and evaluation of quantum networking concepts, components, protocols and architectures developed both within and beyond the member agencies. It will enable cross-cutting agency synergy in sensor development, secure communications, distributed computing, and other use cases.

Address the need for technologies that ensure hardware supply chain security for the manufacturing, packaging, and integration of advanced and trusted computing ecosystem electronics.

Testbeds and prototypes, in addition to enabling further software development, form a key investment vehicle through which to strengthen and diversify our microelectronics supply chains. For example, DARPA's Electronic Resurgence Initiative 2.0 and NIST's Cybersecurity Supply Chain Risk Management are aimed at both national security capabilities and commercial supply chains. Moreover, DOE/NNSA's and DOE/SC's exascale supercomputers, which feature state-of-the-art AI-capable accelerators from multiple vendors, significantly enhanced supply-chain resiliency in the now-critical AI hardware market by partnering on the development of, and demonstrating both the hardware and software ecosystems for, a diversified set of product offerings.

Highlighted Examples 3.6
• DARPA's Electronics Resurgence Initiative (ERI) 2.0 is aimed at both national security capabilities and commercial economic competitiveness. It's a thematic portfolio of research programs to ensure US leadership in next-

generation microelectronics research, development, and manufacturing, creating a national capability for three-dimensional heterogeneous integration hardware manufacturing. It is also pursuing focused research in manufacturing complex 3D systems and developing electronics for extreme environments. New methods for designing, fabricating, packaging, and testing these imminently disruptive technologies are essential to US resilience and competitiveness.

- NIST's Cybersecurity Supply Chain Risk Management (C-SCRM) program assists organizations to manage risks of supply chain compromise related to cybersecurity. C-SCRM involves identifying, assessing, and mitigating the risks associated with the distributed and interconnected nature of information, communication, and operation technology product and service supply chains. It covers the entire life cycle of a system, including design, development, distribution, deployment, acquisition, maintenance, and destruction. The Risk Management Framework (RMF) provides a process that integrates security, privacy, and cyber supply chain risk management activities into the system development life cycle. The risk-based approach to control selection and specification considers effectiveness, efficiency, and constraints due to applicable laws, directives, Executive Orders, policies, standards, or regulations. Managing organizational risk is paramount to effective information security and privacy programs; the RMF approach can be applied to new and legacy systems, any type of system or technology such as IoT, control systems, and within any type of organization regardless of size or sector. The RMF is one of many publications developed by the Joint Task Force.

Strategic Objective 4. Fostering a Diverse, Capable, and Flexible Workforce

Expand the diverse, capable, and flexible workforce that is critically needed to build and sustain the future advanced computing ecosystem.

The vision of Strategic Objective 4 is to foster a diverse, capable, and flexible workforce, one that can effectively leverage an advanced computing ecosystem and build the tools, operate the systems, and support a broad range of users. Developing and leveraging this advanced computing ecosystem requires a future workforce to take full advantage of innovative technologies, software, and data systems and rapidly evolving methods such as foundational models which underlie new efforts in generative AI. To ensure that the workforce of the future remains engaged in FACE, agencies will need to provide the necessary career incentives and career paths, including partnerships across government agencies, non-profits, and industry stakeholders. If this strategic objective is accomplished, it will establish a critical conduit for training and retaining highly skilled, diverse experts and we will achieve and sustain a domestic cadre of talent to booster US economic, research, and national security goals. The execution for this strategy is supported by the subobjectives as outlined in the following subsections.

Create the diverse workforce necessary to achieve the goals of future advanced computing ecosystem, support U.S. innovation, and push the leading edge of computation.

Federal agencies are expanding efforts to increase recruitment and retaining strategies with new policies in Diversity, Equity, Inclusion, and Accessibility (DEIA) and targeted new programs that support FACE. For instance, DOD, DOE/SC, and NASA have specific policies around DEIA that enable them to recruit and engage the best talent from the full spectrum of society and diverse workforce recruitment and retaining strategies working with US academic institutes to achieve goals of FACE, with special attention paid to attracting interns from Historical Black Colleges and Universities and Minority Serving Institutions. Several agencies have sustained scholarship programs such as the NIH Data and Technology Advancement National Service Scholar Program, DOE/SC's Reaching a New Energy Sciences Workforce (RENEW) initiative, Mendenhall Research Fellowship Program from USGS and DOE/NSF Better Science Software Fellowship (BSSw), and graduate scholarship programs at DOE and NSF, all of which emphasize the inclusion of researchers from underrepresented groups. Several agencies fund research projects around science, technology, engineering, and mathematics (STEM)-related workforce initiatives, such as the NIST NICE program and NSF CyberTraining program. Larger centers such as the Minority Serving – Cyberinfrastructure Consortium (MS-CC) funded by NSF, and those funded through programs such as the DOE/NNSA Minority Serving Institution Partnership Program (MSIPP) and the DOE/NNSA Tribal Education Partnership Program (TEPP), are efforts that provide sustained workforce development guidance for Historically Black Colleges and Universities (HBCUs), Hispanic-Serving Institutions (HSIs), Tribal Colleges and Universities (TCUs), and other minority serving institutions (MSIs). While these programs have been impactful, there still remains the challenge of bridging the potential technology divide between the well-resourced institutions and lower-resourced institutions, exacerbating the need for additional training and recruiting efforts. Mitigating these factors requires additional resources for FACE training activities.

Highlighted Examples 4.1
• RENEW aims to build foundations for DOE SC research at institutions historically underrepresented in the SC research portfolio. RENEW leverages SC's unique national laboratories, user facilities, and other research infrastructures to provide training opportunities for undergraduate and graduate students, postdoctoral researchers, and faculty at academic institutions not currently well represented in the U.S. science and technicians with the critical skills and expertise needed for the full breadth of SC research activities. Principal investigators, key personnel, postdoctoral researchers, and students of RENEW awards will be invited to participate in program research meetings and/or SC-wide professional development events. • NSF has invested over $20M in the MS-CC, which is a collaborative initiative to improve cyberinfrastructure at HBCUs, TCUs, HSIs and other MSIs. In collaboration with Internet2 and the American Indian Higher Education Consortium, MS-CC is developing mechanisms to increase access to cyberinfrastructure resources, funding, and professional development opportunities for faculty, staff, and students at HBCUs, TCUs, HSIs, and other MSIs. MS-CC is taking an agile and adaptive approach to operating as a consortium, with a long-term commitment to learning and adjusting based on successes and lessons learned, matching to the diverse size and missions of these colleges and universities. The MS-CC is broadening participation in STEM by historically underrepresented groups in the United States's research enterprise, enabling new perspectives to emerge and expand capabilities for the nation. MS-CC is advancing our nation's economic growth, national security and global prosperity in ways that reflect the unique expertise and talent from HBCUs, TCUs, HSIs and other MSIs. DOE/NNSA Minority Serving Institution Partnership Program is an initiative to create and support sustainable career pathways to prepare a diverse workforce of talented students who can make an immediate impact on the Nuclear Security Enterprise (NSE). Award recipients work in collaboration with DOE/NNSA NSE to align curriculum and education focus areas to NSE areas of interest and expand their research capacities in STEM areas, including computing, through student enrichment programs, new courses, scientist to scientist interactions, engaging faculty in research meetings and activities, and facilitating access to NSE facilities. In FY22, the program engaged 245 interns from 56 MSIs and supported over 1,000 students from diverse demographic backgrounds.

Develop training, upskilling and reskilling strategies that exploit the use of state-of-the-art technologies and anticipate future technologies and solutions.

Federal agencies are focusing on training and career incentives for recently matriculated students and fellows and are upskilling researchers for better use of high-end computing facilities. Many agencies offer training and career advancement opportunities such as: NASA's STEM engagement that has a Fellowship Activity for underrepresented and underserved minorities; the DOE Computational Science Graduate Fellowship, established in 1991, a collaboration between DOE/SC and DOE/NNSA, which provides opportunities to students pursuing doctoral degrees in fields that use high-performance computing to solve complex science and engineering problems; DOE/SC's computational user facilities offer extensive training programs on new and emerging technologies and on the new exascale supercomputing systems; USGS training opportunities for researchers of all skill levels, from introductory Software Carpentry and HPC 101 workshops; and DOE/NNSA ASC's AI for Nuclear Deterrence program provides upskilling and multi-disciplinary teaming opportunities to existing and new laboratory staff. Existing programs have been greatly successful but given that the technology landscape is rapidly evolving due to multiple computing paradigms and rapidly changing software and AI domain, these efforts need to be sustained and updated to ensure the success of this strategy.

Highlighted Examples 4.2
• The DOE Computational Sciences Graduate Fellowship (CSGF) Program is a nationally recognized program that has supported doctoral students in their pursuit of novel scientific and engineering discoveries using high-performance computing (HPC) resources since 1991. The DOE CSGF is also a primary workforce development program for HPC – for DOE and the Nation. The DOE CSGF provides tuition and an annual stipend, and requires students to pursue an approved program of study that combines a scientific or engineering discipline with computer science and applied mathematics. The program also requires students to complete a 12-week practicum at one of the DOE national laboratories. The DOE CSGF has provided 565 fellowships since 1991, which includes 107 current fellows. Recipients have been increasingly diverse over time with regard to gender and the specific fields of study in which they pursued a degree. The Mathematics/Computer Science Track recipients of CSGF pursue doctoral degrees in applied mathematics, statistics, computer science, computer engineering or computational science — or their academic equivalent — with research interests that help use emerging high-performance systems more effectively. This track allows students to focus on issues in high-performance computing as a broadly applicable technology and not on a particular science or engineering application. • The NSF CSGrad4US Fellowships program, launched in 2021, supports graduate study leading to research-based doctoral degrees in Computer Science disciplines and is another nationally-recognized program that supports students in the computing fields at an accredited, non-profit institution of higher education having a campus located in the United States, its territories or possessions, or the Commonwealth of Puerto Rico. The 3-year fellowship program supports and mentors recipients of the fellowships by creating a funding opportunity to pursue a PhD in the computing disciplines and provides an opportunity for bachelor's degree holders to return to academia and pursue research-based doctoral degrees. Since its launch in 2021, a total of 169 individuals have been selected for the CSGrad4US Fellowship program in three application cycles. Of those, 70 recently began the CSGrad4US Mentoring Program portion, during which they are paired with a coach and work through a series of mentoring sessions and activities. There are currently 68 CSGrad4US Fellows who have already begun their PhD programs.

Provide the necessary incentives, career paths, reward structures, and foster on-the-job training for retaining computing professionals, technologists, and practitioners.

Federal agencies have targeted leadership development programs and summer fellow internships to support and retain talented leaders in FACE activities. For instance, NASA has a variety of programs for career development such as Leadership Development Program, Foundations of Influence, Relationship, Success, and Teamwork, etc. that are also critical for succession planning; DOD has an expanded workforce development strategy and the ability to host faculty from HBCU/MIs at DOD sites as summer appointments and has a Digital Talent Management Forum which is a department-wide effort to address the challenges in recruiting, developing, and retaining the digital workforce. USGS offers workshops and new courses designed to highlight the latest tools and technologies, reflect upgrades to on-prem high performance computing systems, and meet the ever-evolving needs of researchers across the Bureau. NIST has a vibrant postdoctoral program, a Summer Undergraduate Research Fellowship program and a Summer High School Intern Program that provide a broad set of research opportunities to interested candidates. Many agencies have specific programs for junior researchers such as the DARPA's Young Faculty Award (YFA) program and the early career programs at DOE and NSF. The Strengthening the Cyberinfrastructure Professionals Ecosystem program at NSF was specifically created to support deeper integration of cyberinfrastructure professionals' services into research, while fostering education, training and recognition that address CI workforce development needs. Retaining computing professionals at agencies and universities has been a well-documented challenge, especially due to strict competition from the private sector, and sustained efforts will be needed to maintain the desired FACE workforce. The NSF-funded career center for Research Computing and Data Computing Professionals (RCD-Nexus) has been one such dedicated effort in creating career resources for the computing professionals and more investments across the agencies will be needed in the future for a broad impact. The ability to attract talent who can effectively support the needs of the FACE initiative in this highly competitive labor market will be a continuous challenge and will require additional investments.

Highlighted Examples 4.3
• Through its Young Faculty Award program, DARPA has provided funding opportunities since 2006 as a forward-looking way to familiarize rising researchers in junior positions with national-security-relevant work within the DOD. • Research Computing and Data Resource and Career Center or RCD-Nexus is an NSF-funded Cyberinfrastructure Center of Excellence pilot that was funded to develop a Research Computing and Data Resource and Career Center that provides institutions and individuals with the products, tools, services, and community to build and sustain successful RCD operations. A key component of this effort is to help expand the development of new RCD professionals and to support them throughout their careers. Since its inception in May 2021, the center has conducted research in developing career-arc narratives for CI professionals, focusing on women researchers, developed a RCD capabilities model that is increasingly being adopted by academic institutions including minority serving institutions, have setup interest groups that focus on topics such as RCD staff workforce development and student workforce development, and have developed a HR Job Family Matrix that is being adopted by RCD hiring managers across the country.

Build synergies across government, academic, nonprofit, and industry stakeholders focused on workforce development and training.

The workforce development efforts across all sectors need to be coordinated to foster a workforce that can better anticipate and exploit emerging computing technologies. To that effect, agencies are partnering with stakeholders to develop training and opportunities to enable a FACE-savvy workforce. For instance, DHS/S&T has partnered with Oak Ridge Institute for Science and Education (ORISE) and the American Association for the Advancement of Science to offer fellowships for new Ph.D.'s and professionals to hone their skills against real mission problems through S&T training offerings. NSF and DOE have a joint fellowship program called Better Scientific Software (BSSw) Fellowship to foster and promote practices, processes, and tools to improve developer productivity and software sustainability of scientific codes.

Highlighted Examples 4.4
• The Better Scientific Software (BSSw) Fellowship, supported by NSF and DOE, fosters and promotes practices, processes, and tools to improve developer productivity and software sustainability of scientific applications and libraries. Best practices for scientific software development are developed by discussions involving industry, academic, and government experts. Best practices broadly adopted by industry are adapted and augmented for

scientific and engineering applications. Quantitative analysis of development approaches is undertaken by efforts such as the DOE-supported Interoperable Design of Extreme-scale Application Software (IDEAS) project. The program has been resoundingly successful since its inception and has supported 16 fellows and 16 honorable mentions between 2021 and 2023, from academia, DOE laboratories, and non-profits, and continues to support the growing community of BSSw Fellowship alums who can serve as leaders, mentors, and consultants to increase the visibility of those involved in scientific software production and sustainability in the pursuit of scientific discovery.

- The Data and Technology Advancement (DATA) National Service Scholar Program was started by NIH in 2020 to supports data scientists working on biomedical research and allows them to recruit experts from academia and industry to engage in high-impact NIH projects. The program has supported 21 scholars since its inception in 2020 and brought in experts in data and computer sciences and related fields to work for 1-2 years on problems that involve massive sized biomedical data sets to improve human-health and well-being.
- The Data Science Corps (DSC)—a component of NSF's Harnessing the Data Revolution (HDR) ecosystem— was created to support education and workforce development by focusing on building capacity for harnessing the data revolution at the local, state, and national levels to help unleash the power of data in the service of science and society. With a mission to help build a strong, national data science infrastructure and workforce, DSC engaged data science students and professionals in real-world data science implementation projects. In 2020, 10 DSC awards were made, totaling up to $15 million over a period of 3 years to support undergraduate and graduate students at colleges, universities, and Minority Serving Institutions across many states to bring together students of multiple disciplines, such as computer science, mathematics, statistics, and other sciences. NSF also focuses on creating innovation ecosystems in all regions around the nation via programs like the NSF Engines and Convergence Accelerator. The innovation ecosystem represented by startup industries is also an important community served by NSF. In both cases, there is a need for access to high performance computing systems, data infrastructure, and AI computing infrastructure along with a well-trained workforce. NSF is planning engagements with these communities to obtain a better understanding of their needs and demands with respect to training for future advanced computing ecosystems.

Foster relevant, mission-focused, on-the-job training in the form of fellowships, academic programs, internships, and sabbaticals, in both intramural and extramural agency programs, federally funded R&D centers, and National Laboratories.

To better engage the future workforce and to prepare them for successful careers in the computing field, it is important that agencies establish on-the-job training programs, in the form of fellowships, academic programs, internships, and sabbaticals in both intramural and extramural agency programs, federally funded R&D centers, and National Laboratories. With rapid advancements in the computing technology landscape, it is critical that current employees are given opportunities to supplement their background knowledge with real-world practice. Several federal agencies have programs at different levels to support this, including those listed in the previous section, such as the fellowship opportunities at DHS/S&T. Additionally, federal agencies are meeting workforce challenges by sponsoring industry experts and academic faculty to serve at agencies in temporary appointments through the Intergovernmental Personnel Act assignments. Agencies are also making investments in programs that develop educational curricula and other materials used for education and training activities, inclusive of all levels and institution types, such as the previously mentioned NSF CyberTraining, and DOE/NNSA MSIPP and TEPP programs. Agencies have also invested in undergraduate, graduate, and post-graduate cross-disciplinary research training programs, such as NIST's programs offered by the Division of Training, Workforce Development, and Diversity and DOD's ORISE Research Participation Program. Many agencies such as DOE/SC, DOE/NNSA, NASA, NIH, NIST and NSF, organize events such as hackathons around computing and data science topics to provide hands-on experience to their workforce in these areas. For instance, DOE/NNSA's Lawrence Livermore National Laboratory has organized computing hackathons that have allowed employees to develop new skills and explore ideas outside their day-to-day work.

Highlighted Examples 4.5

The ORISE Research Participation Programs at DOD are educational and training programs designed to provide college students, recent graduates, and university faculty opportunities to participate in project-specific DOD research and development activities. Participants in the program can be students who are enrolled in an accredited U.S. college or university pursuing a degree in science, technology, engineering, or mathematics, postgraduates and post-doctorates who have received their degree in an appropriate STEM discipline within 5 years of the appointment start date, or full-time faculty from an accredited U.S. college or university. Every participant at DOD has a guest appointment at a DOD-designated facility and is expected to devote time and effort in pursuing the activities of the research program, publishing research results, participating and presenting at appropriate scientific conferences and meetings, and participating in technical activities at the DOD facility. Different DOD facilities often collaborate with other federal agencies through this program. For instance, the program at the U.S. Army Aeromedical Research Laboratory is managed by an interagency agreement between the U.S. Army Medical Research and Development Command and DOE. Similarly, DOD HPCMP sponsors two summer research opportunities through ORISE: the High-Performance Computing Internship Program and the Faculty Immersion Experience. These 10-week experiences are offered in collaboration with more than a dozen DOD hosting organizations nationwide. Both programs seek to strengthen DOD and academic collaboration, enhance research capabilities, and encourage broader university-level participation in high-end computing.

- NASA has been organizing yearly code hackathons since 2020, in collaboration with DOE labs and industrial partners (OpenACC), to prepare workforce for effectively accessing the emerging compute technologies and resources, in particular the General Purpose Graphical Processing Units, and to improve fidelity and cycles of science and engineering development. The goal is to facilitate a rapid, collaborative learning environment while accelerating critical codes of direct relevance to either traditional high-performance computing (HPC) centric applications or AI/ML technologies. The hackathon has been run as virtual events, including multi-day intensive coding activities that partner applications teams with experts in programming and code performance. This allows the teams to gain hands-on experience porting and optimizing their codes with necessary tools and technologies for emerging compute systems. The hackathon paves a way for continued integration of new technologies into the full projects.
- NIST offers opportunities for students to become involved in research across a broad number of areas of science and engineering through programs such as the NIST Summer Undergraduate Research Fellowship and Summer High School Internship. These programs offer students an opportunity to work with NIST staff on projects that expose them to the kind of skills they need to be successful as they advance in their careers.

Recent Funding

To quantify the growth of FACE efforts within the federal agencies, this report references two NITRD Program Component Areas (PCAs): Enabling R&D for High-Capability Computing Systems (EHCS) and High-Capability Computing Infrastructure and Applications (HCIA). PCAs are the primary mechanism in which federal agencies report their networking and information technology research and development efforts on a yearly basis. The EHCS PCA focuses on advancing and translating new approaches in high-capability computing, including R&D in novel computing paradigms, hardware architectures, algorithms, software, data analytics, system performance, reliability, trust, transparency, energy efficiency, and other methods that enable extreme data- and compute-intensive workloads. The HCIA PCA focuses on providing the operation, integration, and utilization of high-capability computing systems and infrastructure supporting computation-intensive and data-intensive application workflows, including software and services, communications, storage, and data infrastructure, coordination services, and other necessary resources for the effective use of high-capability computing.

While FACE efforts span many of the PCAs in which federal agencies report[3], the EHCS and the HCIA PCAs are most closely aligned with the FACE efforts and are a good indication of the growth of efforts undertaken in this area. Table A below shows the dollars (in millions) that the relevant agencies reported for FY21-FY23. While the funding per agency fluctuated from year to year, both the EHCS and HCIA PCAs totals increased by over 20% from FY21 to FY23, which shows the growth and commitment by the federal agencies in this important area.

Table A. EHCS and HCIA Actuals/Enacted from NITRD Supplements ($M)

AGENCY	FISCAL YEAR	EHCS	HCIA	TOTALS
DARPA	FY21 Actual	5.1	0.0	5.1
	FY22 Actual	5.1	0.0	5.1
	FY23 Enacted	5.1	0.0	5.1
DOD	FY21 Actual	51.0	268.2	319.2
	FY22 Actual	49.5	189.2	238.7
	FY23 Enacted	33.6	256.5	290.1
DOE	FY21 Actual	112.1	645.4	757.5
	FY22 Actual	158.8	678.9	837.7
	FY23 Enacted	152.0	780.9	932.9
DOE/NNSA	FY21 Actual	6.0	0.0	6.0
	FY22 Actual	24.0	0.0	24.0
	FY23 Enacted	16.0	0.0	16.0
DOI	FY21 Actual	0.0	0.0	0.0
	FY22 Actual	0.0	2.1	2.1
	FY23 Enacted	0.0	5.8	5.8
EPA	FY21 Actual	3.5	3.0	6.5
	FY22 Actual	3.3	3.5	6.8
	FY23 Enacted	3.3	3.5	6.8
NASA	FY21 Actual	2.5	61.8	64.3
	FY22 Actual	3.0	76.6	79.6
	FY23 Enacted	3.1	69.9	73.0
NIH	FY21 Actual	76.3	331.0	407.3
	FY22 Actual	142.2	414.5	556.7

[3] https://www.nitrd.gov/program-component-areas/nitrd-pcas-2023/

AGENCY	FISCAL YEAR	EHCS	HCIA	TOTALS
	FY23 Enacted	156.5	477.6	634.1
NIST	FY21 Actual	9.3	9.6	18.9
	FY22 Actual	9.1	9.7	18.8
	FY23 Enacted	8.9	10.0	18.9
NOAA	FY21 Actual	0.0	65.5	65.5
	FY22 Actual	0.0	70.5	70.5
	FY23 Enacted	0.0	93.4	93.4
NSF	FY21 Actual	179.2	191.5	370.7
	FY22 Actual	180.0	209.6	389.6
	FY23 Enacted	165.8	209.4	375.2
Totals	FY21 Actual	445.0	1,576.0	2,021.0
	FY22 Actual	575.0	1,654.6	2,229.6
	FY23 Enacted	544.2	1,907.0	2,451.2

Table A Notes:

- PCA number are from the NITRD Supplement to the President's Budget[4, 5, 6, 7]
- Amounts are in U.S. dollars in millions.
- Totals might not sum exactly as a result of rounding.
- DARPA is a DOD research organization, but it reports its budgets separately from the DOD Services research organizations and the Office of the Secretary of Defense (OSD).
- The DOE/NNSA Budget is listed separately from that of other DOE offices.

Conclusion

The federal government has made strategic investments and developed key partnerships with industry and academia to realize the FACE objectives, resulting in significant progress towards creating a robust FACE strategic national asset. The US benefits significantly from the current FACE assets, enhancing advancements in science and engineering, bolstering economic competitiveness, and strengthening national security. Nonetheless, continued support is vital to ensure that this strategic national asset can keep pace with the rapidly evolving computing technology landscape and support the growing national demands for advanced computing.

[4] https://www.nitrd.gov/pubs/FY2021-NITRD-Supplement.pdf
[5] https://www.nitrd.gov/pubs/FY2022-NITRD-NAIIO-Supplement.pdf
[6] https://www.nitrd.gov/pubs/FY2023-NITRD-NAIIO-Supplement.pdf
[7] https://www.nitrd.gov/pubs/FY2024-NITRD-NAIIO-Supplement.pdf

Table 1. Supporting Data for Objective 1: Advanced Computing Ecosystem as a Strategic National Asset[8]

SUBMITTING AGENCY	PROGRAM OR ACTIVITY	LINK
FEDERATE A SPECTRUM OF CAPABILITIES AND CAPACITIES		
DOD	High Performance Computing Modernization Program (HPCMP)	https://www.hpc.mil/
DOE/NNSA	Advanced Simulation and Computing (ASC)	https://www.sandia.gov/asc/
DOE/SC	Integrated Research Infrastructure (IRI)	https://www.osti.gov/biblio/1984466
USGS/SSAR	Science Synthesis Analysis and Research Program	https://www.usgs.gov/programs/science-analytics-and-synthesis-sas
NASA	High End Computing (HEC) Program	https://hec.nasa.gov
NIH	Cloud Interoperability Initiative	https://datascience.nih.gov/nih-cloud-platform-interoperability-effort
NIH	Common Fund Data ecosystem	https://commonfund.nih.gov/dataecosystem
NSA	Project 38	https://crd.lbl.gov/divisions/amcr/computer-science-amcr/cag/research/project-38/
NSF	Advanced Computing Systems and Services Program	https://new.nsf.gov/funding/opportunities/advanced-computing-systems-services-adapting-rapid
NSF	Leadership-Class Computing Facility	https://www.nsf.gov/awardsearch/showAward?AWD_ID=2139536&HistoricalAwards=false
ADDRESS THE NEEDS OF EMERGING APPLICATION WORKFLOWS		
DOD	Defense Innovation Unit prototype interface development to access DOD HPCMP assets and cloud assets	https://www.diu.mil/solutions/portfolio/catalog
DOD	Galaxy workflow manager development	https://www.stellarscience.com/project/galaxy/
DOD	Modern container technologies such as Docker, Kubernetes on HPC platforms	
DHS	DHS S&T Data Analytics Technology Center, including evaluation of the value of emerging infrastructure and analytic capabilities	https://www.dhs.gov/science-and-technology/DA-TC
USGS/SSAR, ACIO	Variety of heterogenous scientific workflows across in-house HPC and commercial cloud computing platforms	
NASA	High End Computing (HEC) Program	https://hec.nasa.gov
NIST	Workshops on security for HPC systems	https://nvlpubs.nist.gov/nistpubs/ir/2023/NIST.IR.8476.pdf
NNSA/ASC	Evaluation of AI/ML technologies and hardware to its stockpile stewardship application needs	https://www.sandia.gov/asc/
PROMOTE/SUPPORT THE AVAILABILITY, INTEGRITY, AND SECURITY OF CRITICAL ADVANCED COMPUTING COMPONENTS		
DOD	US-Australia project Agreement for scientific computing technologies	https://www.whitehouse.gov/briefing-room/statements-releases/2023/10/25/fact-sheet-delivering-on-the-next-generation-of-innovation-and-partnership-with-australia/
NASA	High End Computing (HEC) Program	https://hec.nasa.gov
NIST	CHIPS R&D Program	https://www.nist.gov/chips/research-development-programs

[8] This list is not a comprehensive listing of federal efforts but showcases select highlights.

NIST	Development of community standards, guidance, and practices for cybersecurity across most of the Federal government	https://www.nist.gov/cybersecurity
NNSA	Advanced Simulation & Computing (ASC) program for R&D partnership with industry on advanced memory, next generation architecture and HPC network technologies	https://www.sandia.gov/asc/
ACCELERATE ACCESS TO INNOVATIVE COMPUTING PARADIGMS, TECHNOLOGIES, AND CAPABILITIES		
DOD	Collaborated with industry to develop low power AI Inference processor	
DOE/SC	DOE HPC user facilities: National Energy Research Scientific Computing Center (NERSC), Leadership Computing Facilities (LCFs) at Oak Ridge National Laboratory (ORNL), and Argonne National Laboratory (ANL)	https://www.nersc.gov/; https://science.osti.gov/ascr/Facilities/User-Facilities/OLCF# https://www.olcf.ornl.gov/frontier/; https://www.anl.gov/; https://www.anl.gov/aurora
DOE/SC	ESnet	https://www.es.net/
DOE/SC	Innovative and Novel Computational Impact on Theory and Experiment (INCITE) Program	https://science.osti.gov/ascr/Facilities/Accessing-ASCR-Facilities/INCITE/About-incite
USGS/SSAR	Science data management activities and services, including Community for Data Integration	https://www.usgs.gov/programs/science-synthesis-analysis-and-research-program; https://www.usgs.gov/centers/community-for-data-integration-cdi
NASA	Quantum Artificial Intelligence Laboratory	https://www.nasa.gov/intelligent-systems-division/discovery-and-systems-health/nasa-quail/
NNSA	Advanced Simulation & Computing (ASC) program	https://www.sandia.gov/asc/
LEVERAGE CROSSCUTTING SYNERGIES AND EFFICIENCIES		
DOD	Participation in the DoE/ECP Industry and Agency Council	https://www.exascaleproject.org/industry-and-agency-council/
DOD	US-Australia project Agreement for scientific computing technologies	https://www.whitehouse.gov/briefing-room/statements-releases/2023/10/25/fact-sheet-delivering-on-the-next-generation-of-innovation-and-partnership-with-australia/
NASA	High End Computing (HEC) Program	https://hec.nasa.gov

Table 2. Supporting Data for Objective 2: Robust, Sustainable Software and Data Ecosystem[9]

SUBMITTING AGENCY	PROGRAM OR ACTIVITY	LINK
ENSURE A ROBUST AND SUSTAINABLE SOFTWARE ECOSYSTEM		
DHS/S&T	Develops computing and data analytic solutions for DHS	https://www.dhs.gov/sites/default/files/2023-06/privacy-pia-dhsall055a-dat-june2023.pdf
DOE/SC	Investments in software sustainability, building on the successes of ECP	https://science.osti.gov/-/media/ascr/ascac/pdf/meetings/202004/Transition_Report_202004-ASCAC.pdf
DOE/SC, NNSA	The Exascale Computing Project (ECP)	https://www.exascaleproject.org/
DOE/SC, NNSA	Extreme-scale Scientific Software Stack (E4S)	https://e4s-project.github.io/
DOD	Increased funding of Computational Research and Engineering Acquisition Tools and Environments (CREATE) software tools	https://centers.hpc.mil/CREATE/index.html
NASA	Develops and maintains several critical software systems and packages to enable the various NASA missions	
NIH	Supports enhancement of biomedical and behavioral software tools for sustainable open science	https://datascience.nih.gov/tools-and-analytics/administrative-supplements-to-support-enhancement-of-software-tools-for-open-science
NIST	Contributed to Executive Order 14028 that recommended minimum standards for software testing (NIST IR 8397).	https://nvlpubs.nist.gov/nistpubs/ir/2021/NIST.IR.8397.pdf
SUPPORT NEEDS FOR NOVEL SOFTWARE DEVELOPMENT		
DOD	Increased funding to support three-year Institutes dedicated to novel software development	https://hpc.mil/calls/call-for-fy23-dod-hpcmp-institute-proposals
DOE/SC	Extreme-scale Software Stack (X-Stack): Programming Environments for Scientific Computing	https://www.energy.gov/science/articles/doe-provide-12-million-research-adapting-scientific-software-run-next-generation
NASA	Develops new software as needed to support the evolving agency needs, particularly in the areas of data analytics, machine learning, and knowledge discovery	
NIH, NSF	Smart and Connected Health in Artificial Intelligence and Advanced Data Science	https://datascience.nih.gov/sch
NNSA	ASC continues to invest in some key next-generation software packages after ECP concludes	
ENSURE A ROBUST DATA ECOSYSTEM		
DOD	HPCMP collaborative data like ecosystem	https://www.hpc.mil/
DOE/SC	Public Reusable Research (PuRe) Data initiative	https://science.osti.gov/Initiatives/PuRe-Data
USGS/SSAR	Science data management activities and services, including training and collaboration opportunities through the Community for Data Integration (CDI)	https://www.usgs.gov/centers/community-for-data-integration-cdi
NASA	Significant efforts in distributed collaborative systems to enable swarms of UAVs, constellations of satellites, etc.	https://www.nasa.gov/isd-collaborative-and-assistant-systems

[9] This list is not a comprehensive listing of federal efforts but showcases select highlights.

NIH	Science and Technology Research Infrastructure for Discovery, Experimentation, and Sustainability (STRIDES) Initiative	https://datascience.nih.gov/strides; https://www.nih.gov/news-events/news-releases/nih-makes-strides-accelerate-discoveries-cloud; https://www.nih.gov/news-events/news-releases/nih-expands-biomedical-research-cloud-microsoft-azure
NIST	Office of Data & Informatics	https://www.nist.gov/data-informatics
DEVELOP, DEPLOY, OPERATE, AND PROMOTE TRUSTED SERVICES AND CAPABILITIES		
DOD/HPCMP	Cybersecurity HPC services; Serve as DOD Cybersecurity Service Provider	
DOE/SC	CITADEL security framework	https://www.olcf.ornl.gov/2021/05/05/nccs-introduces-citadel-security-framework; https://www.olcf.ornl.gov/2022/12/01/secure-science-with-citadel/; https://www.olcf.ornl.gov/2023/02/10/autocoding-cancer/
NASA	High End Computing (HEC) Program	https://hec.nasa.gov
NIH	Research Auth Services	https://datascience.nih.gov/data-infrastructure/researcher-auth-service
NSF	Cybersecurity Center of Excellence, Trusted CI	https://www.trustedci.org/; https://zenodo.org/records/10257813
EXPLORE INNOVATIVE MODELS FOR PPP		
NIH	Science and Technology Research Infrastructure for Discovery, Experimentation, and Sustainability (STRIDES) Initiative	https://datascience.nih.gov/strides
NNSA	Advanced Simulation & Computing (ASC) program, including work with software vendors to provide continued support for some mission-critical compiler packages	https://www.sandia.gov/asc/

Table 3. Supporting Data for Objective 3: Foundational, Applied, and Translational R&D[10]

SUBMITTING AGENCY	PROGRAM OR ACTIVITY	LINK
ENSURE HARDWARE LEADERSHIP		
DOE/SC	Quantum Information Science (QIS) initiative	https://science.osti.gov/Initiatives/QIS
DOE/SC	Microelectronics initiative	https://science.osti.gov/Initiatives/Microelectronics
NASA	Investments in disruptive technologies such as quantum	https://www.nasa.gov/content/nasa-quantum-artificial-intelligence-laboratory-quail
NASA	Workshops on quantum sensing	https://www.nasa.gov/general/nasa-quantum-sensing-workshop/
NIST	Research portfolio in quantum information science	https://www.nist.gov/quantum-information-science; https://jila.colorado.edu/; https://jqi.umd.edu/; https://quics.umd.edu/
NIST	Exploration of neuromorphic components and architectures	https://www.nist.gov/programs-projects/neuromorphic-computing
NSF	Cybersecurity Center of Excellence, Trusted CI	https://www.trustedci.org/
ADVANCE SOFTWARE AND SOFTWARE-HARDWARE RESEARCH		
DOD	Software development initiatives in CREATE and in Institutes	https://centers.hpc.mil/CREATE/index.html
DOE/SC	Scientific Discovery Through Advanced Computing (SciDAC) program	https://scidac.gov/
NIST	Research on software abstractions based on Data Flow Graphs	https://github.com/usnistgov/hedgehog
ADDRESS CHALLENGES AND OPPORTUNITIES RELATED TO GROWING DATA VOLUMES AND SUCCESSFUL TRANSLATION OF DATA INTO INSIGHTS		
DHS/S&T	Data Analytics Technology Center, addressing challenges in big data	https://www.dhs.gov/science-and-technology/DA-TC
DOD	CREATE Program	https://centers.hpc.mil/CREATE/index.html
DOE/SC	Investments in the management and storage of scientific data for innovative approaches to large-scale data analytics	https://science.osti.gov/ascr/Research/Computer-Science
NASA	Open-Source Science Initiative	https://science.nasa.gov/researchers/open-science/
NIH	All of Us Program	https://allofus.nih.gov/about/program-goals
USGS/SSAR	Investment in a robust hybrid data storage ecosystem	
ENHANCE AI CAPABILITIES		
DHS/S&T	AI research, supported by S&T AI and ML Strategic Plan and forthcoming implementation plan	https://www.dhs.gov/sites/default/files/publications/21_0730_st_ai_ml_strategic_plan_2021.pdf
DOE/SC	Artificial Intelligence for Science initiative	https://science.osti.gov/Initiatives/AI
USGS/SSAR	Developing and testing numerous approaches to AM/ML based scientific research, AI supporting architectures, and data management tools	
USGS/SSAR, ACIO	USGS Tallgrass supercomputer	https://www.usgs.gov/advanced-research-computing/usgs-supercomputers-research
NIH	Bridge2AI	https://commonfund.nih.gov/bridge2ai
NIH	AIM-AHEAD	https://datascience.nih.gov/artificial-intelligence/aim-ahead

[10] This list is not a comprehensive listing of federal efforts but showcases select highlights.

NIST	AI Risk Management Framework	https://www.nist.gov/itl/ai-risk-management-framework
NIST	Trustworthy & Responsible AI Resource Center	https://airc.nist.gov/Home
EXPAND AVAILABILITY OF AND ACCESS TO TESTBEDS, PROTOTYPING, AND RESEARCH INFRASTRUCTURE		
NIST	DC-QNet	https://www.nist.gov/news-events/news/2022/06/dc-area-us-government-agencies-announce-washington-metropolitan-quantum
NSF	Collaborative relationship with DOE under DOE'S ESNet	https://www.es.net/
NSF	Dear Colleague Letter: Enabling Quantum Computing Platform Access for NSF Researchers	https://www.nsf.gov/pubs/2022/nsf22092/nsf22092.jsp
ADDRESS THE NEED FOR TECHNOLOGIES THAT ENSURE HARDWARE SUPPLY CHAIN SECURITY		
DARPA	Electronics Resurgence Initiative 2.0	https://www.darpa.mil/work-with-us/electronics-resurgence-initiative
DARPA	Next-Generation Microelectronics Manufacturing (NGMM) program	https://www.darpa.mil/news-updates/2023-07-20
NIST	Joint Task Force	https://csrc.nist.gov/Projects/risk-management/fisma-background#ftn1
NIST	Cybersecurity Supply Chain Risk Management (C-SCRM) program	https://csrc.nist.gov/Projects/cyber-supply-chain-risk-management

Table 4. Supporting Data for Objective 4: Fostering a Diverse, Capable, and Flexible Workforce[11]

SUBMITTING AGENCY	PROGRAM OR ACTIVITY	LINK
CREATE THE DIVERSE WORKFORCE NECESSARY		
DOD	Expanded the diverse workforce recruitment and retaining strategies	https://orise.orau.gov/hpcmp/index.html
DOE/SC	Reaching a New Energy Sciences Workforce (RENEW) initiative	https://science.osti.gov/Initiatives/RENEW
DOE/SC	Funding for Accelerated, Inclusive Research initiative	https://science.osti.gov/Initiatives/FAIR
DOE/SC, NNSA	Computational Science Graduate Fellowship	https://www.krellinst.org/csgf/
NASA	Diversity, Equity, Inclusion, and Accessibility (DEIA) Program	https://www.nasa.gov/wp-content/uploads/2018/08/2022_administrator_policy_statement_on_deia_at_nasa_tagged.pdf?emrc=60aa9d
NIH	Data and Technology Advancement National Service Scholar Program	https://datascience.nih.gov/data-scholars-2023
NNSA	Predictive Science Academic Alliance program	https://www.nnsa-ap.us/Programs/Predictive-Science-Academic-Alliance-Program
NIST	NICE program	https://www.nist.gov/itl/applied-cybersecurity/nice
NIST	Effort to diversify its technical workforce and to extend opportunities to students and underrepresented groups	https://www.nist.gov/careers/student-opportunities
NSA	Future Computing Summer Internship Program	https://www.lps.umd.edu/2024-future-computing-summer-internship/
USGS	Pathways Internship, Recent Graduate, and Presidential Management Fellowship Programs	https://www.usgs.gov/human-capital/pathways-internship-program; https://www.usgs.gov/human-capital/pathways-recent-graduates-program; https://www.usgs.gov/media/files/presidential-management-fellow-pmf-program-fact-sheet
DEVELOP TRAINING, UPSKILLING, AND RESKILLING STRATEGIES		
DOE	Computational Science Graduate Fellowship	https://www.krellinst.org/csgf/
DOE/SC	Computational User Facilities	https://science.osti.gov/ascr/Facilities/User-Facilities
USGS	Variety of training opportunities for researchers of all skill levels	
NASA	Training and career advancement opportunities as well as numerous incentives to retain and recruit the appropriate workforce	https://www.nasa.gov/learning-resources/internship-programs/nasa-fellowships/
NIH	Informatics Technology for Cancer Research Education Resource	https://grants.nih.gov/grants/guide/rfa-files/RFA-CA-19-042.html
NNSA	ASC's AI for Nuclear Deterrence program	
PROVIDE THE NECESSARY INCENTIVES, CAREER PATHS, AND REWARD STRUCTURES		
DOD	Expanded the workforce development strategy to double the number of interns recruited, with emphasis on HBCU and MI partners	
NASA	A variety of programs for career development	https://www.nasa.gov/careers/
NASA	Leadership Development Program	
NASA	Foundations of Influence, Relationship, Success, and Teamwork	

[11] This list is not a comprehensive listing of federal efforts but showcases select highlights.

NIST	Various avenues available to assist professional staff interested in developing new skills	https://www.nist.gov/iaao/academic-affairs-office/postdoctoral-students-nrc-postdocs; https://www.nist.gov/iaao/academic-affairs-office/professional-research-experience-program
NSF	Research Computing and Data Computing Professionals (RCD-Nexus)	https://rcd-nexus.org/
BUILD SYNERGIES ACROSS GOVERNMENT, ACADEMIC, NONPROFIT, AND INDUSTRY STAKEHOLDERS		
NIH	Open Data Science Gateway for the DS-I Africa consortium	https://elwazi.org/
USGS/SSAR	Development of a new joint Computational Center for Earth Sciences	
FOSTER RELEVANT, MISSION-FOCUSED, ON-THE-JOB TRAINING		
DARPA	Young Faculty Award (YFA) program	https://www.darpa.mil/work-with-us/for-universities/young-faculty-award
DHS/S&T	University Centers of Excellence	https://www.dhs.gov/science-and-technology/centers-excellence-rd
DHS/S&T	American Advancement for the Association of Science fellowship	https://www.nist.gov/iaao/academic-affairs-office/postdoctoral-students-nrc-postdocs
NSF, DOE	Better Scientific Software Fellowship (BSSW)	https://bssw.io/pages/bssw-fellowship-program
NIST	Postdoctoral program	
NIST	Summer Undergraduate Research Fellowship program	https://www.nist.gov/surf
NIST	Summer High School Intern Program	https://www.nist.gov/iaao/academic-affairs-office/high-school-students-ship
USGS/SSAR	Workshops, including workshop on Introduction to Deep Learning	

List of Acronyms and Abbreviations

Acronym	Definition
3DHI	Three-Dimensional Heterogeneously Integrated
ACCESS	Advanced Cyberinfrastructure Coordination Ecosystem
ACIO	Associate Chief Information Officer
AI	Artificial Intelligence
ALCF	Argonne Leadership Computing Facility
ANL	Argonne National Laboratory
ARL	Army Research Laboratory
ASC	Advanced Computing and Simulation
BSSw	Better Science Software
CEDAR	Cybersecurity Environment for Detection, Analysis, and Reporting
CHIPS	Creating Helpful Incentives to Produce Semiconductors
CI	Cyberinfrastructure
CIO	Chief Information Officer
CISE	Computer and information Science and Engineering
C-SCRM	Cybersecurity Supply Chain Risk Management
CREATE	Computational Research and Engineering Acquisition Tools and Environments
CSGF	Computational Sciences Graduate Fellowship
CSSI	Cyberinfrastructure for Sustained Scientific Impact
DAOS	Distributed Asynchronous Object Storage
DATA	Data and Technology Advancement
DCO	Defensive Cyberspace Operations
DC-QNet	Washington Metropolitan Quantum Network Research Consortium
DEIA	Diversity, Equity, Inclusion, and Accessibility
DHS	Department of Homeland Security
DNA	Deoxyribonucleic acid
DOC	Department of Commerce
DOD	Department of Defense

Acronym	Definition
DOE	Department of Energy
DOI	Department of the Interior
DSC	Data Science Corps
E4S	Extreme-Scale Scientific Software Stack
ECP	Exascale Computing Project
ECP-IAC	Exascale Computing Project-Industry and Agency Council
EHCS	Enabling R&D for High-Capability Computing Systems
EPA	Environmental Protection Agency
ERI	Electronics Resurgence Initiative
ESNet	Energy Sciences Network
FACE	Future Advanced Computing Ecosystem
FIT	Failures in Time
FY	Fiscal Year
GPU	Graphics Processing Unit
HBCU/MIs	Historically Black Colleges and Universities/Minority Institutions
HBCUs	Historically Black Colleges and Universities
HCC	High-Capability Computing
HCIA	High-Capability Computing Infrastructure and Applications
HDR	Harnessing the Data Revolution
HEC IWG	High End Computing Interagency Working Group
HPC	High Performance Computing
HPCC	High Performance Computing and Communications
HPCMP	High Performance Computing Modernization Program
HR	Human Resource
HSIs	Hispanic Serving Institutions
IDEAS	Interoperable Design of Extreme-scale Application Software
INCITE	Innovative and Novel Computational Impact on Theory and Experiment
IRI	Integrated Research Infrastructure

Acronym	Definition
ISS	International Space Station
IT	Information Technologies
IWG	Interagency Working Group
LCCF	Leadership-Class Computing Facility
LCFs	Leadership Computing Facilities
MS-CC	Minority Serving-Cyberinfrastructure Consortium
MSIPP	Minority Serving Institution Partnership Program
MSIs	Minority Serving Institutions
NAIRR	National AI Research Resource
NASA	National Aeronautics and Space Administration
NCO	National Coordination Office
NERSC	National Energy Research Scientific Computing Center
NextG	Next Generation
NGMM	Next-Generation Microelectronics Manufacturing
NICE	National Initiative for Cybersecurity Education
NIH	National Institutes of Health
NIJ	National Institute of Justice
NIST	National Institute of Standards and Technology
NITRD	Networking and Information Technology Research and Development
NIWC-P	Naval Information Warfare Center Pacific
NNSA	National Nuclear Security Administration
NOAA	National Oceanic and Atmospheric Administration
NSE	Nuclear Security Enterprise
NSF	National Science Foundation
NSTC	National Science and Technology Council
OAC	Office of Advanced Cyberinfrastructure
ODNI	Office of the Director of National Intelligence
OKN	Open Knowledge Network

Acronym	Definition
OLCF	Oak ridge Leadership Computing Facility
OpenACC	Open Accelerators
ORISE	Oak Ridge Institute for Science and Education
ORNL	Oak Ridge National Laboratory
OSTP	Office of Science and Technology Policy
PCAs	Program Component Areas
PPP	Public-Private Partnership
Proto-OKN	Prototype Open Knowledge Network
QIS	Quantum Information Science
QuAIL	Quantum Artificial Intelligence Laboratory
RAJA	Resource-Adaptive Java Agent
RCD	Research Computing and Data
RCN	Research Coordination Networks
RDT&E	Research, Development, Test, and Evaluation
RENEW	Reaching a New Energy Sciences Workforce
RINGS	Resilient and Intelligent Next-Generation Systems
S&T	Science and Technology
SAGE	Seismological Facility for the Advancement of Geoscience
SaTC	Secure and Trustworthy Cyberspace
SC	Office of Science
SciDAC	Scientific Discovery through Advanced Computing
SDC	Silent Data Corruption
SSAR	Science Synthesis, Analysis and Research
STEM	Science, Technology, Engineering, and Mathematics
STRIDES	Science and Technology Research Infrastructure for Discovery, Experimentation, and Sustainability
TCUs	Tribal Colleges and Universities
TEPP	Tribal Education Partnership Program

Acronym	Definition
TIP	Technology, Innovation and Partnership
USGS	U.S. Geological Survey
USNO	US Naval Observatory
YFA	Young Faculty Award