SLAC National Accelerator Laboratory
Annual Laboratory Plan
FY 2018
Approval
This SLAC Annual Laboratory Plan for fiscal year 2018 has been reviewed and approved by:

Electronically approved

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SLAC National Accelerator Laboratory

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About the cover image: Depiction of an “angular streaking” scheme that enables the attosecond details of individual X-ray pulses to be read by a detector, akin to reading the face of a clock. Performed at the Linac Coherent Light Source at SLAC National Accelerator Laboratory, ultrashort X-ray pulses photoionize neon while the circular polarization of an infrared laser field modulates the corresponding photoelectron energy and angle of the emission. (Image credit: Terry Anderson/SLAC National Accelerator Laboratory)

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1. Mission and Overview

SLAC National Accelerator Laboratory is a vibrant multi-program laboratory whose mission is to deliver scientific discoveries and develop tools that transform our understanding of nature and help address the most challenging scientific and technological problems facing industry and society. To date, four Nobel Prizes have been awarded for research done at SLAC.

SLAC is the world-leading laboratory in X-ray and ultrafast science due in large part to our X-ray user facilities: the Stanford Synchrotron Radiation Lightsource (SSRL), and the Linac Coherent Light Source (LCLS), the world’s first hard X-ray Free Electron Laser (XFEL) and a revolutionary tool for chemistry, materials sciences, biology, plasma physics, and matter under extreme conditions.

Since our founding in 1962, SLAC has made revolutionary discoveries that have established our leadership in high energy physics. SLAC continues to be a major contributor to exploring the physics of the universe, with leadership roles in all five science drivers of the Particle Physics Project Prioritization Panel (P5), including probing the nature of dark energy with the Large Synoptic Survey Telescope (LSST).

With five decades of excellence in accelerator physics, SLAC is the leader in advanced accelerator concepts, such as plasma wakefield acceleration (PWFA), and drives the development of critical accelerator technologies with a broad range of applications.

As stewards of renowned user facilities, SLAC hosts, supports, and collaborates with more than 4,000 U.S. and international researchers, including many students, at SSRL, LCLS, and the Facility for Advanced Accelerator Experimental Tests (FACET), as well as in laboratory-hosted science programs.

Through continued diversification of our research programs, SLAC aims to strengthen our impact, specifically exploring applications of our core capabilities in support of applied energy programs in the U.S. Department of Energy (DOE) and the missions of other federal agencies, and expanding our collaborations with industry. To do this SLAC leverages our location in Silicon Valley and our strong relationship with Stanford University (Stanford).

Stanford manages the Laboratory for DOE, providing significant advantages in research, education, and operations. Stanford is home to and attracts some of the world’s best and most innovative scientists. Capitalizing on this, SLAC jointly operates three institutes and two research centers with Stanford.

Today, SLAC, Stanford, and DOE, are piloting a new management contract that streamlines many of the Laboratory’s standard management processes, eliminates duplication, and increases the Laboratory’s autonomy, making it more efficient and effective.

2. SLAC at-a-Glance

Location: Menlo Park, Calif.
Type: Multi-program Laboratory
Contractor: Stanford University
Responsible Site Office: SLAC Site Office
Website: www.slac.stanford.edu

Physical Assets:
- 426 Acres and 149 Buildings
- 1.7M GSF in Buildings
- Replacement Plant Value: $1.917B
- 0.038M GSF in 39 Excess Facilities
- 0 GSF in Leased Facilities

Human Capital:
- 1,531 FTE Employees
- 36 Joint Faculty
- 212 Postdoctoral Researchers
- 79 Undergraduate Students
- 220 Graduate Students
- 2,692 Facility Users
- 19 Visiting Scientists

FY17 Costs by Funding Source ($M):

Lab Operating Costs: $590.6
DOE Costs: $575.3
SPP (Non-DOE/Non-DHS) Costs: $15.3
DHS Costs: $0
SPP/DHS as % Total Lab Op. Costs: 2.6%

1. Replacement Plant Value is the sum of buildings ($1.3B), other structures and facilities ($800M), and trailers ($7M)
2. SLAC began tracking undergraduate interns in FY17, so we do not have historical data
3. Facility users as reported to DOE by the user facilities’ LCSL, SSRL, Faced, and test facilities ASTA, ESTB and NLCTA
3. Summary of Changes to Laboratory Core Capabilities

SLAC’s mission to deliver scientific discoveries and develop tools that transform our understanding of nature and help address the most challenging scientific and technological problems facing industry and society is founded on our six core capabilities, described in Appendix 1 of this Annual Laboratory Plan (ALP):

1. Accelerator Science and Technology,
2. Large-Scale User Facilities/Advanced Instrumentation,
3. Condensed Matter Physics and Materials Science
4. Chemical and Molecular Science
5. Plasma and Fusion Energy Science, and
6. Particle Physics.

SLAC’s strategy is to: (1) advance our state-of-the-art core capabilities; (2) leverage our core capabilities in support of our strategic initiatives; and (3) develop emerging capabilities in anticipation of future mission needs. Changes to the Laboratory’s core capabilities in the past year are summarized below.

3.1 Accelerator Science and Technology

SLAC has launched a comprehensive program in high-brightness beams for future accelerator applications, including detailed start-to-end simulations to study collective effects that degrade beam emittance, and development of Continuous Wave (CW) Superconducting Radio Frequency (SRF) electron sources and plasma-based sources. This work is critical for the success of future X-ray experiments, as well as Ultrafast Electron Diffraction (UED), Ultrafast Electron Microscopy (UEM), and future colliders. [Supports SLAC’s strategic initiatives in X-ray and ultrafast science (discussed in Section 4.1 of this ALP), and physics of the universe (discussed in Section 4.2).]

The Free Electron Laser (FEL) research and development (R&D) program to improve LCLS capabilities delivered the first ever sub-femtosecond X-ray laser pulses, opening up new measurement possibilities in high-field science, charge transfer chemistry, and high-resolution structure determination. The program also successfully implemented a new bunch compression mode for short, high-peak-power XFEL pulses, pushing the existing record by a factor of three. [Supports SLAC’s strategic initiative in X-ray and ultrafast science.]

Radio Frequency (RF) acceleration technology development focuses on (1) transcending the efficiency and cost limits of power sources from RF through terahertz (THz) frequencies, (2) creating electrodynamic modeling tools to accelerate transformational advances, and (3) developing innovative accelerator structures and power sources optimized for high efficiency and low cost of manufacturing. These efforts enhance the capabilities of existing DOE accelerator facilities and form a foundation for future high-performance facilities, as well as opening up a broad range of new initiatives from medicine to national security. These efforts have been enhanced by a High Energy Physics (DOE-HEP) Early Career Award for THz accelerator R&D. [Supports SLAC’s strategic initiative in electron accelerator physics (discussed in Section 4.3).]

3.2 Large-Scale User Facilities/Advanced Instrumentation

LCLS installed the world’s flattest X-ray mirrors, providing substantial improvement in beam quality, throughput, and operational modes. A new “split-and-delay” X-ray optical system was installed on the X-ray Correlation Spectroscopy (XCS) instrument to allow robust scanning of two X-ray pulses with delays in the 0.1 to 100 picosecond timeframe that is typical for material dynamics. The Matter in Extreme Conditions (MEC) instrument increased the energy of its optical pump laser systems by a factor of three, with improved pulse-shaping and enhanced stability, greatly exceeding initial design goals – addressing a core demand from geoscience and extreme materials communities. All these capabilities are now integrated into LCLS operations. [Supports SLAC’s strategic initiative in X-ray and ultrafast science, and advances the Laboratory’s core capability of large-scale user facilities (discussed in Appendix 1.2).]

LCLS completed a major reconfiguration of the Near Experimental Hall to open up space for future instrument developments and critical support laboratories in anticipation of LCLS-II, the upgrade to LCLS. The design of an instrument suite to take advantage of the orders-of-magnitude increase in average power and spectral brightness matured into a specific plan during FY 2017, following extended consultation with the user community. The new capabilities selected include a globally unique dual-XFEL instrument area for X-ray
pump/probe studies; a high-resolution resonant inelastic X-ray scattering (RIXS) spectrometer for quantum material studies; and systems to take advantage of the highest time resolution for atomic and molecular physics. [Supports SLAC's strategic initiative in X-ray and ultrafast science, and advances our core capability of large-scale user facilities.]

SSRL is developing high-throughput measurements using in situ and operando studies of materials synthesis, growth, and assembly to enable the acceleration of functional materials discovery and design and provide a platform for research in new materials at the Stanford Institute for Materials and Energy Sciences (SIMES). In another collaboration with SIMES, studies of quantum materials have been enhanced by the addition of advanced growth capabilities to be used in conjunction with both the angle-resolved photoemission spectroscopy and soft X-ray RIXS facilities. SSRL is also developing and implementing ultra-high-energy-resolution fluorescence detection capabilities for X-ray spectroscopy (transition edge sensor and analyzer optics technology for soft and hard X-rays, respectively) for application to catalysis and chemistry in collaboration with the SUNCAT Center for Interface Science and Catalysis, including pushing the time resolution into the picosecond domain. [Supports SLAC's strategic initiative in X-ray and ultrafast science, and advances the Laboratory's core capabilities in large-scale user facilities; condensed matter physics and materials science (described in Appendix 1.3); and chemical and molecular science (described in Appendix 1.4).]

The UED facility continues to make performance improvements that expand our ultrafast science capabilities, the latest development being a THz to mid-infrared pump source. We have developed single-shot UED capability and successfully deployed it to the scientific community. Additional enhancements under development include capabilities to study liquid samples and smaller probes with better temporal resolution and higher flux. [Supports SLAC's strategic initiative in X-ray and ultrafast science, and advances the Laboratory's core capability in accelerator science and technology (described in Appendix 1.1).]

SLAC has implemented a new suite of four cryo-Electron Microscopy (cryo-EM) machines, complementing the development and expansion of the X-ray micro-focus macromolecular crystallography and imaging capabilities at SSRL and LCLS, for studying the structure and function of biological materials in space and time. Key new faculty and staff hires are leading the development of this internationally competitive science program, complementing SLAC's leadership and expertise in operating, maintaining, and supporting large-scale user facilities. The new micro-focus undulator beamline at SSRL, the Macromolecular Femtosecond Crystallography (MFX) instrument at LCLS, and the suite of cryo-EM instruments represent complementary cornerstones for imaging biological function in space and time. [Supports SLAC's strategic initiatives in X-ray and ultrafast science, and bioimaging (discussed in Section 4.5); and advances the Laboratory's core capability in large-scale user facilities.]

In addition to extensive ongoing efforts to address the dramatic increase in data throughput once LCLS-II starts operations, the data acquisition (DAQ) and data management efforts have been expanded to address the growth of cryo-EM and UED. [Supports SLAC's strategic initiatives in X-ray and ultrafast science, and data analytics (discussed in Section 4.4); and advances the Laboratory's core capability in advanced instrumentation (described in Appendix 1.2).]

3.3 Condensed Matter Physics and Materials Science and 3.4 Chemical and Molecular Science

The Condensed Matter Physics and Materials Science and Chemical and Molecular Science programs in the Energy Sciences Directorate continue their leading research in the various Basic Energy Sciences (DOE-BES) programs, including quantum materials, bio-inspired materials, energy storage materials, chemical catalysis, and ultrafast chemical science. Areas of particular focus within these programs include research aligned with:

- **SLAC's strategic initiative to be the world-leader in X-ray and ultrafast science**: The role of ultrafast X-rays for forefront studies in atomic, molecular and optical physics, in quantum materials, and in catalysis have all been identified as priority areas of research. New program initiatives have been formulated to explore intramolecular electron dynamics on the attosecond timescale. Important research directions have been identified to use the capabilities of ultrafast X-rays to probe light-induced states of matter and to correlate lattice motion and the electron response of quantum materials. Within the area of heterogeneous catalysis, opportunities have been defined to apply ultrafast X-rays to capture the short-lived intermediates that often play a crucial role in selectivity and to probe the fundamentals of energy flow in

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thermal and photocatalysis. These initiatives all rely on the major advances in experimental capability for ultrafast X-ray measurements that will be provided by LCLS-II.

Crucial to the success of these and relative research initiative to take full advantage of investments in LCLS-II will be the recruitment of scientific expertise in this emerging area of research. Several strategies, including Panofsky Fellowships and joint SLAC-Stanford appointments, are being implemented to assist in recruitment in this research area. The relative newness of this research field, combined with the high demand for expertise associated with the worldwide expansion of XFELs, makes recruitment of world-class researchers a challenge and priority for the laboratory.

- **SLAC's world-leading program in catalysis**: An important component of SLAC's DOE-BES research is the SUNCAT catalysis program. This program addresses a wide variety of fundamental phenomena through integrated experimental and theoretical research. An important component of the overall research activity, supported through the Joint Center for Artificial Photosynthesis (JCAP) program, addresses CO2 electrocatalysis. The JCAP research agenda benefits strongly from the broader SUNCAT capabilities in both theoretical and experimental catalysis that have been developed over many years. Research on CO2 electrocatalysis within the JCAP program has demonstrated the importance of the interfacial phenomenon, such as local pH variation and the presence of cations and anions in the electrified interface, in determining catalytic activity and selectivity. So while the overall SUNCAT program advances JCAP research, discoveries from the JCAP program also inform the SUNCAT research agenda in significant ways. The two components of JCAP and SUNCAT FWP supported research are highly complementary to one another.

All of these programs have strong partnerships with SLAC's LCLS, SSRL, and UED facilities. They are actively involved in defining the science capabilities for LCLS-II and its extension, LCLS-II-HE, as well as upgrades to SSRL and UED capabilities. SLAC has continued to advance and refine the science needs for LCLS-II-HE through a series of "First Experiments" meetings on chemistry, materials physics, atomic and molecular physics, biology, and quantum materials hosted at SLAC in 2017. [Supports SLAC's strategic initiative in X-ray and ultrafast science, and advances the Laboratory's core capabilities in Condensed Matter Physics and Materials Science and Chemical and Molecular Science.]

### 3.5 Plasma and Fusion Energy Science

The High Energy Density (HED) program in the Plasma and Fusion Energy Science Division has initiated a new theory group funded by a Fusion Energy Sciences (DOE-FES) Early Career Award that explores the HED phenomena that will be accessed by SLAC’s HED facilities. [Supports SLAC's strategic initiatives in X-ray and ultrafast science, and HED science (discussed in Section 4.6), and advances the Laboratory's core capability in plasma and fusion energy science (described in Appendix 1.5)]

### 3.6 Particle Physics

The neutrino program at SLAC has been expanded with new hires, leading to new roles and responsibilities on the short-baseline and long-baseline neutrino program, Enriched Xenon Observatory (EXO)-200, as well as neutrino theory. Significant roles in this program have grown to include the Deep Underground Neutrino Experiment (DUNE) cold electronics, the ProtoDUNE DAQ, R&D for the DUNE near detector, machine learning techniques for reconstruction, and neutrino cross section calculations.

SLAC scientists played leading roles in the first physics analyses of the Dark Energy Science program. They also led the Large Synoptic Survey Telescope Dark Energy Science Collaboration (LSST-DESC), which completed its first mock data challenge at the National Energy Research Science Computing Center (NERSC).

The SLAC-led LSST project has begun commissioning operations and is planning the transition to facility operations. The SLAC-led Super Cryogenic Dark Matter Search (SuperCDMS) project at SNOLAB successfully completed its Critical Decision 2/3 review, and the SLAC LUX-ZEPLIN (LZ) effort is leading the grid construction and has begun preparations for science. The Heavy Photon Search (HPS) experiment published its first science result and is completing an upgrade of its vertex detector. SLAC R&D for Cosmic Microwave Background Stage 4 (CMB-S4) was expanded to include a significant effort on microresonator RF electronics in addition to sensor design optimization. [Supports SLAC's strategic initiative in the physics of the universe]
3.7 Quantum Information Sciences as An Emerging Core Capability

As classical measurement and computational techniques approach their limits, the tools and science of quantum information have increasing importance for both fundamental and applied sciences. Research in QIS at SLAC addresses mission needs in DOE-HEP and provides a foundation for new programmatic directions. SLAC will build on our and Stanford's core capabilities in four areas: quantum sensors; fabrication of SC quantum devices; cold-atom quantum simulations and cavity QED; and machine learning.

In addition, SLAC is pursuing new research frontiers both in quantum materials and in the applications of existing and emerging quantum computers to model correlated electron systems. Among the priority areas is research on the control of the interface between electrons in materials and photons that can carry quantum information, particularly through the development of new materials platforms of single quantum emitters. This research builds on the strong capabilities and expertise provided by a combination of SLAC and Stanford researchers. The possibility of modeling correlated electron systems with quantum computers was also identified as a very promising research area, one in which SLAC researchers could collaborate effectively with local expertise in the industrial sector.

[Supports the emerging National Quantum Initiative for quantum R&D (discussed in Section 4.2.5).]
4. Science and Technology Strategy for the Future

SLAC has evolved from a dedicated high energy physics laboratory into the vibrant multi-program national laboratory we are today. At the center of SLAC’s scientific vision is solving the most challenging problems in chemistry, materials sciences, and biology by fully exploiting the potential of the ultrashort, ultrabright pulses of coherent X-rays produced by LCLS. Our vision also focuses on the physics of the universe, specifically leading in the search for dark matter and dark energy, and probing the fundamental nature of the neutrino; as well as driving the frontier of advanced accelerator science and technologies.

Through continued diversification of our research programs, SLAC aims to solve the nation’s critical scientific and technological challenges in energy, environment, health, and national security. We leverage our location in Silicon Valley and our strong relationship with Stanford to increase the impact of our work.

To accomplish our scientific vision, SLAC has developed a strategy that builds on our world-leading core capabilities and leverages Stanford’s intellectual leadership. This strategy focuses on two broad scientific areas – (1) photon science programs enabled by our X-ray user facilities, LCLS and SSRL, and (2) particle physics and particle astrophysics programs – as well as enhancing our world-leading core capability in accelerator science and technology. In support of this strategy, SLAC has four ongoing strategic initiatives, as discussed in Sections 4.1 through 4.4 of this ALP:

- Be the world-leader in X-ray and ultrafast science,
- Foster a frontier program in the physics of the universe,
- Be a world-leading center for electron accelerator physics, and
- Be an innovator for massive-scale data analytics.

In addition, SLAC has identified two emerging strategic initiatives described in Sections 4.5 and 4.6 of this ALP: advance HED science, and create a world-leading bioimaging program. We believe the unique capabilities of LCLS and MEC have created an exciting opportunity for SLAC to lead major advances in plasma physics and materials under extreme conditions, and the recent creation of the Stanford-SLAC cryo-EM initiative provides an opportunity to develop a one-of-a-kind multi-scale bioimaging program at SLAC.

These initiatives will be supported by a targeted effort to attract the world’s best scientists, both as researchers and facility users, who will expand the frontiers of science and develop innovative new technologies. The combination of Stanford, as a world-leading research university, and SLAC, with our resources and capabilities, is uniquely attractive to top talent, which allows us to renew science leadership in existing areas and grow in new research directions.

SLAC’s relationship with Stanford is a critical factor in the Laboratory’s ability to realize our scientific vision and strategy. Over the past year, SLAC has aligned our strategic planning with a concurrent effort at Stanford to identify the challenges and opportunities that lie before us in the years ahead. Stanford continues to make a significant investment in SLAC – more than 125 million over the past seven years – transforming the SLAC site and providing new research infrastructure and capabilities.

Together with Stanford, SLAC has a culture of innovation that will continue to shape the scientific landscape. Our vision, strategic initiatives, core capabilities, and expertise set the foundation for the Laboratory’s future growth and ensures SLAC continues to advance scientific discovery across the spectrum of grand challenges identified by the DOE Office of Science (DOE-SC).

4.1 Be the World-leader in X-ray and Ultrafast Science

From pioneering synchrotron radiation as a tunable source of bright X-rays to creating the world’s first hard X-ray laser, SLAC has been a leader in X-ray science at the heart of the DOE-BES mission.

4.1.1 Scientific Opportunity

XFELs such as LCLS have transformed the ability to investigate the fundamental properties of molecules and materials by providing ultrafast X-ray pulses with dramatically increased brightness. We can now probe systems with exquisite chemical, atomic, and temporal precision – and thus drive enhanced understanding and the growth of applications. LCLS-II and LCLS-II-HE will lead the forthcoming generation of high repetition rate XFEL sources with an average brightness far beyond any existing machine. This unprecedented capability will
greatly extend our ability to probe and control electron motion within a molecule, discover novel quantum phases through coherent light-matter coupling, and capture rare events and intermediate states in the transformation of matter.

### 4.1.2 International Competition

By the end of 2018, there will be five operating XFELs reaching hard X-rays worldwide – LCLS, SACLA in Japan, European XFEL in Hamburg, PAL-XFEL in Korea, and SwissFEL in Switzerland – each of them co-located with a synchrotron facility. The European XFEL in Hamburg is the first hard X-ray facility based on a superconducting (SC) linear accelerator (linac) – with a repetition rate of up to 27,000 pulses per second delivered in 10 hertz bursts, significantly surpassing the performance of LCLS, and with two undulators and four instruments already available, with two more instruments and a third undulator due in the next year. China has ambitious plans to build a high-repetition-rate XFEL with continuous pulse structure, mirroring the planned capabilities of LCLS-II-HE. Overall, competition from these laboratories is very strong, with the most far-reaching efforts coming from the extensive clustering of capabilities, institutes, and supporting laboratories surrounding the European XFEL.

### 4.1.3 LCLS and SLAC Programs

To keep the U.S. at the forefront of X-ray and ultrafast science, SLAC has embarked on a Laboratory-wide strategy that includes LCLS and its upgrades, LCLS-II and LCLS-II-HE, with complementary broad capabilities of SSRL and laboratory-scale programs, such as UED, high harmonic generation X-ray ultraviolet sources, and the substantial synergies with SLAC's new cryo-EM facility. SLAC must capitalize on the opportunity provided by the close integration between our advanced facilities and the research programs in DOE-SC, in particular BES and FES. SLAC must also leverage new opportunities to partner with Biological and Environmental Research (DOE-BER) and the National Nuclear Security Administration (DOE-NNSA) and relevant external agencies such as the National Institutes of Health (NIH). Our highest priority is preparation for early scientific impact of LCLS-II and LCLS-II-HE by aligning our scientific programs and facility investments; engaging Stanford; increasing operational efficiency, reliability, and capacity of the LCLS facility; and acquiring, developing, and retaining the best talent in the field. Three recent highlights at the heart of DOE-SC science illustrate the development of new capabilities by local researchers that are delivering immediate results and are preparing the groundwork for early exploitation of LCLS-II and LCLS-II-HE:

1. **Attosecond frontier**: Access to the attosecond (as) timescale will enable the investigation and control of electron motion before the onset of nuclear motion and transform our understanding of ultrafast processes. While there is a large ongoing effort with laboratory-based instruments, only an XFEL can achieve the element selectivity required to map electron motion at specific atoms. Very recently, LCLS has generated the first attosecond pulses from an XFEL in both the hard X-ray (<200 as) and soft X-ray (<500 as) regimes. Exploitation of these sources is a target area for future growth of the joint SLAC-Stanford PULSE Institute, aligned with a key theme emerging from the recent "Ultrafast X-ray Science Roundtable" sponsored by DOE-BES.

2. **Near-equilibrium dynamics**: The function of molecular machines is finely tuned by subtle changes in their atomic and chemical structure. Understanding and controlling this structure dynamics-function relation represents new frontiers for nanomaterial self-assembly and bioscience. Similarly, subtle changes in local environments can have a dramatic effect on a wide range of emergent phenomena in the field of quantum materials. Our ability to understand and control such processes requires a much deeper insight into the near-equilibrium potential energy landscape of these systems. X-ray pump/probe methods for stimulated dynamics and X-ray Photon Correlation Spectroscopy (XPCS) for studying stochastic dynamics and intrinsic fluctuations of disordered matter at equilibrium are two powerful approaches for understanding structural dynamics in condensed matter systems – with the latter being a further highlight of the “Ultrafast X-ray Science Roundtable.” A significant advance for studying near-equilibrium dynamics is a newly commissioned system at LCLS for generating two X-ray pulses with interferometric precision and controllable delay. X-ray pump/probe and two-pulse XPCS experiments are now underway exploiting this new capability. The full potential of this technique will be realized by the megahertz (MHz) repetition rate of LCLS-II and LCLS-II-HE, which can provide up to \(10^{10}\) snapshots per day to map out subtle phenomena and rare events in naturally evolving systems, such as thermally activated barrier crossing.
3. **Extreme conditions**: In an experiment designed to mimic the conditions deep inside the icy giant planets of our solar system, scientists have observed "diamond rain" for the first time as it formed in high-pressure conditions. Researchers simulated the environment found inside these planets by creating shock waves in plastic with an intense optical laser at the MEC instrument. Using femtosecond X-ray diffraction, they measured the atomic structure and size of the spontaneously forming nano-diamonds. The shorter X-ray wavelength available at LCLS-II will extend this approach to obtain high-precision atomic structures of spontaneously forming nanomaterials.

4.1.4 LCLS-II

The LCLS-II construction project is progressing rapidly and is approximately 67 percent complete as of February 2018. First light is planned for the second quarter of FY 2021, with earlier use of the new tunable undulators and the existing accelerator expected to begin operations in mid-FY 2020. Early scientific exploitation of LCLS-II will be critically important to underpin U.S. preeminence in the rapidly evolving international landscape. Close integration with the DOE-SC programs, in particular BES, is sought in order to drive appropriate time-phasing of instrument capabilities and to create access mechanisms in which user consortia can deliver timely experimental results in these priority areas. We are actively discussing the details of how to achieve this with the user community, our advisory bodies, and DOE program leadership. A principal component of this plan is the design and commissioning of new and adapted instruments to exploit the high repetition rate and spectral brightness of LCLS-II. Based on extensive consultation with the user community, our plans include:

- **First experiments on TMO** include fundamental dynamics of energy and charge, such as charge migration, redistribution and localization; and quantum systems in strong fields and matter in extreme conditions, where the collective effect of multiple X-ray photons creates nonlinear processes and extreme conditions in the target that mimic the interiors of large planets or stars. TMO will enable sophisticated coincidence measurement schemes for probing an evolving reaction at each time step. SLAC has world-leading science programs, including strong-field atomic physics and ultrafast molecular dynamics that drive and use these new capabilities and complementary ultrafast methods. This research is an opportunity for growth and partnership between the PULSE Institute and other leading DOE-BES programs in this area.

- **First experiments at LJE** will use time-resolved RIXS to map the energy distribution and evolution of occupied and unoccupied molecular orbitals of model complexes and functional photo-catalysts in liquid environments. Understanding the excited state dynamics of these fundamental processes is essential for directed design of photo-catalytic systems for chemical transformation and solar energy conversion that are efficient, chemically selective, robust, and based on earth-abundant elements.

- **First experiments on high resolution RIXS + XPCS** will focus on the study of the strong coupling between charge, spin, orbital, and lattice motion in quantum materials. These phenomena give rise to collective modes that determine far-reaching macroscopic material properties such as high-temperature superconductivity, colossal magnetoresistivity, and topologically protected phases. The new instrument for momentum-resolved, high-resolution RIXS will offer transformative capabilities for characterizing collective modes and excited states, and for following their response to tailored external stimuli to disentangle coupled phenomena in the time domain. XPCS is a complementary technique that will probe stochastic charge collective modes in quantum materials. SLAC has very strong programs in this field through SIMES and the Theory Institute for Materials and Energy Spectroscopies (TIMES).
• In 2023, the Tender X-ray Instrument (TXI) for coherent X-ray imaging and X-ray pump/probe and X-ray wave-mixing experiments is scheduled to come online.

4. First experiments at TXI will include coherent X-ray diffractive imaging, small angle X-ray scattering (SAXS), fluctuation SAXS, and time-resolved SAXS. The high repetition rate will open new opportunities for characterizing heterogeneous ensembles of particles in operating (or near-native) environments. TXI will further offer a globally unique capability to combine X-rays from two independent FELs. This will open entirely new fields of nonlinear X-ray science and two-color X-ray methods. SLAC also has a strong program in nonlinear X-ray science through the PULSE Institute, a single particle imaging initiative through LCLS.

4.1.5 LCLS-II-HE

The extension of LCLS-II from its current maximum photon energy of 5 keV is motivated by the scientific need for atomic resolution at high average power (high repetition rate). LCLS-II-HE will reach at least 13 keV (and potentially up to 20 keV), enabling the study of structural dynamics at the atomic scale, with the penetrating power and pulse structure needed for in situ and operando studies of real-world materials and functioning assemblies, such as photocatalysts. These studies address the science challenges identified in the 2015 Basic Energy Sciences Advisory Committee (BESAC) report. SLAC continues to refine the new science enabled by LCLS-II-HE and first experiments through workshops in 2016 (e.g., Scientific Opportunities for Ultrafast Hard X-rays at High Repetition Rate: An Energy Upgrade of LCLS-II in September) followed by a series of “first experiments” meetings on chemistry, materials physics, AMO, biology and quantum materials in 2017 (LCLS-II-HE First Experiments Meeting in July and LCLS-II-HE “First Experiments” Meeting in October). These efforts are ongoing, with the next meeting planned for fall 2018.

4.1.6 Required Resources

By fully exploiting LCLS, and the future LCLS-II and LCLS-II-HE, SLAC is working to solve the most challenging problems in chemistry, materials sciences, and biology.

Maintaining SLAC’s leadership in X-ray and ultrafast science requires SLAC and Stanford investments, specifically:

• Program Development (PD) and Laboratory Directed Research & Development (LDRD) investment in novel X-ray instrumentation and ultrafast pump-probe methodologies to open new scientific opportunities for LCLS and beyond;
• Investment in infrastructure and new capabilities, such as nano-fabrication of X-ray optics, to prepare for LCLS-II;
• Four Panofsky Fellowships supporting single particle imaging, catalysis, attosecond pulse generation, and extreme materials science; and
• The Wallenberg-Bienenstock Professorship, a joint SLAC-Stanford appointment.

Keeping the U.S. at the forefront of X-ray and ultrafast science requires strategic DOE-BES investment or funding profile adjustments in the following areas:

• Operations funding to allow optimum exploitation of LCLS-II;
• Critical R&D – specifically, machine learning, injector, detectors, and data analytics – to ensure a robust experimental platform for LCLS-II and LCLS-II-HE early science;
• Within X-ray and ultrafast science, funding for programs in materials and chemical science across the user community to ensure our scientific leadership and complement our unique facilities; and
• A funding profile that will optimize cost and schedule for LCLS-II-HE and ensure continuity of critical production lines, particularly the technically complex accelerator cryomodules.

4.2 Foster a Frontier Program in the Physics of the Universe

The Fundamental Physics Directorate at SLAC carries out world-leading experimental, observational, and theoretical activities to investigate the physics of the universe. These activities build on SLAC’s core capabilities and our competencies in innovating, designing, and fabricating new and increasingly sensitive instruments. They also capitalize on our ability to handle extraordinarily large datasets that require advanced algorithms, techniques, and simulations to decipher and interpret results. The complete array of strengths at
SLAC are brought to bear on the most challenging questions at the frontier of our knowledge, questions that are well-aligned with the P5 science drivers.

Our highest priority is our leadership on LSST: completing the camera and commissioning and launching the survey to study dark energy. Our growth priorities are accelerating the SLAC effort on DUNE that builds on a suite of neutrino experiments, and the future CMB-S4 mission to provide a precision probe of inflationary cosmology. Ongoing world-class programs include a multi-faceted effort to search for dark matter and studies of the Higgs boson and beyond the standard model physics at the Large Hadron Collider (LHC). Broad theory programs in particle physics and in particle astrophysics and cosmology buttress our experiments by providing leadership in theoretical physics, shaping future U.S. and global programs, originating innovative experiments, and directly contributing to the SLAC experimental program.

The research environment at SLAC attracts the brightest minds studying the physics of the universe. SLAC scientists train numerous students and postdoctoral fellows across the full HEP research program. In the past year, early career researchers at SLAC have won the ATLAS thesis award and a neutrino 2018 poster prize, lead analyses for the first DES publications, and obtained faculty positions elsewhere from their training with the HPS, Kavli Institute for Particle Astrophysics and Cosmology (KIPAC), neutrino, and particle theory groups.

### 4.2.1 Dark Energy and Inflationary Cosmology

The major initiatives to probe the nature of dark energy and inflationary cosmology that are central to P5 are leadership of LSST and LSST-DESC in the nearer term and assuming leading technical, scientific, and project roles in the future CMB-S4 mission. SLAC is uniquely positioned to deliver on these projects by taking advantage of our core competencies and expertise. Our proficiency in the construction and integration of large-scale detectors exploits strategic investments in laboratory capabilities, such as the LSST assembly clean room and eventually a detector microfabrication facility. We provide leadership of the LSST camera project as well as LSST-DESC. Throughout the next decade, LSST-DESC will use LSST data to probe the properties of dark energy, the behavior of gravity on the largest scales, and the density and masses of neutrinos via their impact on the growth of cosmological structure. Our close partnership with Stanford is critical to our strategy through joint faculty and institutes, participation and training of graduate students and postdocs, and the intellectual breadth across closely related scientific endeavors from particle, string, and effective field theory ideas central to cosmology, to studies of galaxies and astrophysical phenomena that will be needed to interpret the survey.

In the coming two years, SLAC will complete construction of the LSST camera, transport it to the project site in Chile, and begin its integration and commissioning. The camera project team is fully mobilized and on track, and the commissioning and facility operations plans are well advanced. In parallel, LSST-DESC is conducting simulated data challenges at NERSC as well as related studies that will drive development of the cosmology analysis pipelines and systematic error checking machinery. This strategy of combining deep knowledge of the instrument performance and data structure with dark energy science leadership is central to SLAC's position leading DOE-HEP's LSST program.

Looking ahead to the future CMB-S4 mission, SLAC is poised to play a lead role in the program. We are making investments in personnel and infrastructure to scale and build the key technologies of SC sensors and highly-multiplexed readout. These investments complement SLAC's established capabilities in detectors and high-speed DAQ, as well as new capabilities and expert technical staff in cryogenic camera design, integration, and testing. SLAC's R&D effort in CMB includes the LDRD-supported design and construction of the Background Imaging of Cosmic Extragalactic Polarization 3 (BICEP3) inflation-search camera, which was promoted as the candidate technology from the CMB-S4 Concept Definition Team. Finally, SLAC is playing key roles in organizing and developing both aspects of the mission: a CMB-S4 science collaboration, as well as the project to build the instruments, in partnership with the other DOE laboratories and university groups.

### 4.2.2 DUNE and the SLAC Neutrino Program

Neutrinos are studied by fundamentally disparate probes that reveal different views of their properties, including their mass, mixing, charge parity symmetry characteristics, and particle-anti-particle nature, as well as their role in cosmology. We will advance this P5 science driver with groundbreaking developments throughout the next decade, with the interactions among these probes becoming increasingly critical to our understanding of the neutrino. The most important growth area at SLAC builds on our activities in DUNE and
the short baseline experiments. Recent staff and faculty hires, with support from PD investment, are significant new steps. Along with our existing team, these new members will focus on DUNE cold electronics, event reconstruction, machine learning, and physics analysis, building on our substantial expertise. Efforts at Fermi National Accelerator Laboratory’s (FNAL) short-baseline MicroBooNE and ICARUS experiments, and the T2K long-baseline experiment in Japan will confront the anticipated analysis challenges of DUNE. We will launch a liquid argon detector R&D program with the goal to lead the design and construction of the DUNE near detector, which will build on our engineering and detector expertise in liquid xenon Time Projection Chambers (TPCs), cold electronics, and utilize the LZ liquid noble test platform. In time, the LSST clean room could house ND construction.

The beam-neutrino program is complemented by leading roles in neutrinoless double beta decay, neutrino astrophysics/cosmology, and theory. SLAC is unique among the labs in engaging effectively all these methods. With EXO-200 led by SLAC and our Stanford partners, and significant participation in the next EXO (nEXO) R&D, the Laboratory is in a strong position to lead nEXO with support from Nuclear Physics (DOE-NP) by exploiting synergies at SLAC, such as cryogenic front-end electronics, and use of the LZ liquid noble test platform.

To further develop these synergies and capitalize on the uniquely broad program at SLAC, we propose forming a West Coast Center for Neutrino Science at the Laboratory. The center would strengthen regional activity and collaboration on neutrino probes among western laboratories and universities. It would host visiting scientists and workshops aimed at providing a complete picture of the properties of the neutrino and foster detector development based on existing infrastructure and capabilities for liquid noble detectors. We propose two core initiatives for the center: (1) an annual workshop focusing on a theme that draws in all neutrino efforts, rotating among key topics, and (2) a visiting scientist program supporting up to four scientists across various neutrino programs.

4.2.3 The Dark Matter Program

SLAC plays a broad and innovative role in the search for dark matter, a key science driver of P5. We are scaling up and improving existing techniques in the core Generation-2 program, as well as developing new techniques and initiatives. As the lead laboratory for SuperCDMS, we are building on our partnership with Stanford in the development of SC sensors and large solid-state detectors. Detector innovations presage a multi-stage program to lead the search for lower-mass weakly interactive massive particles (WIMPs). SLAC plays major technical and scientific roles in the LZ program to field a 10-ton liquid xenon detector for higher-mass WIMPs. We are well-positioned to lead a future large-scale joint dark matter and double beta decay experiment, with core competencies in detector design, xenon purification, testing, and readout. Alongside these direct detection efforts, SLAC has achieved significant constraints on indirect detection with the Fermi Gamma Ray Space Telescope (FGST), with further gains in sensitivity likely. Beyond WIMPs, SLAC is exploring new regions of the dark sector to look for dark photons at Thomas Jefferson National Accelerator Facility with the HPS experiment. Close collaboration with the theory group has led to proposed dark-sector projects with LDRD and PD support. The Dark Matter Radio couples to our work in quantum sensors and theoretical models to search for ultralight axion-like dark matter, and DArk Sector Experiments at LCLS-II (DASEL) will use electron bunches from LCLS-II to search for light dark matter in the MeV-GeV range with the Light Dark Matter Experiment (LDMX).

4.2.4 The Higgs and Physics Beyond the Standard Model in ATLAS

SLAC’s contribution to the AToroidal LHC Apparatus (ATLAS) focuses on the stave assembly for the Inner Tracker (ITk) high-luminosity LHC upgrade. The ITk is needed to exploit the physics potential at higher luminosity, addressing the challenges of higher track density and increased data rate, which are ten times higher than the original LHC design goals. The U.S. is responsible for the ITk Inner Pixel detector system, with SLAC leading the assembly and integration. This system, which is key to the P5 science driver to study the Higgs boson, is technically challenging owing to the data rate as well as radiation tolerance requirements. To support this work, SLAC has installed a high-precision Coordinate Measuring Machine (CMM) in the Building 33 clean room, developed an electronics test stand, and started prototype assembly. This construction project is synergistic to SLAC’s ATLAS research activities in searches for Higgs bosons and new physics in the heavy flavor channels, leadership in the development of jet reconstruction and pile-up mitigation tools that will be
increasingly important in the high-luminosity era, and hosting of a Tier-3 Computing cluster for the U.S. ATLAS community. The SLAC ATLAS and particle theory groups have a long-standing heritage of close interaction, particularly in Monte Carlo event generation, precision quantum chromodynamics, and searches for new physics.

4.2.5 Quantum Information Sciences (QIS) and HEP

As discussed in Section 3.7 of this ALP, classical measurement and computational techniques approach their limits, the tools and science of quantum information have increasing importance for both fundamental and applied sciences. Research in QIS at SLAC addresses mission needs in DOE-HEP and provides a foundation for new programmatic directions. SLAC will build on our and Stanford’s core capabilities in four areas:

1. **Quantum sensors**: SLAC plans to lead the development of quantum sensors to expand the capability of the program in order to execute the P5 science drivers. The earliest application of quantum sensors in HEP is in the search for dark matter with the Dark Matter Radio. Quantum sensors enable the measurement of the coupling of dark matter to electromagnetism better than the standard quantum limit, dramatically increasing the science reach of searches for axion-like dark matter.

2. **Fabrication of SC quantum devices**: The combined capabilities of the planned Detector Microfabrication Facility and Nano-X in the Arrillaga Science Center (ASC) are ideal for the fabrication of SC quantum sensors and systems, enhancing SLAC’s future role in QIS in DOE.

3. **Cold-atom quantum simulations and cavity QED**: In collaboration with Stanford, we are using cold-atom quantum simulations and cavity-QED to probe gauge/gravity duality and the holographic principle and black-hole physics in the laboratory, and to test tensor-network methods.

4. **Machine learning**: SLAC is developing new machine-learning techniques that are needed to address the growing scale and complexity of HEP experiments in all three frontiers. Quantum techniques, including quantum neural networks, will be investigated in a second collaboration with Stanford.

4.2.6 Required Resources

SLAC’s Fundamental Physics Directorate experimental and theoretical programs are at the forefront of advancing our understanding of the physics of the universe, with world-leading contributions across the P5 science drivers.

Carrying out these programs requires SLAC and Stanford investments, specifically:

- PD and LDRD investment in DUNE, LZ, CMB-S4, BICEP-3, Dark Matter Radio, DASEL/LDMX, and new theory efforts;
- Infrastructure investments, including the LZ liquid noble test platform and lab space that will support DUNE ND; the LSST clean room that will later serve both CMB-S4 and DUNE ND; and the ATLAS CMM; and
- Three Panofsky Fellowships that in part support CMB-S4 and ATLAS.

Our priority-ordered requests from DOE-HEP, with an emphasis on building our future programs, are:

- Fund LSST commissioning, facility, and LSST-DESC operations;
- Ramp up resources for the DUNE neutrino effort, and provide support for workshops and a visitor program to launch the West Coast Neutrino Science Center;
- Develop a low-mass dark matter portfolio to include DASEL and LDMX;
- Provide support for quantum sensors, the Dark Matter Radio, cold-atom quantum simulations and cavity QED, and Detector Microfabrication Facility equipment; and
- Accelerate support for CMB-S4 R&D activities.

4.3 Be a World-leading Center for Electron Accelerator Physics

SLAC is leading a multi-laboratory collaboration in the design and construction of the world’s first CW X-ray laser, LCLS-II, an unanticipated revolution. SLAC is also leading the world in FEL R&D, as described in Section 3.1 of this ALP. We’re using our expertise to develop critical related areas such as SC gun R&D, and an SC-RF test and repair facility. Further, SLAC now drives basic research for the next revolution in accelerator technology through the design and construction of FACET-II, the upgrade to FACET, which offers dramatically
increased performance at lower cost and with a smaller size. Based on PWFA technology, FACET-II has the potential to transform particle accelerators by using accelerating gradients 1,000 times higher than achievable by current technology, and FACET-II will demonstrate plasma acceleration of both electrons and positrons at energies relevant to future light sources and colliders. While PWFA technology is mostly applicable for larger scale applications, direct laser acceleration technology is targeted to high gradients in small structures. Stanford and SLAC are pursuing this approach to revolutionize the world of medical applications using funding from the Moore Foundation. In addition to SC and plasma accelerators, SLAC researchers are revolutionizing RF acceleration by creating modern structure topologies, applying advanced manufacturing techniques, and employing novel materials to dramatically improve the efficiency, gradient, and applicability of RF accelerators. These advances directly address the decadal needs in the DOE-HEP RF Acceleration Roadmap.

4.3.1 FACET-II: Realizing the Potential of PWFA

The PWFA program at SLAC, centered around the FACET facility, is recognized as a world-leading program in advanced acceleration research. Our vision is to maintain and expand our position through an integrated strategy that has construction of FACET-II at the center.

The 2016 Advanced Accelerator Development Strategy Report contains a research roadmap for advanced accelerator concepts within the DOE-HEP General Accelerator R&D program. The PWFA program at FACET-II will address key elements of the roadmap over the next decade. Specific areas of emphasis include accelerating electrons with high-gradient, high-efficiency state-of-the-art beam quality, identifying the optimum technique for accelerating positrons in plasma, producing ultra-high-brightness beams from plasma injectors, and developing off-ramp applications enroute to a TeV e-e+ collider.

SLAC has been engaging the community of more than 200 FACET users in annual FACET-II science workshops since 2015, with the goal of defining the first high-profile experiments and exploring additional research directions. As with FACET, we intend to engage a large part of the Stanford community with FACET-II. On average, four undergraduate students and 29 PhD students per year performed their work either directly within the PWFA science program or using the FACET user facility as a tool for further developments.

FACET-II will employ an LCLS-style photoinjector in conjunction with 1 kilometer of the existing SLAC linac to deliver 10 GeV beams to the current experimental area of FACET. FACET-II operation leverages SLAC expertise in delivering high-intensity, low-emittance beams for LCLS and FACET.

Exascale computing will enable fast-converging, high-fidelity simulations of experimental setups, designs of PWFA applications, and multi-stage collider systems. SLAC is collaborating with Lawrence Berkeley National Laboratory (LBNL) on the LBNL-led four-year program entitled “Exascale Modeling of Advanced Particle Accelerators.” The SLAC RF acceleration computational group teams closely with our LBNL collaborators to enhance the code performance and perform large-scale simulation of beam-based plasma acceleration on state-of-the-art supercomputers. The SLAC experimental PWFA programs at FACET-II will provide the arena to benchmark newly developed codes against existing algorithms and experimental data.

Machine learning has applications across the SLAC accelerator complex spanning improved accelerator design (simulations and modeling), beam delivery (tuning, optimization and control), and operational efficiency (prognostics, alarm handling, and anomaly-breakout detection). Such new approaches build on forefront capabilities in start-to-end modeling and will bolster our ability to maximize the performance of LCLS, SSRL, and LCLS-II while pushing to unprecedented peak currents exceeding 100 kiloamperes at FACET-II. Automated optimization procedures have reduced LCLS tuning time by more than half. Machine learning methods that can learn from archived data promise further improvements; an LDRD-supported Bayesian optimizer has demonstrated even faster tune-up, along with the ability to tune up new machine configurations from noise.

4.3.2 Educating the Next Generation of Accelerator Physics Leaders

The science and engineering challenges associated with realizing ambitious programs at state-of-the-art facilities enhances the renowned SLAC-Stanford accelerator education program. The exciting research opportunities enabled by the unique set of operating accelerators and test facilities at SLAC – the Accelerator Structure Test Area (ASTA), the End Station Test Beam (ESTB) and the Next Linear Collider Test Accelerator (NLCTA) – provide an environment in which students can get the requisite hands-on experience.
In its more than 25-year history, the SLAC-Stanford accelerator science education program has produced more than 60 PhDs in accelerator physics, 32 from Stanford and approximately 28 from other U.S. universities and international institutions. Ten of the 28 total awardees of the annual American Physical Society thesis award in beam physics completed their graduate research at SLAC. Today the program features nine graduate students in accelerator physics and engineering and five Stanford faculty. Our ambitious faculty development plan envisions six hires in the next five years, including two in FY 2017-FY 2018, and a curriculum of nine graduate courses, three of which are offered on average every year by the Stanford Applied Physics Department.

### 4.3.3 Required Resources

Accelerator physics research at SLAC covers a broad range of interesting opportunities. FACET-II leverages existing injector components and infrastructure of significant value, the existing middle kilometer of the SLAC linac, and the established FACET experimental area.

Maintaining SLAC as a world-leading center for electron accelerator physics requires SLAC and Stanford investments, specifically:

- PD and LDRD investment in PWFA applications, photocathode research, novel accelerating structure research, and machine learning for LCLS and LCLS-II; and
- Space, administrative support, and fellowships to attract the best students worldwide to our accelerator training program.

SLAC is working with DOE-HEP, DOE-BES, Advanced Scientific Computing Research (DOE-ASCR) and Science Laboratory Infrastructure (DOE-SLI), and DOE support is critical to:

- Complete the initial construction phase of FACET-II and support facility operations;
- Advance our long-term PWFA modeling capabilities;
- Realize the full potential of FACET-II through positron capabilities interleaved with electron operations; and
- Fund renovation of existing space to house a shielded cave and independent cryogenic plant for SRF gun tests; a clean room and assembly area for basic cryomodule repair; and future upgrades.

### 4.4 Be an Innovator for Massive-scale Data Analytics

A comprehensive analysis of SLAC’s upcoming computing needs shows LCLS-II and cryo-EM are the major drivers of our computing and data storage requirements, with HEP having a significant footprint. An innovative approach is necessary to make optimal use of the computing infrastructure at SLAC and elsewhere and to best support research. This needs to include: (1) real-time data reduction and feedback from detectors that generate data many orders of magnitude faster than today; (2) real-time access to DOE’s High-End Computing (HEC) facilities while an instrument is taking data – ultimately utilizing Exascale computers; (3) new machine learning techniques to interpret data faster, enabling efficient operation of the next-generation capabilities at LCLS and the cryo-EM facility, and improving accelerator, detector, and facility operations.

The scientific impact of data science and massive-scale data analytics coupled with LCLS-II and LCLS-II-HE are twofold. First, the combination of high data rates and high-end computing enable real-time data reduction, feedback and analysis during experiments to guide the direction of the research. Second, LCLS-II and LCLS-II-HE will collect $10^8$ to $10^{10}$ scattering patterns (or spectra) per day with sample replacement between pulses. Revolutionary advances in data science are needed to make it possible to map the dynamics of stochastic phenomena, characterize heterogeneous ensembles of particles, or identify and extract new information about rare transient catalytic events or structural changes in matter from these comprehensive data sets.

Future multi-megapixel imaging detectors operating at rates of tens of kilohertz will generate data throughputs on the order of terabytes per second. To manage cost and complexity of the data analysis systems, and to ensure timely extraction of information, it will be essential to reduce the data volumes by at least one order of magnitude while preserving the science content of the data. Innovative architectures are required to implement this reduction with a configurable approach that can adapt to the multiple science areas served by these detectors. SLAC is developing a flexible, hybrid architecture that can execute algorithm and machine learning code on central processing unit (CPU), graphics processing unit (GPU), and field programmable gate array (FPGA) processors to reduce the data through feature extraction, compression, vetoing, and classification techniques.
The real-time computing for data reduction and, most importantly, for feedback defines the scale of the computing infrastructure required onsite and offsite. This real-time feedback, done during experiment operation and between shifts, is instrumental for the user to optimize the experiment and receive datasets as complete as possible before leaving the facility.

After LCLS-II commissioning in 2021, roughly 85 percent of experiments will require up to 1 petaflops of computing power (compared to 0.05 petaflops today) for the computation described above, with a subset requiring up to 60 petaflops. This level of real-time computing is required to dynamically process the data and provide “on-the-fly” analysis that is critical to the execution of the “first experiments” portfolio. When LCLS-II-HE is commissioned, roughly 85 percent of experiments will require up to 5 petaflops, with a peak requirement of more than 100 petaflops. We plan to maximize our use of the HEC facilities, predominantly NERSC, combined with a high-availability production system local to LCLS, time-phased into two stages consistent with the facility upgrade path. In parallel with the start of operation of our cryo-EM facility, a computing infrastructure to support the data processing and storage has been installed.

Finally, new techniques applied through machine learning will accelerate the exploitation of these experiments and extract useful data faster; in particular, pattern recognition applications will revolutionize the way we use new detectors at LCLS, cryo-EM, and LSST. Adapting machine learning to the science problems presented by SLAC’s experimental facilities requires advances in performance and robustness. Storing and processing the enormous datasets that SLAC’s instruments will collect is costly, so the earlier in the data processing pipeline that important data can be identified and unimportant data can be discarded the better. Ideally, these classification decisions would be made at the detectors themselves, which requires the ability to construct much smaller and higher performance classifiers than we can build today. At the same time, learned classifiers can have both false positives and false negatives, so simply knowing the error rate is not always sufficient; we need to better understand the robustness and biases in learned models.

4.4.1 LCLS-II Requires Onsite and Offsite Computing Power

A critical element of our strategy is determining which experiments need to be processed on-site and which experiments can be offloaded to remote HEC facilities. Extensive analysis involving the NERSC and ESnet teams, and consultation with experienced groups from HEP, has shown that it is feasible to offload high-end experimental needs to an HEC if they can be scheduled in advance. However, it is not viable to offload the bulk of experiments to an HEC, since:

- The immediate and intermittent nature of LCLS data analytics jobs will disrupt the HEC, making the offsite processing unsustainable if the HEC were required for all experiments and for a significant fraction of the year during LCLS-II operation.
- Coordinating outages between the HEC and experimental facilities would become impractical if the HEC were required for a more significant fraction of all experiments during the year.
- The impact to the HEC facility, which has a broad range of priorities, complex schedules, and thousands of users, would be unacceptable. Similarly, the risk to LCLS experiments would be unacceptably high.

NERSC is the obvious HEC partner for SLAC because of the physical proximity to SLAC and the existing high-bandwidth ESnet connection. With the Advanced Light Source and its upgrade, ALS-U, LBNL faces a similar challenge and requires the same type of access to NERSC. Close collaboration between the SLAC and LBNL teams is already underway.

NERSC and SLAC experts agree requirements in the 1 petaflops range are best suited to on-site processing, while requirements above 10-20 petaflops must be analyzed at the HEC facility, at least in the next decade.

Unscheduled outages at the HEC facility must be handled on a near-instantaneous, reactive basis to keep up with data-taking even when interruptions occur. This includes switching over to other HEC facilities, continuing data-taking blind while buffering data onsite, and redirecting to local resources. Due to the uncertain nature of this new frontier in data analytics, our strategy must allow for future local scalability and compatibility of architectures with HEC facilities.
4.4.2 SLAC’s Lab-wide Data Analytics Strategy

We plan to create a SLAC-wide Science Data Facility (SDF), mostly driven by the LCLS-II and cryo-EM requirements, focusing on all the SLAC facilities with data analytics demands, and capable of satisfying the computing needs of the laboratory-wide research community. These include, HEP, UED, SSRL, and FACET and stretch from machine learning to complex simulation codes. For various HEP programs we foresee peak needs of up to 1 petaflops driven by the requirements of DESC.

Stanford operates the Stanford Research Computing Facility (SRCF) on the SLAC site, which is currently used by the Laboratory at the level of 20 percent. Our analysis shows that a sizeable fraction (>70 percent) of computing hours of the SDF could be made available to the laboratory-wide community and to Stanford.

Engagement with the facilities mentioned above and with a broad spectrum of DOE and non-DOE funded activities in materials science, chemical science, cosmology, computational sciences, artificial intelligence, and machine learning, provides synergies that will eventually lead to an expansion of the SRCF.

The SDF deployment is planned in two stages. Stage 1 will provide the processing (1 CPU-based petaflops), the storage capabilities (up to 20 petabytes), and a new tape staging system for LCLS-II steady-state operations. We plan to procure the infrastructure for the early science period of LCLS-II as part of the LCLS instrument buildout program through an overall $18 million multi-year data system upgrade. Stage 2 will start in the years leading up to LCLS-II-HE commissioning, nominally planned in 2026. It will provide the required core and border network upgrades (up to 1 terabit per second) and the storage upgrades (up to 50 petabytes). The Stage 2 upgrade will expand the accelerated architectures capabilities (up to 20-50 GPU-based petaflops) required primarily by cryo-EM and LCLS-II, but also for machine learning, simulation, and HEP needs. This expansion is in line with the recent technology decision for the NERSC-9 upgrade.

4.4.3 Required Resources

Over the next couple of years, SLAC has the opportunity to test critical elements of the LCLS-HEC partnership approach via targeted R&D in areas such as workflow automation, porting of LCLS analysis codes, and testing the use of new accelerated architectures. SLAC is working with LBNL/NERSC on a coherent policy on topics including network coordination, user agreements, and multi-year allocations.

Being an innovator for massive-scale data analytics requires SLAC and Stanford investments, specifically:

- PD and LDRD investment in machine learning, data analytics, and computer science to underpin the anticipated needs of LCLS-II and LCLS-II-HE experiments;
- Stanford seed-funding students jointly supervised by six computer science faculties and SLAC staff; and
- Partnering with Stanford to establish a robust local computing platform to address our data science challenges, including exploring the expansion of SRCF at SLAC.

SLAC is working with DOE-BES, DOE-ASCR and HEC facilities, and their support is critical in the following areas:

- Hardware and software development in the LCLS-II era;
- Resources required for an HEC to support LCLS data analytics needs; and
- Funding for the Large Scale Collaboration Building.

4.5 Advance HED Science

The unique capabilities of LCLS and MEC have delivered a wide-ranging set of advances in HED plasma science and the understanding of materials under extreme conditions. Going forward, the combination of a doubling of the peak X-ray energy from LCLS-II with ultra-high intensity pulses from a proposed new petawatt laser will provide access to the priority scientific regimes identified in the 2017 National Academy of Science study on "Opportunities in Intense Ultrafast Lasers: Reaching for the Brightest Light."

4.5.1 Science Case

The future direction of MEC is driven by a wide range of long-standing challenges that require a much more fundamental understanding of atomic dynamics and collective interactions in plasmas. This includes problems such as the nature of plasmas that (1) are used to determine the age of our galaxy, (2) produce the highest energy particles known to humankind, and (3) produce instantaneous radiation bursts found in the most
extreme environments, from fusion plasmas to neutron stars. Within the U.S., only MEC can provide the combination of long-pulse, short-pulse and X-ray laser sources to produce these extreme states of matter through dynamic compression, isochoric heating, or secondary radiation exposure, and determine their physical properties with unprecedented precision using LCLS. These studies provide the foundations that let us test astrophysical models and fusion systems via experiments that can isolate specific areas of uncertainty, such as plasma mediation of cosmic ray acceleration; or direct tests of density functional theory for complex thermodynamic states of matter; and how materials respond in extreme radiation environments that occur in fusion processes.

4.5.2 Proposal to Upgrade MEC

In response to the primary recommendations of the National Academy’s report, and from discussions with DOE-FES and the user community, we propose upgrading the MEC instrument and increasing the power of its laser systems to above 1 petawatt. An optimum configuration is possible that will also provide an approximately three times increase in laser energy for the materials science community, as well as dedicated “laser only” experiments to serve a much broader user base than is currently possible. This fully integrated, self-contained project is consistent with designs for LCLS-II-HE and could take advantage of the upcoming facility shutdown to build a new dedicated laser area and radiation-shielded target area. This facility will make MEC the world-leading instrument for extreme materials science for the next decade, targeting U.S. leadership in the DOE mission space of HED physics and providing the capability to deliver materials data critically needed for the missions of several DOE programs.

4.5.3 Required Resources

To advance HED science, SLAC is pursuing new funding opportunities with DOE-FES and partnerships with DOE-NNSA to educate students at LCLS.

Achieving the above goals requires continued SLAC investments, specifically:

- PD and LDRD investment in dynamic compression and HED theory; and
- One Panofsky Fellow supporting HED science.

SLAC is working with DOE-FES, and their support is critical in the following areas:

- The project to co-locate a world-leading petawatt laser with LCLS; and
- Modest growth of program funding for both the experimental and theory components of the SLAC research effort in this area.

4.6 Create a World-leading Bioimaging Program

Strengthening and expanding SLAC’s portfolio of X-ray science and R&D in support of the DOE-BER mission is a high strategic priority for the Laboratory and Stanford. DOE-BER’s biological systems research aims to provide predictive understanding of plant and microbial systems using both experimental and computational approaches ranging from genomic, proteomic, metabolic, structural, and imaging analyses. Foundational knowledge of the structure and function of these systems guides biosystems design approaches to leverage the natural processes for sustainable biofuel and bioproduct developments. In particular, one of the grand challenges identified in the recent Biological and Environmental Research Advisory Committee (BERAC) report emphasizes the importance of understanding the biological complexity of plant and microbial metabolism and interfaces across a wide range of spatio-temporal scales spanning from molecules to ecosystems. The other grand challenge identified in the report focuses on "effective exploitation of new and emerging technologies in systems biology and physical measurements to accelerate biological discoveries," and specifically mentions the importance of cryo-EM.

SLAC’s strategy is to create a world-leading bioimaging center for integrative, multi-modal imaging that will (1) lead development in instrumentation and methodology, driven by the most difficult biological problems; (2) leverage SLAC’s extensive expertise operating X-ray user facilities to provide wide access for the most compelling science; and (3) advance discovery and innovation in bioenergy, biology, and medical sciences.
4.6.1 Cryo-Electron Microscopy Facility

To understand complex biological systems we must be able to analyze them across many orders of spatio-temporal scales. X-ray beams from SSRL and LCLS provide excellent research tools covering a wide range of spatial resolutions but these tools are limited to crystalline samples (crystallography) with limited resolution for solution experiments (scattering). Recent advancement in cryo-EM has provided structural information from 0.2 nanometers to tens of nanometer spatial scales on non-crystalline samples, bridging to the sub-micron region accessed with optical imaging.

Recognizing the importance of cryo-EM, Stanford and SLAC have created a cryo-EM facility at the Laboratory with four state-of-the-art instruments as part of a major imaging initiative. This cryo-EM capability, as well as cryo-Electron Tomography (cryo-ET), will help SLAC address DOE-BER’s grand challenges – a systems-level predictive understanding of biological processes, including biosystems design, biofuel and biomaterial production, biogeochemical carbon cycling, rhizosphere community interactions, and cellular ultrastructure and physiology.

4.6.2 An Integrated, Multi-modal Imaging Center

With the addition of the cryo-EM facility at SLAC, the Laboratory will take the following steps to realize the goal of creating a world-leading bioimaging center.

First, SLAC will apply our relevant expertise to further advance cryo-EM. For example, understanding cell wall synthesis and degradation at molecular to cellular levels would benefit enormously from a cryo-ET instrument capable of imaging much thicker samples. Significantly improved dynamic cryo-EM and cryo-ET imaging would answer many key questions in virus-microorganism interactions in the rhizosphere. The Stanford-SLAC cryo-EM facility will lead a number of strategic research projects to enable such investigations; examples include enhancing image contrast using improved phase plate optics; developing experimental and computational strategies to visualize single molecular machines inside a cell; engineering new cryo-specimen preparative devices for capturing short-lived reaction intermediates; developing new specimen preparation procedures for milling thick samples while preserving their native structures; and deploying the latest image reconstruction and feature extraction algorithms for knowledge discovery. We envision positioning SLAC as a major player at this biological and chemical research frontier, both within the DOE complex and internationally, for innovative scientific discoveries in bioenergy and biomaterials.

Second, we will pursue synergistic integration of SLAC’s world-class X-ray user facilities. For example, cryo-EM/cryo-ET analysis of extremely large complexes in the cell can benefit from synergistic use of high resolution X-ray crystallography, solution small angle X-ray scattering, and X-ray fluorescence imaging. Cryo-EM and XFEL single particle X-ray scattering analyses are complementary and benefit from synergistic algorithm developments.

Third, we will integrate SLAC’s X-ray facilities, the new cryo-EM facility, and super-resolution optical imaging and biocomputational expertise at Stanford to map the structure trajectories of molecular machines in cells in action at unprecedented details from sub-nanometer to 10s of nanometers resolution range. This information will answer many outstanding and fundamental questions in the bioenergy and environmental science areas relevant to DOE-BER’s mission, including soil microbiome and viral ecosystem adaptation to environmental changes, lignin valorization, and carbon dioxide fixation using bacterial, archaean, and engineered enzyme pathways.

4.6.3 Required Resources

SLAC is pursuing new funding opportunities with DOE-BER and NIH, in partnership with Stanford and outside principal investigators (PIs), to create a world-leading bioimaging program.

Achieving the above goals requires further SLAC and Stanford investment; together we have and will invest in:

- Space renovation in Building 6 and the purchase of four state-of-the-art instruments for cryo-EM;
- Recruitment of faculty: one joint SLAC/Stanford and one Stanford;
- One Panofsky Fellow focused on cryo-EM and XFEL and one Bio-X pre-doctoral fellow; and
- Space buildout in the ASC for the NIH cryo-EM center.
SLAC is working with DOE-BER, and their support is critical in the following areas:

- The effort to use Focused Ion Beam Scanning Electron Microscopes (cryo-FIB-SEM) to prepare frozen-hydrated biological cell and tissue samples for 3D cryo-ET investigations;
- Software development for cryo-EM, including the requirement of a senior scientist to lead and develop integrative big data analytics in each and across different imaging modalities; and
- Growth of SLAC research in DOE-BER science mission areas.
5. Technology Transfer, Commercialization and Partnership Strategy

5.1 Vision and Strategy

SLAC’s vision to expand our basic sciences impact and our R&D directions towards critical national needs while leveraging our world-leading expertise and capabilities provides the foundation for our strategic partnerships, technology transfer, and commercialization strategy. Key components of this strategy include expanding SLAC’s impact in use-inspired programs and areas such as biosciences, energy, and national security. In addition, through ongoing and envisioned strategic partnership activities, we aim to advance the state-of-the-art in our R&D facilities and capabilities, accelerate the translation of discovery to application, and reveal the fundamental questions at the core of real-world problems. Ultimately, our Strategic Partnership Projects (SPP) portfolio aims to strengthen the expertise and skillset of our staff and attract world-leading experts, which in turn ensures that we deliver with excellence in the DOE mission areas of scientific innovation and discovery, energy, and national security, as highlighted in the examples that follow.

Over the past five years, SLAC’s SPP and Cooperative Research and Development Agreement (CRADA) funding has more than tripled, growing from $9 million in FY 2013 to $30 million in FY 2018. SLAC intends to double our SPP in the next 10 years from our current 8 percent of the Laboratory’s operating funds received\(^1\). Two key elements of our strategy to accomplish such growth are our relationship with Stanford and position within the Silicon Valley ecosystem. Stanford and SLAC are already demonstrating the success of this strategy through joint appointments and joint long-range strategic planning efforts. For example, a SLAC and Stanford partnership in biosciences is paving the way for the development of a state-of-the-art cryo-EM facility at SLAC. Co-locating this instrumentation and new user base with SLAC’s existing user facilities and communities is expected to bring tremendous opportunities for innovation, discovery, and partnerships with other federal and private sector entities.

SLAC’s unique position in Silicon Valley has already allowed us to deploy our user facilities, core expertise, and R&D capabilities in advanced accelerator technologies, instrumentation, and data analytics to provide innovative solutions and undertake otherwise high-risk efforts with potential significant impact in the applications that industrial partners are pursuing. Such partnerships with industry will provide enhanced opportunities for our staff to contribute to leading-edge R&D with near-term market application, much of which will result in valuable Intellectual Property (IP) that further solidifies our reputation as a scientific and technical resource and partner.

5.2 Supporting SLAC’s Core Capabilities and Strategic Initiatives

We are engaging in several SPP projects that build and enhance SLAC’s existing and emerging core capabilities that in turn enable the strategic initiatives outlined in Section 4 of this ALP. The remainder of this section highlights notable examples and future efforts for SPP in support of our core capabilities and strategic initiatives.

5.2.1 Accelerator Science and Technology

Supports the X-ray and ultrafast science, physics of the universe, electron accelerator physics, and bioimaging strategic initiatives

We support our core capability in accelerator science and technology with partnerships targeting international collaborations that advance the frontiers of accelerator science and technology, thus benefiting the pursuit of fundamental scientific questions and the development of future facilities in high energy and FEL physics. Through partnerships that enable technological advances in accelerators and RF technology, we aim to provide innovative methods and solutions in applications from biomedical sciences to national security, as well as basic sciences problems. Overall, our partnerships in accelerator science and technology stimulate the scientific and technological creativity of our staff and help us maintain and recruit a leading-edge workforce.

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\(^1\) Operating funds exclude funding received for major construction projects.
SLAC continues to extend our multi-year partnership with the European Organization for Nuclear Research (CERN) in order to support the LHC Accelerator Research Program. Additionally, SLAC continues to broaden collaborative multi-year partnerships with the Institute of High Energy Physics (IHEP) in China and the High Energy Accelerator Research Organization (KEK) in Japan to perform advanced accelerator-technology research for the design of circular electron positron colliders, high luminosity feedback, collimators and X-ray beam monitors. SLAC manages an ongoing collaboration with the Deutsches Elektronen-Synchrotron (DESY) to advance SCRF and FEL technology. This collaboration has been essential to kick-start the LCLS-II project and train SLAC workforce, while providing FEL operation expertise for our partner.

SLAC partners to address national security challenges, including the continuation of a partnership with the Defense Advanced Research Projects Agency (DARPA) to develop intense and compact neutron sources. SLAC is pursuing several first-time partners, including the Army Research Laboratory. In this collaboration, we will develop and demonstrate an ultra-compact, high-efficiency, moderate-power W-band source.

Through partnering with the Stanford School of Medicine’s Department of Radiation Oncology, we plan to develop the next generation of cancer treatment facilities using advanced RF accelerator and source technologies developed at SLAC. Our partnership around the PHASER concept, an electron-based, multi-beamline system, aims to deliver radiation dose to the treatment site at an extremely high rate and, consequently, a very short time, a critical success factor in cancer radiation treatment.

In the area of advanced RF accelerator technology, our partnership plan focuses on (1) transcending the efficiency and cost limits of power sources from RF through THz frequencies; (2) creating electrodynamic modeling tools to accelerate the design realization cycle of devices employing novel geometries that will yield these transformational advances; and (3) developing innovative accelerator structures and power sources with topologies and materials optimized for high-efficiency, low-cost manufacturing that achieve order-of-magnitude scale improvements in the RF accelerator system cost/capability curve. We plan to develop high-power sources for a broad application space that uses this frequency range in fields ranging from communications to the manipulation of biological systems to determine structural information. Millimeter-wave/THz is expected to be a growth area and a significant contributor towards efforts that rely on THz radiation for pump-probe experiments in chemistry, biology, and materials sciences.

5.2.2 Large-Scale User Facilities/Advanced Instrumentation

Supports the X-ray and ultrafast science, data analytics, and bioimaging strategic initiatives

We pursue partnerships with other U.S. federal agencies and international collaborators to advance the development of our user facilities and develop new research facilities and state-of-the-art instrumentation.

LCLS is executing strategic partnerships with NIH that expand the LCLS research capabilities to support the biosciences user communities and our research programs in these areas. In FY 2017 we executed an agreement with NIH to develop an MFX beamline, which opens up the capability to efficiently collect unique and damage-free diffraction data from radiation-sensitive and/or micron-sized crystals of challenging biological systems, including multi-protein complexes and membrane proteins.

SSRL continues to partner with NIH, coordinating with DOE-BER to support the development and operation of nine dedicated and shared X-ray beamlines and associated instrumentation and techniques. Additionally, we have extended our partnership with the Scripps Research Institute for an additional five years, which contributes to building a new state-of-the-art undulator microfocus beamline at SSRL to perform macromolecular crystallography research. The capabilities of this new beamline, along with others at SSRL, will increasingly enable discovery science important to the biopharma sector.

In partnership with Stanford, we are developing a state-of-the-art cryo-EM facility to provide capabilities that help address, in concert with our established X-ray approaches, DOE-BER's mission and grand challenges. In addition, we have a pending proposal with NIH to establish a national cryo-EM user facility at SLAC that meets the emerging national need for cryo-EM as a tool for atomic-resolution structural biology and to train the next generation biosciences researchers. The proposed national user facility will seamlessly integrate the latest cryo-EM instrumentation with the computing resources necessary to assess high-throughput bio-imaging data in real time.

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5.2.3 Condensed Matter Physics and Materials Science, and Chemical and Molecular Science

Supports the X-ray and ultrafast science strategic initiative

Bridging DOE’s basic and applied sciences programs and industry to tackle energy-related challenges is the primary focus of our partnerships. Our partnerships leverage our user facilities, R&D capabilities, and unique relationship with Stanford to answer fundamental scientific questions and lead the way towards promising solutions.

DOE-SC and Energy Efficiency and Renewable Energy (DOE-EERE) – along with industrial partners working on batteries, photovoltaics (PV), and catalysts – are engaging with SLAC to use SSRL for energy-related materials, chemical sciences research, and technology development. SSRL, through established partnerships with multiple Original Equipment Manufacturer battery and energy storage entities, continues to perform in situ and operando X-ray analysis to enable the creation of next-generation battery technology. These partnerships allow our science staff to work on commercially relevant technologies and real-world optimization challenges faced by energy storage companies.

SSRL researchers are continuing to conduct leading-edge research in PV with Stanford researchers and other national laboratories by using our synchrotron user facilities and scientific expertise to perform in situ and operando X-ray analysis of rapid thermal processing for thin-film solar cells as well as in situ analysis on roll-to-roll printed, highly efficient organic solar cells. As part of the new DuraMAT Energy Material Network, we are beginning to see increased engagement from the PV industry looking at encapsulants and anti-soiling materials as well.

5.2.4 Plasma and Fusion Energy Sciences

Supports the HED science strategic initiative

The role of SPP in the core capability of plasma and fusion energy sciences is under evaluation. Sections 3 and 4 of this ALP detail SLAC’s stewardship of this capability through our DOE efforts.

5.2.5 Particle Physics

Supports the physics of the universe strategic initiative

In particle physics, SLAC pursues and leads large-scale collaborations in order to address complex scientific challenges and projects that require the combination of unique expertise from partners such as private entities, other federal agencies, and national laboratories.

As a leader in the LSST Consortium, SLAC is building and testing the LSST camera, a DOE-HEP project. The Consortium includes the privately-funded LSST Corporation, and the Association of Universities for Research in Astronomy (AURA), which leads the National Science Foundation (NSF) Major Research Equipment and Facilities Construction-funded telescope and site. SLAC, AURA, and the LSST Corporation entered into a partnership agreement to manage the program during construction and operation.

We are expanding our involvement in the Cryogenic Dark Matter Search (CDMS) Collaboration, which is supported jointly by DOE and NSF, by continuing to partner with UC Berkeley in the development of low temperature phonon-mediated detectors to detect the rare scattering of WIMPs on nuclei and distinguish them from backgrounds. The partnership involves NSF, three DOE laboratories, and SNOLAB, the host facility in Canada.

5.2.6 Cross-cutting Capabilities

Supports the X-ray and ultrafast science, physics of the universe, electron accelerator physics, data analytics, bioimaging, and HED science strategic initiatives

The areas below represent important crosscutting capabilities that support SLAC’s portfolio of core capabilities and strategic initiatives.

Sensors and detectors: SLAC is partnering with a local startup, which has developed a novel technology for non-thermal annealing of semiconductors and other materials. Applications within HEP include post-foundry formation of backside diffusion contacts on CMOS image sensors and charge-coupled devices, less-costly
processes for manufacturing thin silicon sensors without silicon-on-insulator, possible healing of defects, thin entrance windows for ultraviolet light, annealing of direct bonded wafers, etc.

SLAC continues to execute an SPP with the European XFEL, in which SLAC is leveraging our expertise and capabilities in instrumentation design in order to develop large-area X-ray detectors for spectroscopy, imaging, and scattering investigations at the European XFEL.

SLAC is partnering with the National Aeronautics and Space Administration (NASA) to develop the Athena Wide Field Imager, which involves the evaluation of high-speed, low-noise readout schemes for Depleted P-channel Field Effect Transistor detectors suitable for the science goals of the Athena mission and implementing in microelectronic hardware.

**Electronics:** SLAC's broad and deep expertise in mixed signal integrated circuit design is enabling partnerships with start-ups and established companies in 3D-imaging (e.g., driverless car LIDAR), Improvised Explosive Device detection (Radar), and IP block design for peripheral processor blocks.

SLAC is participating in the DUNE DAQ Consortium, in collaboration with FNAL, Brookhaven National Laboratory, CERN, Boston University, and Oxford University, and will contribute to the hardware and architecture working groups, leveraging our engineering team's knowledge and experience to aid in the design of DAQ options for the DUNE project.

**Metrology:** Metrology spans a wide range of applications at SLAC including sub-nanometer precision measurements and characterization of X-ray optics essential to the performance of our user facilities. Metrology for biosciences is a new effort spearheaded at SLAC through a Joint Initiative for Metrology in Biology (JIMB). JIMB will catalyze engagements amongst SLAC, Stanford, National Institute of Standards and Technology (NIST), and other partners to create foundational measurement science tools and standards for 21st century biosciences and biomedicine.

**Data:** SLAC continues to partner on large-scale scientific and industry projects that involve large dataset management. Notably, SLAC is providing expertise for advances in database design and software as part of the LSST Consortium. Additionally, SLAC is in the process of expanding an existing collaboration with a commercial start-up in the autonomous vehicle space to manage and analyze large datasets. SLAC will be working with Stanford through SUNCAT to develop infrastructure to automate atomic-scale simulations of catalytic properties and integrate them into a catalysis data warehouse. This effort will form the basis of parametrizing a machine learning-accelerated approach in catalysis design.

SLAC is also conducting research in smart grid technology and has partnered with other national laboratories, the DOE Grid Modernization Consortium, and the California Energy Commission. A primary focus of these partnerships is in data analytics, including integration of disparate datasets for a holistic overview of the distribution grid, and machine learning techniques to provide added insight into planning, operation, and recovery of the grid.

**5.3 Commercialization and Technology Transfer**

SLAC generates IP through our R&D efforts, which has the potential to move innovations into the marketplace. As highlighted above, SLAC has entered multiple SPPs with private sector entities in which SLAC is developing technical solutions for industry challenges, with the expectation that the commercial customer will implement a SLAC-developed solution into their products. SLAC has performed collaborative work with telecom companies, autonomous vehicle component design companies, and medical device companies, and these companies either have developed or are in the process of developing commercial products based at least in part on these SLAC innovations. We have expanded the breadth of our IP license portfolio by working closely with Stanford's Office of Technology Licensing (OTL) to out-license SLAC-based designs and proprietary software. Our intent is to use royalty revenue to invest in additional R&D and technology transfer related activities.

In concert with the OTL, SLAC is successfully executing numerous new IP licenses and combination CRADA and IP license agreements. We are working with laboratory personnel to increase the awareness and processes for disclosing new IP, including patent disclosures and software, with the expectation that the number of patent disclosures at SLAC will increase in the coming years. Additionally, SLAC participates in multiple cross-laboratory and multi-entity initiatives that focus on the development of valuable IP and effective transfer of
technologies to U.S. industry. Consortia such as CalCharge, DuraMAT, Battery500, the Joint Center for Energy Storage Research (JCESR) and others enable SLAC to use our facilities and expertise to assist in numerous technology areas with commercial relevance.

### 5.4 Funding and Resources

#### Table 1: Non-DOE Funding (BA in $M)

<table>
<thead>
<tr>
<th>Sponsors</th>
<th>FY 2017 Actual Funding Received(^2)</th>
<th>FY 2018 Estimated Funding Level</th>
<th>FY 2019 Request</th>
</tr>
</thead>
<tbody>
<tr>
<td>Department of Defense (DOD)</td>
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<td>0.5</td>
<td>1.0</td>
</tr>
<tr>
<td>NRC</td>
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<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Department of Health and Human Services (DHHS)/NIH</td>
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<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Department of Commerce (DOC)/NIST</td>
<td>0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>All Other Federal Work</td>
<td>1.5</td>
<td>0</td>
<td>2.0</td>
</tr>
<tr>
<td>Non-Federal Work</td>
<td>17.3</td>
<td>22.1</td>
<td>22.0</td>
</tr>
</tbody>
</table>

\( ^2 \) Please list other SPP sponsors that provided or are expected to provide the laboratory with $5 million, or more, during one or more of the FYs 2016-2018; you may also include other sponsors you believe are significant but that do not meet this $5 million threshold. Do not include CRADAs or ACT agreements.

| Total SPP\(^2\)                                      | 19.3                                 | 27.6                           | 30.0            |
| Laboratory Operating\(^1\)                          | 327.4                                | 337.0                          | 347.0           |
| **SPP as % of Lab Operating**                        | 6%                                   | 8%                             | 9%              |
| Department of Homeland Security (DHS)                | 0                                    | 2.0                            | 2.0             |
| **SPP + DHS as % of Lab Operating**                   | 6%                                   | 9%                             | 9%              |

Agreements for Commercializing Technology (if applicable)

| ACT as % of Lab Operating                             |                                      |                                |
| CRADAs (External Funding Only)                       | 1.8                                  | 0.7                            |
| **CRADAs as % of Lab Operating**                      | 0.5%                                 | 0.2%                           |

\( ^1 \) Laboratory Operating excludes funds received for major construction projects. This table represents funds received, while the pie chart in Section 2 of this ALP represents costs incurred.

\( ^2 \) Laboratory Operating excludes funds received for major construction projects. This table represents funds received, while the pie chart in Section 2 of this ALP represents costs incurred.
### Table 2: Laboratory Technology Transfer Activities Non-Programmatic ($M)

<table>
<thead>
<tr>
<th>Activity</th>
<th>FY 2017 Actuals</th>
<th>FY 2018 Estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statutory ORTA Funds</td>
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<td></td>
</tr>
<tr>
<td>Total Lab Overhead for ORTA activities(^1)</td>
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<tr>
<td>Statutory ORTA Funds as % of Total Lab Budget</td>
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<tr>
<td>Technology Transfer Program Licensing Income</td>
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</tr>
<tr>
<td>Licensing Income used for technology transition activities(^2)</td>
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<td>0</td>
</tr>
<tr>
<td>Licensing Income used for technology transition activities as % of Total Licensing Income(^3)</td>
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<td>0</td>
</tr>
<tr>
<td>Other Funds</td>
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</tr>
<tr>
<td>Expenditure of other non-federal funds for technology transitions activities(^4)</td>
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</tr>
<tr>
<td><strong>Total Non-Programmatic</strong></td>
<td>0.037</td>
<td>0.050</td>
</tr>
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</table>

### Table 3: Laboratory Technology Transfer Activities Using Programmatic ($M)

<table>
<thead>
<tr>
<th>Activity</th>
<th>FY 2017 Actuals</th>
<th>FY 2018 Estimates</th>
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<td>Technology Commercialization Fund</td>
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<td>Small Business Vouchers</td>
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<td>Technologist in Residence Program</td>
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<tr>
<td>CRADAs Funds from DOE Programs</td>
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</tr>
<tr>
<td>Other</td>
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<td>0</td>
</tr>
<tr>
<td><strong>Total Programmatic</strong></td>
<td>0</td>
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</tr>
</tbody>
</table>
6. Infrastructure

6.1 Overview of Site Facilities and Infrastructure

SLAC’s site resides on 426 acres of land leased to DOE by Stanford in unincorporated San Mateo County on the San Francisco Peninsula. As a critical partner of SLAC, Stanford has invested more than $127 million in infrastructure needs and laboratory research equipment over the past seven years; these investments include constructing three new buildings containing more than 140,000 gross square feet (GSF), renovating SLAC’s SSRL Beamline 12-1, purchasing instruments for the new cryo-EM facility, improving the Laboratory’s central quad, and removing trailers, recycled steel, and concrete materials to reduce site risks and improve overall site appearance.

SLAC maintains a total of 2.25 million GSF in facility assets, which include 149 buildings, 23 other structures and facilities (OSFs), and 39 trailers. More than a quarter of this square footage is in OSFs, which make up tunnels and other unique experimental facilities, the largest of which is the 2-mile-long underground tunnel that houses the linac. As of FY 2017, 81 percent of buildings are rated “adequate,” up from 58 percent in FY 2016; however, 4 percent are considered “substandard” and 15 percent are rated “inadequate” due to their age and old utility systems.

SLAC’s major utility systems include electric, chilled and hot water, domestic water, storm sewer, sanitary sewer, natural gas, fire alarm, telecommunications, and compressed air. Primary 230 kilovolt (kV) power is provided to the Laboratory by 5.4-mile DOE-owned transmission lines. A secondary 60 kV transmission line provides an additional power source from Pacific Gas and Electric Company (PG&E). Ensuring reliability of these utility systems through infrastructure modernization is a vital part of our campus strategy.

SLAC does not have any new leases of 10,000 GSF or more, and there were no dispositions of DOE land through leasing, sale, or gift in FY 2017. Our lease agreement identifies up to 25 acres of unused land on the SLAC site that can be returned to Stanford in three phases. The first phase includes a 12.5-acre tract on the northwestern portion of the main campus of the DOE-leased property; Stanford has not identified a timeline for any phase.

SLAC’s Long-Range Vision illustrates how we use our existing facilities, anticipates opportunities for the future, and ensures capital improvements and investments to achieve the Laboratory’s strategic initiatives. Through infrastructure investments in our existing facilities and future planned projects, we sustain and promote the mission and goals of DOE. SLAC’s last major campus planning exercise was completed in 2015 and many site improvements shown in our Long-Range Vision have since been implemented. The next update of our Long-Range Vision is planned for FY 2019.

6.2 Campus Strategy

SLAC’s campus strategy is designed to ensure our strategic initiatives are mission-ready for the future and to set the foundation for the Laboratory’s growth and expansion. Our strategy has three primary objectives:

1. Revitalize utilities to reduce highest risks and ensure mission readiness,
2. Provide collaborative spaces to exploit compelling new science opportunities, and
3. Modernize existing facilities to support strategic initiatives.

SLAC leverages five funding sources to accomplish these activities:

1. SLAC Indirect;
2. DOE-SLI, specifically Line Item (DOE-SLI-LI) and General Plant Projects (DOE-SLI-GPP);
3. DOE-Program-GPP;
4. Stanford; and
5. DOE Safeguards and Security.

SLAC’s recent, current, and planned total indirect investments range from $12-14 million per year out of the Laboratory’s total General and Administrative (G&A) budget of $106 million in FY 2018. We anticipate continued annual investment of 10-12 percent of our overall indirect budget each year on such projects. The remainder of this section identifies the infrastructure investments required to our objectives. See Figure 1 for SLAC’s planned facility and infrastructure investments.
Figure 1: SLAC's Planned Facility & Infrastructure Investments
6.2.1 Revitalize Utilities to Reduce Highest Risks and Ensure Mission Readiness

In recent years, SLAC has hired professional utility system stewards to manage critical engineering areas, such as our electrical and mechanical systems. As a result, we have a more accurate picture of infrastructure conditions and better infrastructure mission readiness plans, which have substantially improved our process for assessing the status of critical infrastructure. The Laboratory's highest infrastructure mission readiness risk is cooling water systems; no longer electrical systems, as has been the case for many years. Five years ago we experienced frequent electrical failures and significant electrical system-related fires. Improvements in preventive maintenance and physical modernization have dramatically improved electrical reliability and safety.

Approximately 48 percent of SLAC's buildings are more than 40 years old and most of the Laboratory's utility distribution systems are more than 50 years old. Reliability and maintenance of utility infrastructure is one of our most significant challenges and risks. Through application of our mission readiness process, we have identified the Laboratory's highest infrastructure risks as:

1. **Cooling water**: Our highest infrastructure risk is the reliability and efficiency of our aging and inadequate cooling water systems.

2. **Electrical**: Historically our highest infrastructure priority was to reduce operational and safety risks associated with our electrical systems. DOE-SLI-GPP projects, such as the K-substation Upgrades (KSU) and Medium and Low Voltage Revitalization (MLVR) projects, helped reduce this risk and revitalize most of the electrical infrastructure of the linac that serves as the backbone for LCLS, LCLS-II, LCLS-II-HE, and FACET-II. The KSU project modernized the 12.47 kV substations and 480 V distribution equipment throughout the first third of the linac. The MLVR project, which is in progress, replaces original substations, underrated equipment, and variable voltage substations (VVS) breakers in the remaining two-thirds of the linac.

3. **Underground utilities**: Original underground utilities – sanitary sewer, storm drains and piping, domestic water, and sump pumps – have reached end-of-life and have reduced building service capabilities.

Through the support of DOE-SLI, DOE-GPP, SLAC indirect, and Stanford investments, SLAC has made significant improvements to address our infrastructure risks over recent years. We will continue to build on these improvements and carefully evaluate burdens placed on existing infrastructure as new facilities and equipment come online.

The following projects help address our **cooling water risks**:

- **Construct and Reconfigure the Low-Conductivity Water (LCW) Cooling Water System, $8.8 Million (FY 2018)**: It enables cooling water systems to be isolated for maintenance by reconfiguring, resizing, and constructing a new LCW system. It also replaces failed and obsolete heat exchangers (HX) and the associated piping, controls, and electrical power system. Completion of this project improves reliability and sustainability, reduces operational cost, and minimizes disruption to multiple science programs. SLAC's original LCW system is beyond the end of its useful life and requires separation of components and loads to eliminate single point of failure for multiple science programs.

  *Funding: DOE-SLI-GPP (recently provided)*

- **Construct and Replace Cooling Towers, $9.4 Million (FY 2019)**: It enables localized cooling for critical loads at the Laboratory through the installation of two new, high-efficiency evaporative cooling towers. It replaces SLAC's oversized and end-of-life cooling tower system, the only cooling source for the Beam Switch Yard to SSRL, LCLS experimental halls, research yard end stations, and experimental facilities. These new towers will have a higher efficiency rate, reduce cost of operations, reduce water consumption, and provide higher reliability for multiple science programs.

  *Funding: DOE-SLI-GPP (SLI recently informed SLAC this project will be funded in FY 2019)*

3 To coordinate improvements and avoid disruptions to linac operations, the LCW and CT projects should be completed during the scheduled FY 2019 year-long shutdown for the LCLS-II installation project.
• **Upgrade Chilled Water System Pumps and Site Utility Piping at Building 23, $2.4 Million (FY 2018):** It includes improvements to increase water flow and pressure to supply chilled water to the ASC. Building 23 is our central Campus Utility Plant (CUP).

*Funding: SLAC Indirect*

• **Repair/Replace Underground Linac Cooling Water Laterals at Sectors 0-20, $2.7 Million (FY 2018-FY 2019):** It replaces corroded 50-year-old water valves and laterals that supply cooling water to Sectors 1-20 of the linac and Klystron Gallery.

*Funding: SLAC Indirect*

• **Upgrade Heat Exchanger (Hx) 2 Building and Equipment at Beam Switch Yard, $5.6 Million (FY 2017-FY 2019):** It makes structural, mechanical, electrical, and radiation protection upgrades to the existing multi-program Hx2 facility.

*Funding: SLAC Indirect*

• **Upgrade Hx4 Building and Equipment at Beam Switch Yard, $2.5 Million (FY 2018-FY 2019):** It makes structural, mechanical, and electrical upgrades to the existing multi-program Hx4 facility.

*Funding: SLAC Indirect*

• **Renovate Sector 30 Magnet Cooling System (Hx5) at Beam Switch Yard, $0.9 Million (FY 2018-FY 2019):** It provides additional cooling for increased reliability and availability and reduced risk of unplanned outages, as well as mechanical upgrades to the multi-program Hx5 (formerly the PEP-II LCW system).

*Funding: SLAC Indirect*

• **Linac Cooling Infrastructure System (LCIS), $19.7 Million (FY 2022-FY 2023):** It provides vital cooling water revitalization with increased cooling infrastructure capacity and functionality to support multiple programs along the linac FACET-II, LCLS, LCLS-II, and LCLS-II-HE. It also provides a new 15 megawatt cooling tower, new cooling tower piping to the existing 16 inch underground cooling tower water header, non-rad-LCW systems for cooling solid state amplifier racks located in the linac gallery, and a rad-LCW cooling system for equipment in the linac tunnel.

*Funding: DOE-SLI-GPP*

The following projects help address our **electrical risks**:

• **Repair/Replace Alternate Electrical Feeder, $2.5 Million (FY 2019):** It will repair/replace alternate 12 kV and low-voltage feeder, which supports multiple programs and buildings.

*Funding: SLAC Indirect*

• **Master Substation and 230 kV Line, $1 Million (FY 2019):** It provides remote switching of 230 kV switches at Tower 1 from the master substation, as well as disconnects and relays at the PG&E substations. This also provides protection to SLAC’s main transmission line and the DOE-owned 230 kV.

*Funding: SLAC Indirect*

• **Upgrade Linac 12 kV Feeder and Switch Installation (ULFI), $15 Million (FY 2022):** It provides an electrical grid to the linac, addressing the need for electrical reliability in support of LCLS, LCLS-II, LCLS-II-HE, the cryoplant, and FACET-II. It will add two new 12 kV feeders from the master substation down the length of the linac, which will be connected to existing 12 kV cabling by the addition of a new switch. Completion of this project supports the electrical infrastructure of multiple current and future science programs to their respective areas and provides a redundant line to the power-sensitive cryogenic plant to reduce risk and increase reliability of our electrical infrastructure. It should be completed before LCLS-II linac cool-down because the tie-in will require the cryoplant to be offline; it’s currently scheduled after the FY 2019 year-long LCLS facility shutdown.

*Funding: DOE-SLI-GPP*
**Modernization of Linac MCCs, VVS Low-voltage Breakers, K-substation Low-voltage Breakers (MLMB), Sectors 10-30, $14 Million (FY 2022-FY 2023):** It replaces original 1960s equipment that has become obsolete and is now long past its service life. It also replaces motor control centers (MCCs), Variable Voltage Substations (VVSs) breakers, and K-substation low-voltage breakers. Completion of this project will improve system reliability for all linac operations (FACET-II and LCLS), reducing the risk of beam down time, and provide safer operations.

Funding: DOE-SLI-GPP

Lastly, the following projects help address our underground utilities risks:

**Underground Utilities Infrastructure Revitalization (UIIR), $19.2M (FY 2021):** It repairs and replaces aging underground infrastructure for reliability of sanitary sewer, storm drain piping, domestic water, and sump pumps and storm drains throughout the site. It also addresses additional failing sump pumps and sanitary and storm sewer piping identified by specialized assessments and inspections.

Funding: DOE-SLI-GPP

Four of the above items for linac electrical and cooling systems improvements (ULFI, MLMB, UIIR, and LCIS) total $67.9 million. An alternate possibility is a single SLI line item request for Linac Electrical and Cooling Modernization for $68 million beginning in 2021 and completing in 2024.

In addition, other science projects described in Section 4 will likely require DOE program-funded improvements (e.g., petawatt laser, LCLS-II-HE, etc).

### 6.2.2 Provide Collaborative Spaces to Exploit Compelling New Science Opportunities

DOE-SLI funding for construction of new buildings and for renovation and modernization of existing buildings has been instrumental in supporting the Laboratory's transformation to a multi-program laboratory. The Operations Support Building (Building 28), Research and Support Building (Building 52), Administrative and Engineering Building (Building 41), and Science and User Support Building (SUSB, Building 53) have enabled SLAC to consolidate and optimize space, dispose of trailers, meet sustainability goals, and provide new modernized spaces for scientists, users, and support staff.

The opening of SUSB in 2015 established a main entry point for onboarding users and personnel, conference space, and laboratory management offices. The most recent phase of the security infrastructure upgrade project, completed in 2017, expanded general site access by approximately 50 acres, improving protection of DOE assets, safety of personnel, ease of movement around the site, and collaboration across science disciplines.

DOE and Stanford partnered to construct the multi-capability ASC (Building 57), with Stanford funding and completing the complete exterior cold/dark shell and DOE-SLI-LI investment funding the interior science fit-out of the building. With occupancy to begin in late FY 2018, the ASC will initially include metrology and calibration laboratories, laser laboratories, an optics nanofabrication facility, and the SLAC-Stanford joint institutes, PULSE and SIMES. The ASC will also include future cryo-EM labs for biology and a microfabrication detector clean room to build detectors for programs such as LCLS and CMB-S4.

The following projects provide necessary future mission spaces:

**Large Scale Collaboration Building (LSCB), $41 Million (FY 2019-21):** A natural progression from the previous DOE-SLI-LI investments in SUSB and PSLB, it is a proposed new building to co-locate 100 to 150 scientists, engineers, and researchers to address the data and imaging requirements of SLAC's large-scale user facilities. The need for data analytics and complex simulation codes is driven by future extremely large data rates of terabytes per second streaming from detectors for experiments at LCLS-II and LCLS-II-HE, as well as demands from LSST, cryo-EM, HED science, SSRL, and FACET-II. LSCB will enable interactions that will catalyze advancements in the development of new imaging tools and software. Early examples of a cross-functional approach have already produced strong results in the ability to interpret complex images in a wide variety of situations through the application of machine learning and other artificial intelligence methodologies. Synergies can be realized across all major DOE-sponsored programs at SLAC with a broad spectrum of researchers in materials science, chemical science, cosmology,
computational support, artificial intelligence and machine learning, exascale applications, QIS, and private partnerships.

**Funding:** DOE-SLI-LI

- **Near Experimental Hall Reconfiguration, $13.5 Million (FY 2019):** It renovates the six existing experimental hutches to prepare for installation of up to three new high repetition rate capable science instruments for the new LCLS II soft and hard X-ray beam upgrades. The design of this three instrument suite will take advantage of the orders-of-magnitude increase in average power and spectral brightness matured into a specific plan, following extended consultation with the user community.

  **Funding:** DOE-Program-GPP

- **Cryo Electron Microscopy (Cryo-EM) Center in the ASC $56.3 Million (FY 2019):** Following on the heels of a Stanford and SLAC investment to create an initial cryo-EM facility (Building 6) in 2017, SLAC will build out a larger scale cryo-EM suite in the ASC to adapt the facility for new capabilities consistent with our growing portfolio of programs in cryo-EM. SLAC intends to create a world-leading bioimaging center that will: (1) lead development in instrumentation and methodology; (2) leverage SLAC’s extensive expertise operating X-ray user facilities to provide wide access for the most compelling science; and (3) advance discovery and innovation in bioenergy, biology, and medical sciences. The new lab will complement the development and expansion of X-ray crystallography and imaging capabilities at SSRL and LCLS for studying the structure and function of biological materials in space and time. Key new faculty and staff hires are leading the development of this internationally competitive science program. SLAC’s construction project will provide for design and construction of spaces to meet the emerging national need for cryo-EM as a tool for atomic resolution structural biology, synergistic with DOE-BER and DOE-BES interests.

  **Funding:** SLAC Indirect

- **Detector Microfabrication Facility (DMF) in the ASC, $11 Million (FY 2019-21):** It expands our detector microfabrication capability in support of DOE-BES and DOE-HEP with direct benefits to ongoing and future research for LCLS, the Fundamental Physics Directorate, and the Energy Sciences Directorate. In addition, it will provide fabrication capability for hard X-ray detectors, SCX-ray detectors, and CMB-S4 detectors. The facility is a planned 5,400 square foot NSF International Standards Organization Class 5 fabrication clean room that will be located on the ground floor of the ASC. The capabilities of the facility and current Nano-X suite are ideal for the fabrication of SC quantum sensors and systems, enhancing SLAC’s role in QIS for CMB-S4.

  **Funding:** SLAC Indirect

- **Stanford Guest House Expansion, $38 Million (FY 2021):** It is planned to add 120 rooms (44 standard rooms, 74 double rooms, and 2 suites), interior gathering areas, conference areas and other guest amenities in an approximately 47,000 GSF expansion to the current Stanford Guest House. The current building provides 110 guest rooms (95 single and 17 double rooms) with various conference and guest amenities in a three story approximately 35,000 GSF building.

  **Funding:** Stanford

- **Stanford Research Computing Center-II, $52 Million (FY 2020-2023):** Stanford will complete a feasibility study in FY 2019 for the SRF expansion (SRF-II). Both SRF and SRF-II will continue to provide the Stanford and SLAC research community with computing facilities designed specifically to host high-performance computing equipment. SLAC benefits from this by being able to house scientific computing resources in a state-of-the-art facility that uses 39.4 percent less energy per square foot than the national average.

  **Funding:** Stanford

**6.2.3 Modernize Existing Facilities to Support Strategic Initiatives**

SLAC recently completed the following projects to support multiple programs, achieve improved infrastructure reliability, and reduce risk: (1) built ventilated enclosures in the linac to provide personnel...
safety, (2) installed a new domestic water line for fire protection serving the linac and cryoplant, and (3) installed lighting in the stairway and refuge areas as part of the personal protection system in the tunnel.

In 2017, SLAC's institutional risk assessment and assurance process identified a critical electrical and fire risk to mission readiness and operational safety. The DOE-owned 230 kV transmission lines that bring power to SLAC traverse difficult terrain, making detailed inspection, maintenance, and vegetation management challenging. To assess the actual risks, SLAC conducted aerial inspections of the 5.4-mile-long transmission lines to check for signs of equipment deterioration and accurately map vegetation risks. The report for this inspection will be presented in late summer 2018 and will be used to develop a long-term maintenance strategy, which includes vegetation management and transmission tower maintenance. Additionally, SLAC is working with PG&E to install improved fault protection engineering controls.

The following projects provide continuing modernization of the Laboratory's assets:

- **Replace Upper and Lower Roofs at Building 26 Heavy Fabrication Facility, $1.7 Million (FY 2017-FY 2019):** It replaces the upper and lower roofs of Building 26, which is used for fabrication, assembly, and testing of electronic and mechanical devices used throughout SLAC. The high bay area is also used to store incoming high-value equipment for LCLS-II.
  
  *Funding: SLAC Indirect*

- **Install 2 HVAC Units at Building 34, $1.1 Million (FY 2018-FY 2019):** It installs new HVAC units, which were pre-purchased for use in Building 34 for labs and offices. Building 34 currently houses the Accelerator Controls Group which runs the linac.
  
  *Funding: SLAC Indirect*

- **Campus Building Renovation Project (CBRP), $96 Million (FY 2022-25):** It modernizes aging laboratory and office spaces in buildings around SLAC's central quad for future programs supporting the missions of DOE-BES, DOE-HEP, and DOE-BER. The scope of this modernization could cover from 83,000-125,000 GSF of existing space. Mechanical utilities; heating, ventilation, and air conditioning (HVAC) units; roofing systems; and electrical systems will be replaced and upgraded to comply with current codes and reduce deferred maintenance. Modernized office and work space designs address projected laboratory staffing growth (approximately 150 FTE employees above the personnel using the LSCB). This project renovates buildings that house infrastructure to support the full life-cycle of the Laboratory's accelerator systems; engineering and scientific talent in particle and X-ray detector systems, sensors, application-specific integrated circuits, and electronics for a broad range of advanced applications. Renovations of substandard office and lab spaces will provide more workspaces per square foot and help meet sustainability requirements. Recent assessments identified additional requirements for this project, specifically failing roofs, building enclosures, and utility infrastructure.
  
  *Funding: DOE-SLI-LI*

- **Site Security and Access Improvements, $7.5 Million (FY 2020-2021):** As the final phase of security projects at SLAC that have spanned the past decade, it will complete the protection of DOE assets and enhancement of science collaboration across the Laboratory. The ability to successfully grow and open the site for collaboration required a phased approach to ultimately reduce the accelerator area, converting all of the PEP Ring Road vicinity into a general access area. In addition, this project will support a reconfiguration of SLAC’s main gate at Sand Hill Road, which requires modernization to improve safety and efficiency, and will add radiation portal monitoring capability at SLAC’s two external gates.
  
  *Funding: DOE Safeguards and Security*

### 6.3 Asset Management

#### 6.3.1 Replacement Plant Value (RPV)

Facilities Information Management System (FIMS) is the DOE's corporate real property database required by DOE Order 430.1C Real Property Asset Management (RPAM). DOE relies on FIMS extensively for making daily management decisions as they relate to condition, use, mission, status, maintenance, operations, and disposition of real property. Complete and accurate information on real property assets is critical to DOE for
managing facilities and satisfying several external reporting requirements such as the Federal Real Property Profile, Office of Management and Budget, Congress, and the taxpayers.

One such data element that required local level refinement is RPV. In the third quarter of FY 2017, we began the effort to accurately calculate RPV by using a modified DOE model to reflect the uniqueness of our facilities and the higher costs associated with the San Francisco Bay Area. As a result of this adjustment, RPV in the coming years will increase. The reported FY 2017 RPV for SLAC was $1.92 billion, whereas the RPV in April 2018 is $2.7 billion. While this is a large increase, the OSFs that were evaluated during this time included approximately 560,000 square feet for all tunnel facilities. We began the review with these facilities because they appeared to have the lowest and most inaccurate RPV values. We do not anticipate any large increases as we continue to update RPV on our infrastructure. Twenty to thirty assets will be updated each year until all of our 260 assets are reviewed in a onetime effort completed over 10 years.

To ensure validity of the data, we will rely on the data quality enforced through the annual FIMS data validation. On a yearly basis, we will review updates and gain concurrence from DOE on the methodology, modified models, and factors used to adjust RPV.

6.3.2 Deferred Maintenance (DM)

In 2016, a collaboration of science laboratories under the Infrastructure/Mission Readiness Working group developed a process to better define DM and Repair Needs (RN). Applying the new flowchart methodology, SLAC revised items which were previously miscategorized as DM and RN. In conjunction with the new process, SLAC implemented a new Facilities and Operations Division (F&O) management model in which professional stewards were appointed as subject matter experts responsible for assessing systems and developing a plan to address infrastructure gaps. As a result of bringing in subject matter expertise, particularly in the area of underground utilities and infrastructure, we identified many additional deficiencies. These stewards also performed a thorough review of previous cost estimates, revealing that the data was dramatically underestimated due to the number of deficiencies and market escalations. Furthermore, the high cost of construction and labor in the Bay Area were factored in these calculations.

As a result of using the new methodology, updated assessments, and revised cost estimates, SLAC has a revised baseline DM from $28.4 million in our FY 2017 ALP to a more accurate $80.3 million this year. Even with this higher but more realistic DM amount, the overall SLAC Facility Condition Index earns a “good” rating by industry standards. The DM calculates to approximately 3 percent of RPV, which is less than industry standard. Assets identified as high risks are addressed through our campus strategy infrastructure investments. Current DOE-SLI investments in KSU and MLVR, and SLAC IGPP investments such as underwater cooling water laterals are beginning to reduce our DM. As we complete the proposed projects discussed above, we will be able to retire a significant portion of this DM.
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Notes:

1. Total includes funding from prior fiscal years.

### 6.5 Integrated Facilities and Infrastructure (IFI) Crosscut Data Table

#### SLAC National Accelerator Laboratory

**SC Integrated Facilities and Infrastructure (IFI) Crosscut Data Table**

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<td>SLI GPP</td>
<td>9,900</td>
<td>8,800</td>
<td>9,400</td>
<td>0</td>
<td>0</td>
<td>18,000</td>
<td>23,600</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>GPP</td>
<td>1,300</td>
<td>690</td>
<td>4,048</td>
<td>7,000</td>
<td>3,500</td>
<td>699</td>
<td>679</td>
<td>0</td>
<td>5,550</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total DOE Capital Investment</td>
<td>35,200</td>
<td>9490</td>
<td>28,448</td>
<td>22,000</td>
<td>33,700</td>
<td>84,699</td>
<td>51,279</td>
<td>23,000</td>
<td>5,550</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>IGPP</td>
<td>12,167</td>
<td>6,375</td>
<td>20,002</td>
<td>15,180</td>
<td>9,300</td>
<td>8,700</td>
<td>9,108</td>
<td>10,200</td>
<td>9,700</td>
<td>10,200</td>
<td>10,700</td>
<td>11,800</td>
<td>11,800</td>
</tr>
<tr>
<td>Total Capital Investment</td>
<td>47,367</td>
<td>16,465</td>
<td>48,450</td>
<td>37,180</td>
<td>37,200</td>
<td>93,399</td>
<td>60,387</td>
<td>33,200</td>
<td>15,250</td>
<td>10,200</td>
<td>10,700</td>
<td>11,800</td>
<td>11,800</td>
</tr>
</tbody>
</table>

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<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Predictive, Preventive and Corrective M&amp;R</td>
<td>14,271</td>
<td>11,157</td>
<td>11,402</td>
<td>11,402</td>
<td>11,300</td>
<td>11,000</td>
<td>10,800</td>
<td>10,600</td>
<td>10,400</td>
<td>10,200</td>
<td>10,000</td>
<td>9,800</td>
<td>9,600</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Annual Required Maintenance (should be consistent with 1/8/2018 definition of ARM data in FIMIS Data Dictionary) ($000)</th>
<th>2017* Actual</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
<th>2025</th>
<th>2026</th>
<th>2027</th>
<th>2028</th>
<th>2029</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation, Surveillance &amp; Maintenance (OS&amp;M) of Excess and Unutilized Facilities</td>
<td>140,161</td>
<td>150,319</td>
<td>157,835</td>
<td>165,727</td>
<td>174,013</td>
<td>182,714</td>
<td>191,849</td>
<td>201,442</td>
<td>211,514</td>
<td>222,090</td>
<td>233,194</td>
<td>244,854</td>
<td>257,097</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
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<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Disposal and Demolition</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>51</td>
<td>51</td>
<td>102</td>
<td>102</td>
<td>255</td>
<td>255</td>
<td>255</td>
<td>255</td>
<td>204</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Other Data Required to Characterise the Campus Strategy reflected in the Infrastructure</th>
<th>2017* Actual</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
<th>2023</th>
<th>2024</th>
<th>2025</th>
<th>2026</th>
<th>2027</th>
<th>2028</th>
<th>2029</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deferred Maintenance Projection ($000)**</td>
<td>80,823</td>
<td>80,257</td>
<td>75,139</td>
<td>69,625</td>
<td>73,106</td>
<td>61,703</td>
<td>64,788</td>
<td>64,627</td>
<td>67,858</td>
<td>66,327</td>
<td>69,644</td>
<td>73,126</td>
<td>76,782</td>
</tr>
<tr>
<td>Replacement Plant Value Projection ($000)*****</td>
<td>1,916,654</td>
<td>2,754,749</td>
<td>2,892,486</td>
<td>3,037,111</td>
<td>3,188,966</td>
<td>3,348,415</td>
<td>3,515,835</td>
<td>3,691,627</td>
<td>3,876,208</td>
<td>4,070,019</td>
<td>4,273,520</td>
<td>4,478,196</td>
<td>4,711,356</td>
</tr>
<tr>
<td>Building Area Increases (Total $SF)</td>
<td>125,622</td>
<td>0</td>
<td>45,000</td>
<td>23,800</td>
<td>14,400</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Building Area Removals (Total $SF)</td>
<td>0</td>
<td>0</td>
<td>1417</td>
<td>1417</td>
<td>2928</td>
<td>1566</td>
<td>4821</td>
<td>8001</td>
<td>4507</td>
<td>3567</td>
<td>3939</td>
<td>2816</td>
<td></td>
</tr>
<tr>
<td>Excess Facilities (Total $SF)</td>
<td>349,793</td>
<td>349,793</td>
<td>349,793</td>
<td>33562</td>
<td>32145</td>
<td>29227</td>
<td>27651</td>
<td>22880</td>
<td>14829</td>
<td>10322</td>
<td>6675</td>
<td>2816</td>
<td></td>
</tr>
<tr>
<td>Assets Classified as “Inadequate”: RPV</td>
<td>1,435,139</td>
<td>1,514,751</td>
<td>1,536,452</td>
<td>1,633,763</td>
<td>1,830,197</td>
<td>1,940,009</td>
<td>2,056,410</td>
<td>2,179,794</td>
<td>2,310,582</td>
<td>2,449,217</td>
<td>2,596,170</td>
<td>2,751,940</td>
<td>2,917,057</td>
</tr>
<tr>
<td>Assets Classified as “Inadequate”: GSF (if GSF applicable)</td>
<td>1,701,665</td>
<td>1,827,487</td>
<td>1,827,487</td>
<td>1,827,487</td>
<td>1,827,487</td>
<td>1,827,487</td>
<td>1,898,179</td>
<td>1,912,717</td>
<td>2,012,717</td>
<td>2,127,177</td>
<td>2,237,177</td>
<td>2,327,177</td>
<td>2,427,177</td>
</tr>
<tr>
<td>Assets Classified as “Inadequate”: # of</td>
<td>14</td>
<td>14</td>
<td>10</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Assets Classified as “Inadequate”: RPV of</td>
<td>$157,023</td>
<td>$164,864</td>
<td>$175,107</td>
<td>$83,818</td>
<td>$88,009</td>
<td>$92,409</td>
<td>$97,030</td>
<td>$101,881</td>
<td>$106,975</td>
<td>$112,824</td>
<td>$117,940</td>
<td>$123,837</td>
<td>$130,029</td>
</tr>
</tbody>
</table>
6.6 Computing Infrastructure

SLAC has a strategy that supports and enables the Laboratory’s strategic initiatives by providing scientific computing services, support, cybersecurity, and productivity tools. SLAC partners with the science community on future requirements to enable alignment, planning and development of new capabilities.

The Laboratory’s computing and supporting infrastructure is located primarily within the aging SLAC Computation Center, an approximately 17,000-square-foot data center built in 1977, hosting over 3,000 physical servers (80 percent high-performance computers for science, 20 percent for business systems), networking infrastructure, storage, telecommunications, wireless systems, and High-Performance Computing systems.

SLAC also uses SRCF, a data center that was built by Stanford on the SLAC site with the agreement that SLAC can use up to 16.6 percent of the facility’s capacity. SRCF recently received a perfect Energy Star score of 100/100, outperforming 100 percent of similar data centers nationwide. SRCF uses 39.4 percent less energy per square foot than the national average. The computing space allocated to SLAC is based on power usage and is equivalent to 25 racks (500 kw/hour), of which we are currently using about 14 racks. SLAC is developing plans to exploit the remaining SRCF allocation, deploying new, lifecycle-managed equipment in the facility in cases where the data center’s risk profile is appropriate.

6.6.1 Information Technology (IT) R&D

IT R&D at SLAC supports the Laboratory’s mission related to computing services and infrastructure.

SLAC is engaged in gathering requirements for the science facilities and HEP programs, seeking convergence on cost-effective shared solutions whenever possible. Planning for the important strategic needs of the Laboratory’s scientific community, including LCLS-II and cryo-EM, continues to be a top priority for SLAC. This includes the buildout of significant compute and storage resources in the next two to three years. We recognize that these centers will offer both strategic and tactical direction towards the design and scale of common, shared solutions that can address emerging and growing scientific computing requirements at the Laboratory.

Covering the entire software and hardware stack, SLAC provides planning, consulting, support, and maintenance of institutional compute clusters; flash-based, hard disk, and tape storage systems; operating systems, middleware, and libraries (including licensing); cloud resources; and technical interaction with other laboratories such as NERSC.

SLAC delivers support services for scientific data on disk and tape. Storage capabilities will scale up over time to match the science requirements, which will exceed the capacity of SLAC’s existing 100-petabyte (PB) tape silo. SLAC will host 400 PB of LCLS-II data in 2024 and 1,000 PB by 2028 by deploying an all-new tape silo with periodic upgrades to leverage the most cost-effective storage densities.

SLAC is evolving data management capabilities with the expansion of Storage-as-a-Service to provide cost recovery, reduce the risk of aging equipment, and provide integrity for our scientific datasets. We are also beginning to use hierarchical storage management to drive down the cost of storage for our users and to provide more efficient use of storage resources.

In an industry partnership with autonomous vehicle startup Zoox, SLAC intends to collaborate using a shared GPU capability that could be leveraged by science groups within the Laboratory. This development environment could enable investigation into the design, development, and maintenance of leading-edge GPU clusters, as well as high-fidelity simulations of the real world and testing/evaluation of the associated algorithms.

We will need to retire or replace equipment which has reached the end of the manufacturer’s support period. SLAC is developing an end-to-end approach to providing recommendations for lifecycle and sustainable computing.
NERSC facilities are also leveraged, where applicable, with 34 SLAC users accounting for more than 30 million NERSC compute hours\(^4\) in the last year. This accounts for almost a doubling of NERSC computational resources used in two years, signifying the importance of NERSC to meet SLAC’s scientific mission. Understanding and meeting the requirements of using NERSC as a resource for LCLS-II is also a top priority. We are seeking guidance and requirements from our users to focus our service portfolio and better serve the needs of our community.

**Table 4: Existing R&D Systems**

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Primary Funding Source</th>
<th>Costs ($M)</th>
<th>Lifecycle State</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office of the Chief Information Officer (OCIO) Scientific Computing</td>
<td>Scientific Computing IT support and related software license renewals for Unix-based systems; High-Performance Storage Systems and other Scientific Computing infrastructure.</td>
<td>Indirect</td>
<td>2.76</td>
<td>Hardware infrastructure currently undergoing a lifecycle program</td>
<td></td>
</tr>
<tr>
<td>SRCF Infrastructure</td>
<td>SLAC dedicated allocation is 500 Kw/hr power.</td>
<td>Indirect</td>
<td>0.58</td>
<td>Nearing end-of-life</td>
<td>50 percent of racks allocated are used (Sherlock Cluster).</td>
</tr>
<tr>
<td>Science Directorates R&amp;D support staff and systems. Dedicated and Shared clusters (compute batch nodes), disk and tape Storage, and supporting science infrastructure</td>
<td>Scientific research staff and supporting systems within the Science Directorates in direct pursuit of the science. Includes - clusters: more than 14 clusters, &gt; 19,000 cores supported by over 3000 servers.</td>
<td>Direct</td>
<td>6.63</td>
<td>Some systems are being upgraded but the majority are aging.</td>
<td></td>
</tr>
</tbody>
</table>

**Table 5: Planned Acquisitions of R&D Systems**

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>FY 2018 Planned Spending ($M)</th>
<th>FY 2019 Projected Spending ($M)</th>
<th>FY 2020 Projected Spending ($M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OCIO Scientific computing infrastructure replacements, upgrades, and migration to a services-centric business model</td>
<td>Lifecycle management of infrastructure provides centrally-provided services to science</td>
<td>0.1</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>OCIO R&amp;D Systems M&amp;S</td>
<td>Software, hardware, services, and related equipment</td>
<td>1.16</td>
<td>1.19</td>
<td>1.22</td>
</tr>
<tr>
<td>Science Directorates R&amp;D Systems M&amp;S</td>
<td>New infrastructure and software in direct support of R&amp;D</td>
<td>3.38</td>
<td>3.49</td>
<td>3.54</td>
</tr>
</tbody>
</table>

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\(^4\) NERSC compute “hours” are calculated by multiplying the number of nodes utilized by the number of processor cores in each node and the number of hours that the job ran. NERSC supercomputers are comprised of thousands of nodes, each of which has a number of processor cores.
6.6.2 Commodity IT

Commodity IT resources are provided by the Computing Division to support the business operation of the entire laboratory. Commodity IT includes business systems such as financial, human resources, procurement, and health and safety. It also includes end user systems, telecommunications, and cyber security. The total cost of these systems includes any licenses, hardware, maintenance, user support fees, and cloud services, as shown in Table 4.

SLAC has instituted an IT infrastructure lifecycle management program for business IT to address the consequences of aging systems, better use finite data center resources, and optimize budgetary resources. This risk-based program drives the virtualization of bare metal servers, migration of services to more supportable platforms, consolidation of applications, and importantly, the use of cloud services.

The Laboratory continues to expand our use of cloud services in keeping with a “cloud first” strategy. In the past year, Microsoft Office 365 was deployed to all users and Laboratory email services were migrated to the Microsoft Cloud. Two cloud-based business systems, for immigration case management and for business travel management, were also implemented. In the coming year, further services, such as user network file storage, will also be migrated to cloud service providers, which will decrease the data center infrastructure footprint and associated operational load on the organization.

Virtualization continues to make an impact on the Laboratory's IT infrastructure lifecycle efforts and, for the first time, virtual machines made up more than 50 percent of all commodity systems in the data center.

SLAC maintains about 250 business applications and services using 600 servers and supporting infrastructure. To optimize space, risk, and cost, the infrastructure lifecycle management program uses virtualization technologies and cloud adoption, and has a target to reduce business hardware by 60 percent in five years. More than 300 systems have been decommissioned to date. The lifecycle management program helps free capacity for projects such as LCLS-II, reduces risk inherent in operating legacy infrastructure, and enables improved data center energy efficiency.

Identity and Access Management systems need to be updated to allow a single sign-on as a precursor for a global search engine. An architectural analysis is underway and will be completed in FY 2018. Conference room services (video and audio) need to be revamped to provide modern tools for our global collaborative scientific interactions and to enable virtual workforce options.

SLAC has made significant upgrades to the Laboratory's network to enable the science mission, in particular LCLS-II. The Laboratory has replaced our aging network border routers and has collaborated with ESnet to implement 200-GB-per-second connectivity, doubling previous capacity. The upgraded border routers, along with recently replaced core routers, were essential to enable the Laboratory to exploit the increase in bandwidth and reduce the risk of security vulnerabilities and system failure. This updated infrastructure will enable the Laboratory to double capacity again by 2022 in support of LCLS-II requirements to exploit other data analysis facilities, such as NERSC. SLAC continues to partner with DOE Leadership Facilities, ESnet, and data transfer software vendors to ensure capabilities enable the needs of science. The upgrade will enable incremental expansion of internet bandwidth capacity until 2022, when additional upgrades will be required to take ESnet bandwidth to 1 terabit.

SLAC leverages Stanford for software licensing where feasible. The Laboratory also benefits through alignment with the Stanford information security program, by making use of cyber operational tools and implementation for information security such as multi-factor authentication, mobile device management, and backup of personal computers. Further opportunities are being explored under the current contract.

SLAC realized cost saving that were reinvested to enhance enterprise capability in two key categories. First, leveraging solutions provided at no cost or reduced cost by Stanford has provided approximately $520,000 in savings since 2013. Second, the transition from on premise to Microsoft Office 365 has resulted in a savings on server infrastructure of approximately $96,000.
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Primary Funding Source</th>
<th>Costs ($M)</th>
<th>Lifecycle State</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network, storage, and Data Center infrastructure and support staff</td>
<td>Newly replaced network core and border provides 200 Gigabits per second connectivity to ESnet. Includes servers and storage to support Lab.</td>
<td>Indirect</td>
<td>1.35</td>
<td>Portions of network end of life are being upgraded.</td>
<td>Lifecycle management plan in place for the entire network (actively managing servers).</td>
</tr>
<tr>
<td>IT Services support &amp; Computing end points (includes Help Desk desktop and video conferencing support)</td>
<td>IT Services support. Computing end points: ~5,000 SLAC-owned user devices</td>
<td>Mix. Indirect funding for Core services. Chargeback to direct/indirect for Help Desk services.</td>
<td>0.70</td>
<td>Computing end points: 50 percent end of life</td>
<td>Strategy for lifecycle of endpoint management program</td>
</tr>
<tr>
<td>Windows Infrastructure, support staff, and Materials and Services (M&amp;S)</td>
<td>Includes Microsoft licensing and support. Software installation, directory, patch management, login service.</td>
<td>Indirect</td>
<td>1.38</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Telephony</td>
<td>Telephone system is a hybrid private bank exchange (PBX), which supports both time-division multiplexing and Voice over internet protocol (VoIP)-based communications.</td>
<td>Indirect</td>
<td>0.66</td>
<td>Stable/End of Life. Planning in future to migrate to a VoIP systems (or software based phone system).</td>
<td>VoIP replacing the majority of the PBX system.</td>
</tr>
<tr>
<td>Mission Support</td>
<td>Software systems, hardware, database administration, and support for current SLAC mission-supported business.</td>
<td>Indirect</td>
<td>11.8</td>
<td>Business systems applications are undergoing optimizations and upgrades. Hardware infrastructure currently undergoing a lifecycle program.</td>
<td></td>
</tr>
<tr>
<td>Cyber Security</td>
<td>Cyber staff and initiatives towards addressing all federal and DOE requirements.</td>
<td>Direct</td>
<td>2.13</td>
<td>N/A</td>
<td>Stanford provides several cyber security solutions to the Laboratory at no cost or reduced cost.</td>
</tr>
<tr>
<td>Science directorates desktop support staff and systems</td>
<td>Desktop staff and computing resources support directorates such as LCLS, SSRI, etc.</td>
<td>Direct</td>
<td>1.89</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>
### Table 7: Planned Acquisitions of Commodity IT Systems

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>FY 2018 Planned Spending ($M)</th>
<th>FY 2019 Projected Spending ($M)</th>
<th>FY 2020 Projected Spending ($M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commodity Infrastructure Upgrades/Replacements</td>
<td>Reduction of risk associated with end-of-life age of the infrastructure components (network, servers, storage etc.)</td>
<td>0.85</td>
<td>1.23</td>
<td>1.23</td>
</tr>
<tr>
<td>Commodity M&amp;S</td>
<td>Application software, servers, personal computers, peripherals, telephones, conference room systems and related equipment</td>
<td>2.67</td>
<td>2.73</td>
<td>2.73</td>
</tr>
<tr>
<td>Cybersecurity Hardware and M&amp;S</td>
<td>Hardware and M&amp;S costs to support cybersecurity requirements.</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Cloud Strategy (Office365; email; SharePoint; et al)</td>
<td>Migration of email to the cloud; retrofit of customized SharePoint sites to Office365 version; migration of selected business applications to cloud (evaluation).</td>
<td>0.30</td>
<td>0.50</td>
<td></td>
</tr>
<tr>
<td>Identity and Access Management (IAM)</td>
<td>Single sign-on</td>
<td>0.15</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>Enterprise search</td>
<td>Search engine for SLAC online documentation (contingent on IAM)</td>
<td></td>
<td>1.30</td>
<td></td>
</tr>
<tr>
<td>Commodity M&amp;S within the science directorates</td>
<td>Application software, servers, personal computers, peripherals, and related equipment purchased by science</td>
<td>2.03</td>
<td>2.08</td>
<td>2.13</td>
</tr>
</tbody>
</table>

### 6.7 Site Sustainability Plan Summary

SLAC met our FY 2017 target for the majority of DOE’s sustainability goals. Our strategy is to perform building assessments, prioritize opportunities based on achieving DOE goals, and develop projects to optimize energy and water usage as stewards of our DOE site. SLAC made excellent progress this year, including:

- Certifying the Research Office Building (Building 48) as a High-Performance Sustainable Building (HPSB) – the building qualified for an Environmental Protection Agency EnergyStar 2017 Certification following LED lighting and HVAC re-commissioning efficiency improvements, placing the building in the top 20 percent of buildings nationwide for comparable energy performance;
- Completing a Federal Energy Independence and Security Act (EISA) audit Detailed Energy Survey of 24 buildings that identified the highest potential for energy saving opportunities;
- Building an Energy Metering Dashboard with real-time displays and historic electricity trend data on all metered buildings; and
• Completing LED lighting replacement of 40-year-old inefficient Hi-Bay High Intensity Discharge (HID) lamps in Building 750, reducing annual maintenance and electricity costs by $40,000.

SLAC’s next steps are:
• Performing HPSB assessments on existing buildings to select buildings for future certification;
• Re-commissioning energy systems on five buildings for the current EISA audit cycle, scheduled for completion in mid-2020);
• Increasing building manager awareness of the capability to use the metering tool to monitor performance and control energy waste; and
• Implementing additional HID lighting upgrades, beginning with a 35,000-square-foot lighting upgrade to Building 26 in 2018.

Projects evaluated in feasibility studies for a Utility Energy Service Contract did not have an acceptable return on investment due to the low cost of power from the Western Area Power Administration.

SLAC has systematically reduced the number of government vehicles from 224 vehicles in 2005 to 142 leased and two owned today, for an overall reduction of 80 vehicles (35 percent). Our fleet greenhouse gas reduction strategy is to convert to plug-in hybrids and electric vehicles, and decrease vehicle size. Our commitment to increase efficiency is demonstrated by a 78 percent improvement in the average miles-per-gallon rating for incoming 2018 traded vehicles. In addition, a free public transit commuting pass was provided to all SLAC staff in 2018 through Stanford, as an incentive to decrease vehicle commuting and related emissions.

**Figure 2: Electricity Usage & Cost Projections**

![Electricity Usage & Cost Projections](image_url)
7. Human Resources

7.1 Recent History

SLAC’s annual lab-wide talent assessment and planning process is driven by the laboratory initiatives and priorities described in this ALP. Outcomes from our fourth annual process, which concludes in summer, will inform where we target our development efforts going forward. In addition, we’re creating knowledge transfer plans for unique skills and legacy experience to prepare for the large retirement wave coming in the next three to five years. We also recently created an FY 2018 Staffing Resource and Process Improvement Plan for subcontractor management to address the Laboratory’s ongoing notable workload.

Total employee turnover in FY 2017 was 8.35 percent, which is consistent with the past five years. Turnover during this period included workforce adjustments of 17 voluntary and 12 involuntary layoffs, accounting for 24 percent of all departures in FY 2017.

<table>
<thead>
<tr>
<th>Functional Area</th>
<th>FY 2015</th>
<th>FY 2016</th>
<th>FY 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Senior Leadership</td>
<td>6</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Research/Technical Management</td>
<td>256</td>
<td>252</td>
<td>244</td>
</tr>
<tr>
<td>Operations (or research support)</td>
<td>75</td>
<td>74</td>
<td>74</td>
</tr>
<tr>
<td>Technical Research Staff, Non-management</td>
<td>711</td>
<td>723</td>
<td>761</td>
</tr>
<tr>
<td>Operations Support Staff, Non-Management</td>
<td>367</td>
<td>391</td>
<td>388</td>
</tr>
<tr>
<td>Post-docs Employees</td>
<td>119</td>
<td>201</td>
<td>152</td>
</tr>
<tr>
<td>Paid Graduate Students</td>
<td>167</td>
<td>208</td>
<td>220</td>
</tr>
<tr>
<td>Paid Undergraduates</td>
<td>0*</td>
<td>0*</td>
<td>79</td>
</tr>
<tr>
<td>Totals</td>
<td>1,701</td>
<td>1,855</td>
<td>1,925</td>
</tr>
</tbody>
</table>

*SLAC began tracking undergraduate interns in FY 2017, so we do not have historical data.

7.1.1 Workforce Planning

Developing the skillsets necessary to support the LCLS-II and LSST projects and their transitions to operations, as well as skillsets fostering the growth of the Laboratory, continues to be a major focus.

- LCLS-II will require a shift in core expertise at SLAC, which will significantly impact staff deployment across all directorates that work on LCLS. In preparation, we have evaluated staff at the individual level to ensure appropriate task management, career development, and fulfillment of objectives. We spent the last year developing an integrated laboratory plan covering a five-year period for core staff and skills. This plan quantified the staffing challenge of transitioning from the LCLS-II project to operations; the timeliness of LCLS-II-HE; and our drive for greater integration of scientific and engineering activities and opportunities across the Laboratory. Two major aspects of this are the “transition to operations” period and the extended shutdown of LCLS during FY 2019-FY 2020 to enable the construction of LCLS-II. Deployment and retention of staff during this period is a major focus of our lab-wide planning process. A similar employee-by-employee and skillset-by-skillset plan is being developed for the scientists, engineers, and technicians supporting the LSST camera project for the transition from construction to commissioning and facility operations, as well as participation in science opportunities with LSST-DESC.

- Maintaining the requisite intellectual and technical capacity in accelerator science, engineering, and technical support is crucial for the timely commissioning, operation, and early science from LCLS-II, and is critical to maintaining our core capability and realizing future accelerator initiatives. Anticipated retirements will create gaps in leadership from frontline supervisors to division heads.

- Our focus on capability growth, which includes both hard X-ray and soft X-ray, requires expanding the skillsets of our staff (scientific, engineering, technical) in a highly competitive environment within the local area. Our approach is focused on hiring soft X-ray early career staff and then training them in-house, which requires some augmentation of senior personnel, while maintaining our hard X-ray capabilities.
• The next five years will continue to see an intensive need for cryogenics engineering and SRF staff, precision mechanical engineers, optical engineers, systems integration experts, technical project managers, and very-large-scale data experts. These skills are in very short supply and require aggressive and targeted recruitment and development. We are actively engaging with DESY and U.S. national laboratories to train our workforce in cryogenics, cryomodules, and SC linac operations.

• Our growth strategy requires migrating to a culture of entrepreneurship, which requires recruiting staff who will both excel in science and engineering and take an entrepreneurial role in developing new projects and the R&D thrusts of the future. We have launched several successful recruiting efforts, and we continue to seek critical hires in the areas where we intend to expand the laboratory’s multi-program mission. We are also developing scientific leadership, program development, and project management skills in our early and mid-career researchers with the goal of creating and executing opportunities for high-impact R&D across DOE and other federal agencies.

7.1.2 Scientific Leadership

SLAC is led by our senior management team (SMT), chaired by the laboratory director and comprised of: two deputy directors, associate laboratory directors (ALDs) of each of our six mission directorates, directors of each of our six mission support divisions, laboratory counsel and the director of Contractor Assurance and Contract Management (CACM).

SLAC continues to successfully attract high-quality science leadership by appointments to the SLAC faculty. The combination of Stanford and SLAC is uniquely attractive. We will continue this strategy to renew science leadership in existing areas and grow in new research directions, as described in Section 4 of this ALP.

7.1.3 Key Science Appointments

• JoAnne Hewett now leads the newly formed Fundamental Physics Directorate as ALD and serves as SLAC’s Chief Research Officer. Formerly the deputy director of the Science Directorate and director of the Elementary Particle Physics Division, JoAnne has significant experience as a senior leader at SLAC, as well as a distinguished career as a renowned theoretical physicist.

• Tony Heinz now leads the newly formed Energy Sciences Directorate as ALD. Formerly director of the Chemical Sciences Division, Tony came to SLAC from Columbia University. His research has centered on the properties and dynamics of nanoscale materials through the application of optical spectroscopies.

• Bruce Dunham is now ALD for the Accelerator Directorate (AD). Formerly the deputy director for operations of AD, Bruce is an expert in SRF and high brightness photoinjectors.

• Greg Hayes is now project director for LCLS-II-HE; previously, Greg was the acting technical director for LCLS-II and the cryogenics deputy system manager for LCLS-II.

• David MacFarlane is now project director for SuperCDMS. Formerly SLAC’s Chief Research Officer and senior associate dean, David is a prominent experimentalist in HEP.

7.1.4 Key Operations Appointments

All of our key operations appointments in FY 2017, listed below, were internal promotions, which demonstrates the progress made by SLAC’s talent development program.

• Brian Sherin now serves in the newly created role of Deputy Director of Operations. Formerly the director of the Environment, Safety & Health (ES&H) Division, Brian has developed a deep understanding of the lab, as well as strong relationships with our DOE Site Office and Stanford’s Board of Overseers for SLAC.

• Theresa Bamrick is now Chief Information Officer and director of the Computing Division; previously, Theresa was the deputy director of Computing.

• Machelle Vieux is now director of the F&O Division; previously, Machelle was the deputy director of F&O.

• Carole Fried is now Chief Safety Officer and director of the ES&H Division; previously, Carole was the deputy director of ES&H.
• **Melinda Lee** is now director of the Communications Division; previously, Melinda was the manager of Community and Outreach in Communications.

• **Jodi Verleger** is now interim director of the Human Resources Development and Services Division (HRD&S); previously, Jodi was the manager of Organizational and Employee Development in HRD&S.

### 7.1.5 Leadership Development

Our focused talent assessment and development efforts have resulted in a 12 percent increase in staff that could assume a designated leadership position immediately with little risk, referred to as "ready now." Evidence of SLAC's success in this area is the eight promotions of "ready now" staff to senior leadership roles in FY 2017, as described in Section 7.1.3 and 7.1.4 of this ALP. While the increased numbers are encouraging, much work remains to be done. Our talent planning targets long-term development of key science, engineering, and operations leadership positions and staff. Key talent receives development planning and expert resources from Stanford. To support leadership development in FY 2017, SLAC launched a pilot for high-potential managers with a focus on laboratory acumen and leadership intelligence. Its success led to two additional leadership programs being launched in FY 2018 targeting early technical leaders in both science and engineering and direct reporting managers to our SMT. Regular manager all-hands meetings provide development opportunities. The levels of engagement in our updated performance guidance process notably increased in FY 2017; 97 percent of employees participated and the quality of feedback to and from managers improved an additional 15 percent.

### 7.2 Future Challenges and Actions

SLAC's ongoing challenge is to hire, develop, and retain best-in-class science and technical talent and to enhance the Laboratory's leadership capacity to accomplish our science strategies and advance our core capabilities. As international laboratories with competing capabilities come online, demand for our expert staff grows. Many key job groups are recruited from small and very competitive domestic and international pools. Our location places us in the most competitive employment and housing market in the country. We continue to make use of the compensation and housing benefits available to us while also supporting Stanford planning efforts to ameliorate this ongoing threat. Upcoming critical searches include the director of the KIPAC, the director of the PULSE Institute, and the director of HRD&S.

In FY 2017, SLAC implemented an engineering career track that is mapped onto Stanford's compensation structure. We are currently updating and mapping our science career track for completion in FY 2018.

As outlined in our annual DOE-SC Diversity & Inclusion (D&I) plan, SLAC continues to engage and deepen our D&I practice. We hold our senior managers accountable to support our three key 2018-2019 D&I objectives through expectations that they: partner with HRD&S to incorporate bias mitigation into all our people processes (e.g. interview panel preparation, hiring decisions, performance review analysis, etc.); participate in bias awareness presentations; review quarterly diversity and performance metrics; serve as executive sponsors of SLAC's Employee Resource Groups (ERGs); actively engage internship programs with diversity criteria; and discuss inclusive behaviors at staff meetings.

Employee surveys are planned in FY 2018 to better understand engagement levels of all groups and address our inclusion practices. SLAC is spearheading a collaborative, multi-laboratory inclusion study by partnering with the Association of Women in Science to pursue grant funding. Planning is underway and the results of our climate survey this summer will be used by participating labs to baseline questions.

Additional efforts we have planned for FY 2018 include standing up a D&I council, expanding mentoring opportunities for early career science talent, convening a committee of ERG leads, and providing inclusive spaces like lactation rooms and gender neutral restrooms. We have seen notable improvements in hiring female scientists, but there is more work to do in other employee groups. Additionally, the number of women on our SMT has grown from one in 2015 to seven. HR staff are working to extend the diversity of external talent pipelines and supporting management’s development of internal talent. For more information about our 2017 D&I accomplishments and strategies, refer to SLAC's 2018 DOE Annual D&I Plan.
8. Cost of Doing Business

8.1 Overhead Budget Process

SLAC, like all national laboratories, exists in dynamic environments where continual change and evolution is required. To effectively execute SLAC’s strategy, our overhead budgeting must be performed in the context of how the Laboratory can be a distinct and sustainable place. SLAC’s overhead budgeting process aligns our resources with our priorities to support our success. SLAC budgets are focused on the areas described in previous sections this ALP.

We plan our indirect budgets in the following broad portfolios: (1) mission support, (2) strategic priorities, and (3) reserve. The total indirect budget is sized to maintain SLAC’s pricing position relative to the other science laboratories and to maintain costs to programs at or below inflation. We have held year-over-year increases in our mission support spending to two percent for the last four budget cycles. This has challenged the Laboratory to identify and implement cost saving measures such as outsourcing to Stanford and evaluating cloud technologies to reduce our costs while allowing us to increase our investment in our strategic initiatives, core capabilities, and infrastructure.

Budgets for our strategic initiatives include our LDRD program, faculty and senior scientist start-up packages, PD funds, and infrastructure investments. Nearly one-third of our indirect resources are directed toward our strategic initiatives and maintaining or improving our site, as shown in Table 9.

Table 9: Cost of Doing Business Tables

<table>
<thead>
<tr>
<th>FY17 Total Lab Costs = $602M</th>
<th>FY17 Fully Burdened Person Cost = $223K</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Indirect 20%](Indirect 20%)</td>
<td>![Indirect 41%](Indirect 41%)</td>
</tr>
<tr>
<td>![Direct 80%](Direct 80%)</td>
<td>![Fringe 14%](Fringe 14%)</td>
</tr>
<tr>
<td>![Salary 45%](Salary 45%)</td>
<td>![Salary 45%](Salary 45%)</td>
</tr>
<tr>
<td>![Salary 45%](Salary 45%)</td>
<td>![Salary 45%](Salary 45%)</td>
</tr>
</tbody>
</table>
8.2 Major Cost Drivers

**Infrastructure maintenance and investments:** Investing in SLAC’s infrastructure is critical to the success of the Laboratory and of our user facilities. As discussed in Section 6 of this ALP, a major cost driver for the Laboratory is revitalizing the infrastructure and facilities to meet current and emerging needs. The infrastructure mission readiness process described in Section 6 drives how SLAC allocates roughly 10 percent of our indirect budget for site improvements. Infrastructure maintenance also includes upgrading SLAC’s IT systems, including the data center and site-wide networking. SLAC is actively moving towards a life cycle management plan for infrastructure, such as computers, roofs, etc. In the near term, as we work to have a better understanding of the situation, our DM has increased. Our long-term efforts will increase infrastructure reliability while providing for budget stability.

**Workforce needs:** SLAC is challenged with the task of attracting, hiring, developing, and retaining best-in-class science and technical talent. SLAC’s ability to attract and develop bench strength and future leaders is complicated by factors such as the high cost of housing and extremely competitive job market associated with living in Silicon Valley. The workforce and leadership development activities described in Section 7 of this ALP are all done within the indirect cost of “providing business services and mission support.”

8.3 Decisions and Trade-offs

Strategy looks to the future; capabilities are aligned to the past. New or different demands that get placed on processes, systems, people, and practices necessitate shifting resources from one area to another to align with future strategic plans. SLAC is continually working to bring our infrastructure, institutional processes, and human capital into a state of mission readiness for current and future science programs. We use business plans prepared by each directorate as foundational to the laboratory agenda, helping to ensure that our resources and actions align with our strategic objectives, as well as identify high-risk areas and safety and compliance requirements. Reflecting our commitment to carry out the SLAC mission safely, effectively and efficiently, discretionary resources are focused on the six strategic initiatives outlined in Section 4 of this ALP.
Appendix 1: Laboratory Core Capabilities

SLAC is a multi-program national laboratory and the nation’s leading institution for accelerator science and technology devoted to X-ray production, for the broad and deep science enabled by these technologies, and for particle physics and astrophysics. SLAC carries out this strategy through world-leading capabilities in six core areas: Accelerator Science and Technology, Large-Scale User Facilities/Advanced Instrumentation, Condensed Matter Physics and Materials Science, Chemical and Molecular Science, Plasma and Fusion Energy Science, and Particle Physics, described in more detail below.

1. Accelerator Science and Technology

SLAC is the premier electron accelerator laboratory in the U.S. and one of the top accelerator laboratories internationally. Our world-leading research in accelerator science and technology continues to lead to innovations in accelerators at SLAC, DOE-SC, and internationally. These technologies enable the development of bright, coherent X-ray light sources – both free-electron lasers and storage ring light sources – and in Ultrafast Electron Diffraction (UED) and Ultrafast Electron Microscopy (UEM), thereby strengthening SLAC’s core capabilities in materials science, chemical and molecular science, and plasma and fusion science. In conjunction with Stanford, SLAC maintains a renowned accelerator education program – one of only a few in the United States. Accelerator Science and Technology at SLAC encompasses the following broad areas:

**FEL R&D**: LCLS is the world’s first operational hard X-ray Free Electron Laser (XFEL), with a highly successful R&D program that brings new capabilities to the user community on a continuing basis. The goal of the FEL R&D program is complete control of spectral and temporal X-ray properties to drive the discovery potential of LCLS and all its future upgrades. The program includes X-ray seeding for transform-limited pulses; high-power FEL generation by bunch compression and undulator tapering; generation and measurement of sub-fs X-ray pulses; generation of multiple colors and pulses; ultrafast techniques, diagnostics, and optics; and technology development. The R&D program recently implemented a new bunch compression mode for high-peak-power XFEL pulses, pushing the existing record by a factor of three. This mode benefits many fields, including nonlinear X-ray spectroscopy, diffraction, and imaging.

The LCLS-II project uses high-repetition-rate SC accelerator technology. In contrast to the pulsed SC European XFEL, LCLS-II will operate in a highly stable, 1-megahertz (MHz), CW mode. Providing high-brightness electron beams at the undulator is a key component for generating hard X-rays for LCLS-II-HE. High brightness beams are also critical for future experiments in UED/UEM and even PWFA. SLAC has recently launched a comprehensive program in high-brightness beams for future accelerator applications, which includes detailed start-to-end simulations to solve collective effects that degrade beam emittance. The program is developing CW SRF electron sources and plasma-based sources. This work is critical for the success of future X-ray experiments, UED/UEM, and even future colliders.

**Advanced acceleration and RF acceleration R&D**: SLAC plays an internationally unique role in the development of beam-driven plasma wakefield acceleration (PWFA). For SLAC to maintain our leadership in this increasingly competitive field, FACET-II – the follow-on facility to FACET – is under development. FACET-II will be the only facility in the world capable of providing 10-GeV electron and positron beams in support of accelerator science R&D, with the primary focus on investigating key R&D challenges of PWFA-based positron-electron colliders and fifth-generation light sources. SLAC’s capability in RF accelerator technology is tapped by federal agencies, industry, and labs around the world. Within the DOE laboratory system, only SLAC has the integrated capability to conceive, design, prototype, and test RF power sources. The foci of our source R&D efforts are game-changing reduction in source cost, efficiency improvement, and extending frequency reach to the THz regime. SLAC’s systematic investigation of the limits of RF acceleration in high-vacuum metallic structures has been extended to THz frequencies and broadened in scope to study topologies to improve efficiency.

**Accelerator test facilities**: SLAC test facilities also include:

- **The low-energy Accelerator Structure Test Area (ASTA) facility**, a small bunker and test stands equipped with multiple high-power RF sources, flexible laser, and excellent temperature stabilization that allowed efficient development of our UED capability;
• **The medium-energy Next Linear Collider Test Accelerator (NLCTA)**, which provides critical support for R&D programs vital to the future of SLAC, including SC-RF gun studies for LCLS and LCLS-II, high-gradient structure testing, and novel THz accelerator R&D supporting an existing Early Career Award; and

• **The higher-energy End Station Test Beam (ESTB)**, which plays an important national role for detector R&D by providing capabilities unique in the U.S. for small-scale experiment development, deployment, and execution, allowing graduate students and postdocs to get hands-on experience to transition into next-generation faculty and national laboratory investigators.

**UED:** SLAC has successfully realized the most advanced UED facility in the world with a 100-fs time resolution instrument at ASTA. With the addition of a THz to mid-infrared pump source, the SLAC UED facility continues to make performance improvements that expand our ultrafast science capabilities. Single-shot UED capability has been developed and successfully deployed to the scientific community. The next milestone for the UED/UEM program is the development of the worldwide first UED user facility. Additional enhancements under development include liquid sample capabilities and a smaller probe with better temporal resolution and higher flux.

An SRF gun-based UED/UEM facility is under development to enable MHz UED with atomic spatial resolution (0.3 nm) and sub-nanosecond temporal resolution. The higher beam energy will reduce sample damage and the improved temporal resolution will overcome limitations of cryo-EM to reveal important biological processes that happen on nanosecond timescales such as gigahertz protein backbone movement.

*Funding for this core capability comes from DOE-BES, DOE-HEP, SPP customers, and Laboratory Directed Research and Development (LDRD) investments. The core capability supports the DOE-SC mission in scientific discovery and innovation (SC 2, 22, 23, 24, 25, 26).*

2. Large-Scale User Facilities/Advanced Instrumentation

SLAC operates two DOE-SC user facilities (LCLS and SSRL), with a third one, FACET-II, expected to begin operation in 2020. The Laboratory also operates the joint DOE/NASA Fermi Large Area Telescope (LAT) mission, and is a major partner in several particle physics and astrophysics (PPA) instrument projects.

**Linac Coherent Light Source (LCLS):** LCLS is the world’s brightest X-ray source, and the only XFEL in the U.S. As a large-scale international user facility, it offers globally unique capabilities that serve approximately 1,000 users per year, covering a broad array of disciplines that are central to the DOE mission. These disciplines include ultrafast chemical dynamics, catalysis, quantum materials and extreme materials, biochemistry, and fundamental atomic physics. LCLS strategy is focused on high-impact science from the existing LCLS facility and the LCLS-II high repetition-rate facility due to come online in 2020/2021. The design of an instrument suite to take advantage of the orders-of-magnitude improvement in average power and spectral brightness matured into a specific plan during FY 2017, following extended consultation with the user community. The new capabilities include a dual-XFEL instrument area for X-ray pump/X-ray probe studies, a high-resolution resonant inelastic X-ray scattering spectrometer for quantum material studies, and the highest time-resolution systems for atomic and molecular physics.

Advances to LCLS capabilities in 2017 include the creation of the first ever sub-femtosecond pulses (approximately 200 attoseconds with approximately 14 eV coherent bandwidth), opening up new measurement possibilities in high-field science, charge transfer chemistry, and high-resolution structure determination; installation of the world’s flattest X-ray mirrors to provide substantial improvement in beam quality and throughput, as well as to open up new operational modes to increase facility flexibility and capacity; and design and installation of a new “split and delay” X-ray optical system providing very high stability to allow robust scanning of material dynamics over the critical 0.1 to 100 picosecond timeframe. The MEC instrument increased the energy of its optical pump laser systems by a factor of 3, with exquisite pulse-shaping and enhanced stability, addressing a core demand from the geoscience, atomic and plasma physics, and extreme materials communities supported by DOE-FES, National Nuclear Security Administration (DOE-NNNSA), and DOE-BES programs.

FY 2017 contained a six-month shutdown for major reconfiguration of the Near Experimental Hall to open up space for future instrument developments and critical support laboratories. This was successfully completed, and in the remaining part of the year the facility delivered an equal number of user experiments as was achieved in the whole
of FY 2015, representing further advances in the efficiency of operations and addressing a critical limiting factor for X-ray laser facilities.

**Stanford Synchrotron Radiation Lightsource (SSRL):** SSRL serves more than 1,700 unique users annually and produced 546 publications and 83 PhD dissertations to date in FY 2017. Stanford Positron Electron Accelerating Ring (originally SPEAR, now SPEAR3) performance remains excellent, providing high availability and high-current operation. Ongoing R&D is aimed at reducing the SPEAR3 emittance and improving time-resolved capabilities, taking advantage of the collaboration with Stanford, the strong research programs in chemical and materials science at SLAC, and the synergy with LCLS.

New developments in high-throughput measurements using *in situ* and *operando* studies of materials synthesis, growth, and assembly are enabling the acceleration of functional materials discovery and design. The establishment of X-ray emission spectroscopy and high-resolution, fluorescence-detected absorption spectroscopies in the hard, tender, and soft X-ray regimes has provided tools for the understanding catalytic function with atomic-scale precision as well as providing spectroscopic methods for chemical, biological, and environmental sciences. This latter development leverages collaborations with LCLS in detector development and shared X-ray spectroscopy capabilities, as well as collaboration with the Theory Institute for Materials and Energy Spectroscopies (TIMES).

Future developments are consistent with the SSRL strategy:

- Construction of an advanced spectroscopy beamline with 2 to 100 picosecond resolution;
- Construction of two metrology beamlines in support of DOE and DOE-NNSA mission needs;
- Construction of a microfocus macromolecular crystallography beamline funded by Stanford and The Scripps Research Institute;
- Collaboration with SIMES to develop advanced oxide materials growth capabilities coupled to an angle-resolved photoemission beamline;
- Development of a resonant soft X-ray scattering system focused on charge and spin order in correlated electron systems;
- Coordination of R&D programs between SSRL and LCLS in SC detector development; and
- Development of high average power X-ray optics in support of both the LCLS-II and APS-U projects.

SSRL will also develop and expand micro-focus macromolecular crystallography in collaboration with LCLS and complement these capabilities with cryo-EM. The new micro-focus undulator beamline at SSRL, the Macromolecular Femtosecond Crystallography (MFX) instrument at LCLS, and the suite of cryo-EMs represent complementary cornerstones for imaging biological function in space and time.

**Particle physics and astrophysics facilities and instruments:** Taking advantage of SLAC’s core strengths in DAQ, electronics, computing, and detector construction and operation, SLAC has made strategic choices to lead or engage in a specific set of major particle physics and astrophysics projects. SLAC led the upgrades to components of the ATLAS detector at the Large Hadron Collider (LHC) and SLAC’s world-leading theory group played a key role in exploiting LHC physics. As discussed below, SLAC is also exploring high-impact contributions to the national neutrino program with the liquid-argon technology for DUNE and pursuing liquid Xenon-based technology for future neutrinoless double beta decay experiments. Both these efforts build on the foundation of instrument design, prototyping, and testing that SLAC developed from leading the EXO-200 double-decay and from the liquid noble test platform set up for the LUX-ZEPLIN (LZ) experiment.

SLAC led the design, development, construction, and operation of the state-of-the-art Fermi LAT, launched in June 2008 on the Fermi Gamma-ray Space Telescope (FGST), a major space observatory for the study of high-energy processes in the universe. Expanding into dark matter and dark energy searches, SLAC is applying the experience gained from this program to the wide-field Large Synoptic Survey Telescope (LSST) in northern Chile, leading the design, fabrication, and integration of the camera. The technical expertise in building these precision detectors and cameras, combined with the laboratory infrastructure of large clean rooms coupled to integration and testing, leads us to anticipate having a major role in the eventual development and fielding of next-generation experiments for precision cosmology with CMB-S4. SLAC’s plan to take a major role in the CMB-S4 program leads to our priority to establish a Detector Microfabrication Facility in the Arrillaga Science Center (ASC) for the fabrication of SC quantum information sensors and systems. SLAC is also engaged in the construction of the next-generation experiments for direct detection of relic dark matter. We are the lead laboratory for the SuperCDMS project, a collaboration between DOE and the National Science Foundation (NSF), and provide major system contributions to the LZ project. The
experience gained in their construction, commissioning, and operation – whether in space, in underground laboratories, or on remote mountaintops – is key to the successful development of future large-scale instruments for HEP and photon science.

**Advanced instrumentation:** SLAC is an international leader in the development of advanced instrumentation and computational tools to serve the needs of our current and future X-ray and HEP experiments. Notably, SLAC has long-standing, significant expertise and capability in managing very large experimental datasets and actively developing strategies for DAQ and data management for LCLS-II and for future opportunities with LSST, ATLAS, DUNE, Cryo-EM, and UED. Integration of detector and control electronics, data systems, computational science, and algorithm development is critical to the success of these future flagship facilities and benefits from strong ties to relevant departments at Stanford. Recent notable accomplishments include system design for high-bandwidth DAQ (custom sensors, application-specific integrated circuits for detectors, storage and distributed access for 100-petabyte-class datasets); characterization and control of micron-scale photon beams; and highly automated instrument control. Applications include integrated X-ray beamlines and instrumentation for photon science experiments, ultralow background experiments for direct dark matter detection, space-qualified electronic systems, and computational resources for automated and optimized data collection and analysis.

SLAC is at the international forefront in the development of the new concept, where the data from an experimental facility are streamed on-the-fly to a supercomputer for analysis. Such near-real-time interpretation will require computational intensities of unprecedented scales, coupled to a data-path of unprecedented bandwidth. The high repetition rate of LCLS will increase its data throughput by three orders of magnitude by 2025. LCLS users require an integration of data processing and scientific interpretation, both demanding intensive computational analysis. This analysis must be carried out quickly to allow for most efficient use of beam time. Achieving such turnaround on future, much larger, datasets using algorithms with higher fidelity than any facility can support today is the goal of the ‘Data Analytics at the Exascale for Free Electron Lasers’ project (ExaFEL), led by SLAC in collaboration with LBL, LANL and Stanford.

Funding for this core capability primarily comes from DOE-BES and DOE-HEP. Other sources include DOE-BER, DOE-FES, LDRD investments and Strategic Partnership Projects (SPP) from the NIH. SLAC’s efforts support the DOE-SC mission in scientific discovery and innovation (SC 2, 21, 22, 23, 24, 25, 26). ExaFEL is supported by the Exascale Computing Project (SC 17, 20), a joint project of DOE-SC and DOE-NNSA, responsible for delivering a capable exascale ecosystem, including software, applications, and hardware technology, to support the nation’s exascale computing imperative.

3. Condensed Matter Physics and Materials Science

The history of condensed matter physics and materials science at SLAC has been tied to the development of SSRL as one of the first synchrotron light sources to address electronic and structural properties of matter. Over the last decade, the Materials Science Division (also called the Stanford Institute for Materials and Energy Sciences, or SIMES) has developed a strong program in materials science pursuing frontier issues in the assembly and design of materials, their collective quantum dynamics, and their ability to transform energy. A strong focus is on engineering novel collective properties through nanosystem of bio-inspired materials as well as low-dimensional materials and interfaces, resplendent with opportunities to study mission-relevant Grand Challenge problems. The program focuses on key scientific problems that can be addressed using SLAC’s X-ray user facilities, and complements them with world-class materials synthesis, characterization, and theory activities. These efforts involve partnerships between SLAC, Stanford, and industry researchers.

The four focus areas – quantum materials, ultrafast science, bio-inspired materials, and energy storage materials – each address DOE’s missions in science, energy, and security. Through SIMES, SLAC provides a strong coupling to initiatives at Stanford, such as the Global Climate and Energy Project and the Precourt Institute for Energy. SIMES is also involved in larger energy initiatives including DOE-BES’ JCESR Battery Hub, Battery 500, and the Bay Area Photovoltaic Consortium. In addition, SIMES is dedicated to outreach activities for energy science education and training, helping to develop the next generation of talent.

The research programs couple directly to current and future LCLS and SSRL science. Scientists from SIMES have been engaged with SSRL and LCLS in developing and using beamlines and have provided leadership to realize the ultrafast materials science strategy. Many SIMES PIs are key users of SLAC’s light sources and the UED facility, allowing them to pursue important scientific lines of inquiry identified in several recent Basic Research Needs
workshops and roundtable reports. Many of these scientists have contributed important content on quantum materials, synthesis and tool science, ultrafast science, and quantum computing to DOE-BES reports, helping to set a scientific agenda in cooperation with DOE-BES.

Looking ahead, materials science will continue to represent important scientific targets for SLAC’s X-ray user facilities at SSRL and LCLS. With the advent of next-generation X-ray facilities such as LCLS-II, a golden age of scattering and spectroscopy is emerging with unprecedented opportunities for studies at nano-to-microscopic length scales and femto-to-picosecond time scales. Advanced spectroscopic techniques will play a pivotal role in detailed explorations of the electronic, geometric, and excited state properties of crystals, surfaces, interfaces, and complex nanoscale assemblies of atoms and molecules, and how this physics evolves with temperature, pressure, electric and magnetic fields, or other externally controlled parameters. This exploration is not only of intrinsic scientific interest, but also essential for designing new materials with properties tailored for energy and other technological applications, on which the economic well-being and the energy security of the nation will continue to depend in the future.

Funding for this core capability comes from DOE-BES, with related support from Energy Efficiency and Renewable Energy (DOE-EERE) and LDRD investments and serves the DOE-SC mission in scientific discovery and innovation (SC 2, 21, 22, 23).

4. Chemical and Molecular Science

Research in chemical and molecular science forms a significant core capability for SLAC. The research program in this area focuses around two themes: fundamental understanding of chemical catalysis and research at the frontier of ultrafast chemical science. The core capability in both catalysis and ultrafast chemical science benefits greatly from the proximity to and expertise associated with SSRL and LCLS. Both programs, developed over the past decade, have achieved broad recognition for their quality and innovation, as well as for their distinctive profiles within the broader American scientific enterprise.

**Chemical catalysis:** Research into the fundamental aspects of chemical transformation through catalysis is a scientific frontier and important field for energy transformation, storage, and management. As such, research in this area is being carried out under DOE support both within the university system and within the DOE laboratory complex. The SLAC program, however, differentiates itself through our world-leading use of theory to provide a quantitative and predictive understanding of key problems in catalysis under realistic reaction conditions. Over several years, SLAC has developed a theoretical description of surface reactivity and heterogeneous catalysis, electrocatalysis, and photocatalysis. Within this program of predictive fundamental theory for catalysis, we have expanded complementary experimental expertise in catalyst synthesis, characterization, and testing. Catalyst characterization at SSRL facilities is an integral component in catalyst design and has been further strengthened by the hire of a senior staff member at SSRL with a strong background in this area. Our approach to advance chemical catalysis is supported by strong involvement of Stanford faculty, bringing together expertise in catalyst synthesis, characterization, and testing through SUNCAT. The SUNCAT program also provides the fundamental basis for the SLAC involvement in the Joint Center for Artificial Photosynthesis, where SLAC integrates theory and experiment to achieve a mechanistic understanding of electrochemical CO\textsubscript{2} reduction and to devise new catalysts for this process.

**Ultrafast chemical science:** This focus area concerns fundamental aspects of chemical transformation and dynamics at atto- to picosecond time scales. By measuring and modeling change on these ultrafast time scales, we can understand fundamental processes of electronic and nuclear motion on their intrinsic time scales. The impact and success of LCLS has been greatly enhanced by SLAC’s ultrafast science research program. The research program further benefits from strong interactions with Stanford, including the joint SLAC-Stanford PULSE Institute. In terms of its scope, depth, and experimental capabilities, the SLAC ultrafast chemical science program is unique within the U.S., although comprehensive programs are being rapidly developed elsewhere in the world, particularly in conjunction with new XFEL facilities opening abroad.

The experimental capabilities provided by LCLS and LCLS-II are complemented by extensive laboratory capabilities, including high-harmonic generation for time-resolved ultraviolet and soft X-ray spectroscopy, that permit access to dynamics occurring down to femto- and even attosecond time scales. In addition, extensive use is made of SLAC’s UED instrument for probing chemical dynamics. We are currently applying these diverse methods to study of non-Born-Oppenheimer dynamics, strong-field laser-molecule interactions, solution phase
dynamics, non-periodic X-ray imaging, nonlinear X-ray optics, and, most recently, time-resolved studies of reduced dimensional systems. The experimental efforts are coupled to a strong theory program on excited-state molecular dynamics, which is supported by advanced computational capabilities.

Funding for this core capability comes from DOE-BES (SC 2, 21, 22, 23). Selected LDRD investments are supporting scientific discovery and innovation.

5. Plasma and Fusion Energy Science

The SLAC program in plasma and fusion energy sciences is driven by a broad-based vision to exploit the unparalleled capabilities that arise from the unique combination of high-power lasers with LCLS. This program marks the beginning of a new era of precision in HED science by probing the ultrafast changes of matter in extreme conditions. Fusion science research drives new technology developments in 100-Hz repetition rate and high-power petawatt-class lasers, and develops the physics of energetic phenomena and radiation sources important for astrophysics and technical applications.

Our research programs in plasma and fusion energy sciences lie at the scientific frontier and focus on high-pressure and high-temperature plasmas. LCLS X-rays characterize warm dense matter states with an accuracy that can support or refute competing theoretical models. These studies provide critical experimental tests of physics models that are important for the design of full-scale fusion experiments and provide understanding of structural, transport, and radiation physics properties of fusion plasmas. These programs advance fusion experiments at SLAC.

Another major research area is the development of particle acceleration in plasmas with high-power short-pulse lasers. Our experimental efforts are coupled to a theory program that uses 3D particle-in-cell modeling of HED plasmas. It can resolve the femtosecond time scales and sub-micrometer spatial scales for exploration of advanced particle acceleration, ultrafast X-ray probes, and laser-produced fusion neutrons. Our calculations result in new understanding of radiation sources and predict Weibel-mediated collisionless shocks and magnetized shocks that can lead to very high particle energies relevant to the physics mechanisms for explaining the origin of cosmic rays.

The HED program has initiated a new theory group funded by a DOE-FES Early Career Award in theory. The program is expanding SLAC’s footprint in the simulation of HED phenomena, thus exploring new scientific frontiers than will be accessed by our HED facilities.

We have demonstrated ultrafast pump-probe experiments on warm dense matter, achieving unprecedented precision. These experiments are enabled by investments in a diagnostics and technology program specifically aimed at achieving high-resolution measurements in space, time, and energy. We combine these capabilities with developments of cryogenic targets for high-repetition rate studies of liquid hydrogen, deuterium and other important materials for fusion research. In addition, the program has demonstrated novel probe techniques unique to ultrafast studies with X-ray lasers or UED.

We are developing a detailed plan that optimizes the layout and laser drivers of the Matter in Extreme Conditions (MEC) instrument to keep our world leadership role in this area. The upcoming LCLS-II facility modifications of the Far Experimental Hall (FEH) provide opportunities for additional space suitable for a petawatt-class laser driver together with appropriate radiation shielding walls. We will further demonstrate the viability of the experimental concepts in complementary experiments at user facilities and assess the viability of a stand-alone laser facility to support this effort.

Funding for this core capability comes from DOE-FES and LDRD investments and serves the DOE-SC mission in scientific discovery and innovation (SC 2, 24).

6. Particle Physics

SLAC is world leading in the exploration of the frontier of particle physics and cosmology with top activities in a comprehensive suite of underground, surface, and space-based experiments exploring the frontiers of particle physics and cosmology. This effort fully aligns with the science drivers described in the 2014 Particle Physics Project Prioritization Panel (PS) report as the most compelling lines of inquiry showing great promise for discovery over the next decade. Priorities are driven by the pursuit of high-impact science questions in the
field, as identified in collaboration with our world-renowned theory effort and unique contributions to the successful construction of facilities through our world-leading instrumentation capabilities.

The ATLAS experiment at the LHC is exploring TeV mass scales and beyond for elucidating the properties of the Higgs and discovering new particles and interactions, two of the P5 science drivers. For the High Luminosity-LHC (HL-LHC) project, SLAC leads the assembly of the Inner Tracker pixel detector system, as well as studies of pile-up and jet reconstruction. SLAC is well-positioned to assume a major role in the construction of the silicon inner tracker, which is the most important detector subsystem in the planned HL-LHC upgrades. We have the infrastructure and expertise in several key areas, including 3D and CMOS pixels, strip detectors, and high-speed data transmission and readout. SLAC will be the U.S. pixel stave assembly site, a project based on our precision mounting, optical survey and detector integration capabilities.

The nature of the neutrino and many of its fundamental properties remain a mystery, with profound implications for cosmology. SLAC has a long history of developing the experimental techniques incorporated in the Enriched Xenon Observatory (EXO) for neutrinoless double-beta decay (NDBD), which will demonstrate whether the neutrino is its own anti-particle. SLAC and Stanford are currently leading the Enriched Xenon Observatory (EXO-200) NDBD demonstrator experiment. The future for this program resides with the next EXO (nEXO), a multi-ton-scale experiment that may be located at SNOLAB in Ontario, Canada. The Nuclear Science Advisory Committee (NSAC) identified a ton-scale NDBD experiment as the highest priority new experiment for the U.S. Nuclear Physics program, with nEXO being a lead candidate. SLAC has extensive experience in the design, construction, and operation of noble-liquid Time Projection Chambers (TPCs) using ultra-low-background materials along with high-performance, low-noise, high-bandwidth cold electronics. SLAC’s effort in the accelerator-based, long-baseline neutrino oscillation and charge conjugation parity (CP) violation program provides critical expertise various areas for the Deep Underground Neutrino Experiment (DUNE). SLAC instrumentation is a leading candidate for the DAQ and cold electronics systems for DUNE, we intend to play a leading role in the design of the hear detector, and we are building a Stage 2 prototype for the pixelated readout of the Argon-Cube technology in the liquid noble gas teststand recently constructed for LZ. Together, scientific exploitation of nEXO and DUNE position SLAC to become a leading center for neutrino science.

Although extensive evidence exists that dark matter dominates the matter density of the universe, the nature of this matter remains unknown to modern particle physics. Various theories suggest a weakly interacting massive particle (WIMP) as the dark matter candidate, possessing weak-interaction-scale cross-sections with ordinary matter. WIMP detection could be accomplished by fielding ton-scale experiments in mines deep underground, where backgrounds associated with cosmic ray particles can be adequately shielded. The detection of relic dark matter at an underground experiment would be a crucial complement to efforts underway to create dark matter particles directly at the LHC and at future energy frontier accelerator facilities.

SLAC is uniquely positioned to address this cosmological mystery through two leading "Generation 2" experiments to search for WIMP dark matter. SuperCDMS will allow direct searches for relic dark matter candidates at unprecedented levels of sensitivity at low WIMP masses, while the complementary LZ liquid xenon experiment will provide the world’s best WIMP sensitivity at higher masses. Both have been selected as next-generation, direct dark matter search experiments, with SLAC playing a lead role in the SuperCDMS project at SNOLAB. SuperCDMS exercises our expertise in cryogenic germanium sensors and photolithographic fabrication techniques for such devices. LZ leverages our capabilities in large-scale, low-background TPCs, as does EXO. SLAC has optimized the design and production of large germanium sensors for SuperCDMS and is establishing cryogenic test facilities and TPC system test capabilities for noble liquid systems for LZ and, eventually, for nEXO and DUNE.

New ideas based on an ultralight dark matter candidate (hidden photon or axion) have emerged as another possible dark matter theory. Ultralight dark matter searches would open up new pathways for physics beyond the Standard Model, with enormous unexplored phase space in mass (9 orders of magnitude) and coupling (6 orders of magnitude). These ideas are being pursued with the Heavy Photon Search (HPS) experiment at the Thomas Jefferson National Accelerator Facility and potentially with new DArk Sector Experiments at LCLS-II (DASEL) with no impact on X-ray delivery.

FGST is transforming our understanding of the high-energy universe, recently providing insights into the origins of some cosmic rays and has conducted a wide variety of searches for dark matter. SLAC was the lead
laboratory in the construction and integration of the LAT and plays a critical role supporting instrument operations. SLAC’s experience with FGST electronics (done in collaboration with NASA) will be valuable for DUNE, where instruments will be similarly inaccessible during operation.

The dark energy that appears to be driving the accelerated expansion of the universe poses fundamental challenges to understanding quantum field theory and gravity. The detailed properties of dark energy can be constrained through a variety of methods, all relying on deep optical and infrared surveys of major fractions of the sky. The LSST project will provide a wide-field, ultradeep survey of galaxies for precision measurement of dark energy. Based on SLAC’s expertise in complex silicon detector systems, electronics, cryogenics, DAQ, and integrated instrumentation systems, we are leading the construction of the LSSLT 3.2-gigapixel camera system. As the host laboratory, we are working closely with the LSST Dark Energy Science Collaboration (DESC) to achieve its scientific goals. We are developing a camera commissioning and pre-operations plan, along with an LSST facility pre-operations and survey operations plan jointly with the Association of Universities for Research in Astronomy (AURA) and the LSST Corporation. These strategic LSST activities and the investment in dark energy research will make SLAC a powerful center for this science in the 2020s.

Inflation and the early universe pose profound questions for modern cosmology. SLAC and Stanford supported research with the Background Imaging of Cosmic Extragalactic Polarization 2 and 3 (BICEP2/3) experiment. Jointly with the Planck Observatory, BICEP2 has provided the most stringent limits on B-modes from early universe gravitational waves. The Cosmic Microwave Background (CMB) carries the imprint of cosmology and the forces from the inflationary period of the Big Bang. Precision measurements of the CMB are expected to constrain cosmic inflation models. BICEP3, deployed recently at the South Pole, is a new instrument with a two-fold improvement in sensitivity and 10-fold improvement in CMB survey capability. The ultimate experiment in this field, CMB-S4, will build on this and other pathfinder experiments to provide definitive measurements of the universe’s first light with a broad science scope that includes neutrino mass, CMB lensing, and cluster cosmology. SLAC’s unique expertise in SC device design and fabrication, the large-scale integrated focal plane assembly from LSST, along with plans to build suitable microfabrication facilities to allow large-scale production of SC devices, underpin both our CMB-S4 plans and new systems for X-ray applications.

_Funding for this core capability comes from DOE-HEP and DOE-NP, as well as SPP from NSF and NASA, and LDRD investments. SLAC’s efforts serve the DOE-SC mission in scientific discovery and innovation (SC 2, 21, 22, 23, 24, 25, 26, 29)._
Appendix 2: Annual Strategic Partnership Projects Report

The requested funding level at SLAC for SPP in FY 2019 is $30M. This funding level aligns with our anticipated SPP growth strategy as we expand current collaborations and pursue new opportunities with federal agencies, other research institutions, and the private sector.

In FY 2017, SLAC received funding of approximately $21 million under 55 new or ongoing SPP and CRADAs. The optimal size of our partnerships portfolio is envisioned at 15 percent of the laboratory operating budget within the next 10 years, roughly $45 million per year, which will allow SLAC to balance primary mission execution with the ability to sustain critical capabilities and infrastructure. Significant restructuring and process improvements in our partnership support functions were implemented in FY 2017 to enable more efficient partnering and to support the steady growth of our SPP portfolio. The following are notable examples of partnerships executed or broadened in FY 2017, which demonstrate how we achieve our technology transitions, commercialization, and partnerships objectives.

**Federal:** One of SLAC's largest SPP sponsors is NIH, either directly or through Stanford's Sponsored Research Office. NIH-funded programs include ongoing support for the Structural Molecular Biology program (an effort jointly coordinated with DOE-BER) and support for developing new instrumentation and techniques in the areas of structural biology and femtosecond crystallography at LCLS. Further opportunities are being pursued as part of the bioscience strategy. SLAC, in conjunction with Stanford, has established a cryo-EM facility and has begun bringing in NIH funds in support of this facility, with the expectation that this funding from NIH will increase. Additionally, SLAC is anticipating an award from NIH for the new National Cryo-EM Center, which, if awarded, will bring significant funding in support of instruments, resources, and new capabilities to SLAC.

The National Science Foundation (NSF) is a partner with DOE on LSST and provides SLAC with SPP funding through AURA for data management systems, which is expected to be a very long-term collaboration. NSF is additionally funding ongoing research at SSRL directed toward computational morphology prediction of organic photovoltaics.

SLAC is pursuing a project with DARPA, under a proposed three-phase program, to reduce the size and improve efficiency of VLF communication systems. We have broadened our portfolio of federal partners by establishing new partnerships with the Army Research Laboratory and NASA. In the collaboration with the Army Research Laboratory, we will be conducting development and demonstration of an ultra-compact high efficiency moderate power W-band source demonstrator. In the collaboration with NASA, SLAC will evaluate high speed, low noise readout schemes for Depleted P-channel Field Effect Transistor detectors in support of the Athena mission.

**Non-Federal:** Our non-federally-sponsored SPP programs include collaborations with several industry partners in a wide variety of technology areas. For example, we have partnered with industry to develop new equipment and capabilities for LCLS, to harness our capabilities in SSRL to conduct research in battery components and photovoltaic technologies. Given our expertise in battery imaging at SSRL, we are also working with battery companies on proprietary studies, and these collaborations directly enhance capabilities that strengthen SSRL’s role as a national user facility. In our Applied Energy Division, we have established numerous high-value agreements with the California Energy Commission on smart grid technology and vehicle-grid integration. The Applied Energy Division includes numerous new focus areas for SLAC which are expected to be significant areas for SPP growth going forward, as we expand our collaborations in these areas to include private sector partners. Furthermore, we anticipate additional awards from the California Energy Commission in these and in other complimentary areas.

We have extended numerous agreements with industry partners in areas including RF technologies and large dataset management. For example, we are in the process of extending our CRADA with Zoox from the initial three-year term to six years and have also expanded the scope of this collaboration. Leveraging our detector expertise, we have entered into significant multi-year CRADAs and IP licenses with start-ups and established companies to use our expertise in mixed signal integrated circuit design, to pursue collaborations focused on 3D imaging and LIDAR applications, radar applications, and IP block designs for customized processor blocks. We are also collaborating with industrial partners through the Small Business Innovation Research (SBIR) program, developing novel photocathodes for high-brightness photoinjector guns and for improved linac electron beam dynamics for improved FEL performance.
At the very end of FY 2017, SLAC executed an SPP agreement with a major telecommunications company looking at next generation communication technology, with SLAC contributing through our expertise in mm-wave technology and electromagnetics modeling capability.

SLAC has been partnering with a local startup that has developed a novel technology for non-thermal annealing of semiconductors and other materials. Applications within HEP include post-foundry formation of backside diffusion contacts on CMOS image sensors and charge-coupled devices, less-costly process for manufacturing thin silicon sensors without SOI, possible healing of defects, thin entrance windows for UV light, annealing of direct bonded wafers, etc.

Our partnerships include multiple international research collaborators, including a partnership with KEK in Japan to collaborate on high-gradient research and future high-luminosity and high-energy electron accelerator research. We are continuing our long-term collaboration with CERN to support the Compact Linear Collider Project, with XFEL to develop large-area X-ray detectors, and with DESY to advance SCRF technology, as well as a partnership with IHEP in China in multiple accelerator technology areas.

As a leading laboratory in RF R&D, SLAC provides klystrons and RF components to many international and U.S. laboratories. We have an SPP agreement in place with CPI Inc. to use our unique, high-power test facilities to test high-power X-band klystrons that CPI Inc. is under contract to deliver to CERN.

We partner with biopharmaceutical companies to develop new instrumentation and capabilities for synchrotron-based structural biology, as well as proprietary research to accelerate the development of new pharmaceuticals. As an example, we recently extended our long-standing collaboration with The Scripps Research Institute for an additional five years, during which we will conduct macromolecular crystallography research in our SSRL facility.

We have also established new agreements with Stanford either directly or through SLAC-Stanford joint institutes and centers. For example, a collaboration with the Stanford School of Medicine's Department of Radiation Oncology will develop next-generation radiation treatment facilities using advanced RF accelerator and source technologies. Additionally, through SUNCAT, we have partnered in infrastructure development to automate atomic-scale simulations of catalytic properties. We also receive additional contributions from international collaborations, private foundations, and Stanford in other areas that support our strategic initiatives and core expertise, and participate in numerous consortia including CalCharge, DuraMAT, Battery500, and JCESR.

Looking to the future, SLAC is continuing to pursue the construction of the Detector Microfabrication Facility in ASC to further broaden the reach of SLAC technology and expertise to the scientific community at large. The ASC is anticipated to have a three-fold impact: supporting DOE core science programs, maintaining our international leadership in detector and instrumentation science, and enabling strategically aligned SPP growth.
Appendix 3: Laboratory Directed Research and Development Plan (LDRD)

SLAC LDRD Program Objectives

The SLAC LDRD program supports and advances the Laboratory’s mission, core capabilities, and scientific strategy with investments in R&D, aiming to:

- Enable discoveries that will create new or enrich existing research directions
- Enhance existing or develop new R&D capabilities
- Attract and develop early career and other key talent

Although it is only a small percentage of the Laboratory’s operating and capital equipment budget (1.25 percent in FY 2018), the LDRD program provides a significant means of leveraging research dollars. LDRD projects are typically conducted with a scale of effort that involves existing experimental or computational facilities at SLAC. This scale of effort has been sufficient to demonstrate proof-of-principle for a new idea or methodology or develop small-scale R&D capabilities.

Due to heavy investments in SLAC infrastructure in support of our construction projects between FY 2015 and FY 2019, we had to adjust the growth of our LDRD program. We are aiming for a gradual increase in our LDRD rate in the coming fiscal years.

Supporting the Laboratory’s Mission: LDRD investment in Core Capabilities

The LDRD program supports SLAC’s mission by selecting and funding cutting-edge R&D that bolsters the Laboratory’s current and supports important emerging core capabilities. LDRD projects continue to support the research of graduate students and postdoctoral researchers, thus contributing to the education mission of the Laboratory and Stanford. In FY 2017, the SLAC LDRD program funded, either partially or completely, approximately 10 percent of the postdoctoral researchers at SLAC.

Our portfolio of 18 currently active LDRD projects (total multi-year cost of approximately $7 million) has an investment distribution across our core capabilities, as shown in Figure 4 below.

Figure 3: Investment Distribution of Active LDRD Projects Across SLAC Core Capabilities

Examples of LDRD projects with notable impact in each of our core capabilities are listed below.

1. **Accelerator Science and Technology:**

   *Example: Fresh-slice beams at the LCLS-II*

   LCLS-II demands expanded operating modes and capabilities to fulfill the increasing needs of the user community. A large effort has already been devoted to the production of two-color modes for X-ray
5. Advanced Computer Science, Visualization and Data (emerging core capability):

Example: Machine learning for data reduction at LCLS-II and path toward 1MHz detection

Machine learning (ML) has the potential to maximize the information rate of LCLS-II and of the scientific community at large. This project builds an interactive platform whereby users leverage their experience to construct data-driven algorithms and ML models for on-board data processing and compression. These compressed outputs and intermittently sampled validation and anomaly events will then be transferred to remote storage and analysis farms. This highly collaborative project across SLAC and Stanford will deliver a new ML capability aimed at an FPGA-accelerated data reduction platform that handles the high data velocity of the detectors of LCLS-II. Beyond LCLS-II data, the platform will benefit multiple scientific areas and applications, from High Energy Physics and neutrino detection to crystal diffraction, X-ray spectroscopy, and observational cosmology.

3. Condensed Matter and Materials Science

Example: Emergent spintronics in complex oxide heterostructures

This effort aims to resolve central scientific questions surrounding the microscopic origins of and limits of efficient generation, transmission, and conversion of spin currents. While the majority of the field has focused on non-tunable and non-crystalline metallic systems, this project aims at incorporating highly dissimilar oxide materials with unique interplays between spin-charge-orbit degrees of freedom. In addition, it seeks to determine if this technique could constitute a probe of quantum materials. Success in this effort may yield materials with compelling possibilities for emerging low-energy electronic technologies.

4. Chemical and Molecular Sciences

Example: Stimulated X-ray Emission Spectroscopy as a powerful new tool to study transition metal centers at XFELs

Exploring the fundamentally new approach of stimulated X-ray spectroscopy (S-XES), which has the potential to overcome the limitations of $4\pi$ signal collection and also lead to several orders of magnitude larger signal yields, is the goal of this LDRD effort. This proof-of-principle LDRD project, which aims towards first observation of stimulated Kα X-ray emission in Mn(II)Cl$_2$ and NaMn(VII)O$_4$ compounds in solution using LCLS, will impact a wide variety of LCLS-II studies in catalytic reactions involved in biological systems and many important industrial processes.

5. Plasma and Fusion Energy Sciences:

Example: Modeling strong field QED for future SLAC investigations

Our LDRD portfolio over the past years has funded extensive efforts in HED science to study the physics of shocks and particle acceleration through first principles simulations and laboratory experiments. These simulations and experiments have provided insights on how the plasma conditions affect the shock structure, have identified optimal conditions for particle acceleration in HED plasmas, and have demonstrated controlled generation of high-energy ion beams. Particle-in-cell (PIC) simulations used to model plasma conditions are now advanced towards quantum electrodynamics (QED) PIC in a new LDRD this year. This LDRD aims to explore the quantum vacuum at extreme intensity and advance our understanding of QED in the strong-field regime, where the conventional perturbative approach breaks down. This is a proof-of-principle study in a field where SLAC is uniquely positioned to lead an effort with world-class facilities like LCLS-II and FACET-II, and where 10 GeV-class electron beams could be collided with optical or X-ray laser intensities above $10^{21}$ Wcm$^{-2}$ and probe physics beyond the Schwinger limit.

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6. **Particle Physics:**

*Example: Radio for hidden dark matter*

We are developing a novel concept for a hidden-photon search based on a tunable lumped-element resonator — essentially a hidden-photon radio. This LDRD is building a first-stage pathfinder experiment that will set important new model-independent bounds on hidden-photon dark matter over the approximately 500 peV-50 neV (100 kHz-10 MHz) portion of the phase space, down to mixing angles of 10^{-11}. The pathfinder will also provide the technological basis for a follow-on proposal to the DOE-HEP for a full-scale experiment which includes axion detection capabilities. This effort will provide a new dark matter direct detection search with unprecedented sensitivity over the mass range of ultra-light hidden-photon and axion dark matter, a phase space that remains largely unprobed.

**Advancing the Laboratory’s Strategy: LDRD investment in Strategic Initiatives**

Over the years, the SLAC LDRD program has maintained a flexible investment approach to optimize the Laboratory’s ability to respond to new research opportunities and challenges that align with our strategic initiatives. Ideas to be supported by LDRD funding have been encouraged along two specific categories:

- Proposals addressing important scientific or technological concepts that may lead towards the development of new research programs and/or capabilities in support of SLAC’s major initiatives
- “Discovery” proposals with high scientific risk and potential for significant impact

Our current LDRD portfolio includes projects initiated between 2015 and 2017 with a mix of 3:2 between targeted vs. discovery type of projects. Examples of high risk/high payoff discovery projects are described in previous sections of this ALP towards the conceptual design of a radio for hidden dark matter and the modeling effort for strong field QED for future SLAC investigations.

**Figure 4: Advancing SLAC’s Strategy with LDRD**

Mapping of our current project (multi-year) funding across the SLAC strategy, with blue columns indicating the amount allotted to R&D projects for targeted capability development or other research effort and red columns indicating the amount allotted to R&D in high-risk/payoff ideas.

LDRD has previously funded and continues to fund several targeted projects with notable impact towards our strategic initiatives.

- **X-ray and ultrafast sciences**: LDRD funding is supporting concept development and proof-of-principle prototypes for detectors and other instrumentation aiming at X-ray spectroscopy (XES, XAFS) and imaging. These concepts and prototypes are addressing critical capabilities enabling LCLS-II early science by understanding the functionality and addressing the challenges of the future, fully scaled, state-of-the-art
instruments at LCLS-II. Other targeted efforts are supporting the development of table-top high-repetition-rate soft X-ray sources and THz sources to perform preliminary scientific investigations that will translate to experiments at LCLS-II and possibly expand the suite of pump-probe experimental platforms at LCLS-II.

- **Physics of the universe:** After a significant LDRD commitment in the past three years towards the development of LUX/LZ prototype detector, the current LDRD portfolio in this initiative is primarily supporting discovery-type projects (see radio for hidden dark matter). Some targeted investment is allocated towards developing next-generation microsystem interconnects and assembly technologies that make use of the edges of semiconductor chips to extend systems into the third dimension, thus increasing the circuitry per pixel by a factor between 10 and 100 in a very cost-effective manner. This research is relevant to HEP and LCLS-II detection systems.

- **Electron accelerator physics:** LDRD effort is targeting the phase-space manipulation of electrons (and other charged particles) with applications in advanced accelerator concepts for LCLS-II, compact FELs, and laser-based acceleration technology, such as dielectric, plasma, or free-space acceleration, and UED. R&D supports both electron bunching schemes (see “Fresh-slice” example) and ultrafast light modulation sources to tailor the electron phase-space distribution with high spatio-temporal precision.

- **Massive-scale data analytics:** Maximizing the scientific throughput and impact of LCLS-II by developing new paradigms for DAQ, reduction, and analysis, as well as efficient (autonomous) FEL machine operation and tuning at the high-repetition rates of LCLS-II, is the primary objective of the targeted LDRD efforts in this initiative. The massive data analytics challenge that cuts across several disciplines and organizations at SLAC is being addressed with LRD-funded effort that is highly innovative, collaborative, and bridges scientific efforts across SLAC, Stanford and the X-ray sciences community. Autonomous operation of LCLS-II requires significant advances on many fronts, from "hands-free" parameter changes for X-rays, samples, and lasers, to anomaly/breakout detection of beam faults, to “zero parameter” pipelines that allow users to close the experimental loop. As a first step along this path, targeted LDRD is developing proof-of-principle machine learning optimization algorithms that can eventually form the base for future autonomous operation of LCLS-II.

- **HED science:** Targeted investment at SLAC is planned in the form of new infrastructure and facility development outside of LDRD.

- **Bioimaging:** Targeted investment at SLAC is planned in the form of new infrastructure and facility development outside of LDRD.

**SLAC LDRD Administration and Management**

The SLAC LDRD program is planned and managed through a formal process consistent with DOE Order 413.2C (revised 10-22-2015). A schedule for proposal submission, review, and reporting is developed and issued annually. In addition, the LDRD program manager works with the Directorate Offices and Budget Office to monitor funded LDRD projects throughout the fiscal year to track budgetary allocations, ensure the separation of program funding and LDRD support, and ensure full compliance with DOE orders, directives, and contract requirements.

SLAC’s formal process for the allocation of funds for LDRD relies on individual scientific investigators and scientific leadership of the Laboratory to identify opportunities with significant impact towards our institutional goals. From year to year, the distribution of funds among the scientific program areas will change. This flexibility optimizes the Laboratory’s ability to respond to new research opportunities and challenges. LDRD policy and program decisions are the ultimate responsibility of the Laboratory Director. The LDRD Program Manager supports administration and reporting on the LDRD program. LDRD accounting procedures and financial management are consistent with the Laboratory’s accounting principles and stipulations under the contract between Stanford and DOE, with accounting maintained through the Office of the SLAC Chief Financial Officer.

Annually, the Laboratory Director issues a call for proposals to the ALDs, who solicit from their R&D staff conceptual ideas to be considered for proposal development. Investigators submit new LDRD proposal concepts and each ALD manages a process for approval of selected concepts to be developed into full proposals, which are then submitted to the LDRD program. The SLAC Science Council members advise the
LDRD program manager in the selection of subject matter experts from outside the Laboratory to conduct an initial full proposal review. The external reviewers rate the proposals based on the potential impact of the science, the degree of innovation, the validity of the technical approach, and the feasibility of accomplishing the research plan with the resources requested. A second, internal review team hears presentations from each of the proposers describing their research and answering questions. The Science Council finally evaluates the strategic merit of the proposals towards the lab’s current and future missions to inform the Director’s final selection. The Laboratory Director selects the proposals to be funded and submits the LDRD project listing to the DOE SLAC Site Office for concurrence.

Overall, the SLAC LDRD review process ensures that proposals are selected based on:

- Scientific and technical merit
- Alignment with SLAC’s strategic directions
- Distinction from programmatic work discussed in the Field Budget Report
- Consideration of administrative, budget, environment, and health and safety information

Since the call and review process occurs prior to the final budget being established, the awards may be deferred to later in the fiscal year depending on budget availability. Most projects are two years in duration, and never exceed 36 months.

All projects funded by LDRD must meet SLAC EH&S requirements. Consistent with National Environmental Policy Act (NEPA) goals, the SLAC NEPA planning office reviews each LDRD proposal to determine the level of NEPA documentation, if any, that is required. Typically, projects supported by the LDRD program are bench-scale research or conceptual designs and do not involve modification to buildings or other structures.

**FY 2019 Funding Request**

SLAC requests an allocation of 2 percent of the FY 2019 operating and capital equipment budget for the FY 2019 LDRD program. This allocation is projected to be about $6.8 million based on current budget plans. Any revisions of this rate will be reflected in our ALP presentation in June.
Acronyms

AD  Accelerator Directorate
ALD  Associate Laboratory Director
ALP  Annual Laboratory Plan
ASC  Arrillaga Science Center
ASTA  Accelerator Structure Test Area
ATLAS  A Toroidal LHC Apparatus
AURA  Association of Universities for Research in Astronomy
BERAC  Biological and Environmental Research Advisory Committee
BESAC  Basic Energy Sciences Advisory Committee
BICEP3  Background Imaging of Cosmic Extragalactic Polarization second upgrade
CBRP  Campus Building Renovation Project
CDMS  Cryogenic Dark Matter Search
CERN  European Organization for Nuclear Research
CMB  Cosmic Microwave Background
CMB-S4  Cosmic Microwave Background Stage 4
CMM  Coordinate Measuring Machine
CRADA  Cooperative Research and Development Agreements
Cryo-EM  Cryo-Electron Microscopy
Cryo-ET  Cryo-Electron Tomography
Cryo-FIB  Cryo-Focused Ion Beam
CW  Continuous Wave
DAQ  Data acquisition
DARPA  Defense Advanced Research Projects Agency
DASEL  DArk Sector Experiments at a purpose-built LCLS-II beamline
DESY  Deutsches Elektronen-Synchrotron
DHHS  Department of Health and Human Services
DHS  Department of Homeland Security
DM  Deferred Maintenance
DOE  U.S. Department of Energy
DOE-ASCR  DOE Advanced Scientific Computing Research
DOE-BER  DOE Biological and Environmental Research
DOE-BES  DOE Basic Energy Sciences
DOE-EERE  DOE Energy Efficiency and Renewable Energy
DOE-FES  DOE Fusion Energy Sciences
DOE-HEP  DOE High Energy Physics
DOE-NNSA  DOE National Nuclear Security Administration
DOE-NP  DOE Nuclear Physics
DOE-SC  DOE Office of Science
DOE-SLI  Science Laboratory Infrastructure
DOE-SLI-GPP  DOE Science Laboratory Infrastructure General Plan Projects
DOE-SLI-LI  DOE Science Laboratory Infrastructure Line Item
DUNE  Deep Underground Neutrino Experiment
EISA  Federal Energy Independence and Security Act
ES&H  Environment, Safety & Health
ESTB  End Station Test Beam
eV  Electronvolt
EXO  Enriched Xenon Observatory
F&O  Facilities & Operations
FACET  Facility for Advanced Accelerator Experimental Tests
FACET-II  Facility for Advanced Accelerator Experimental Tests upgrade
FEL  Free Electron Laser
FGST  Fermi Gamma-ray Space Telescope
FIMS  Facilities Information Management System
FNAL  Fermi National Accelerator Laboratory
fs  Femtosecond
FTE  Full Time Equivalent
GB  Gigabyte
GeV  Gigaelectronvolt
GPP  General Plant Projects
GSF  Gross Square Feet
HEC  High-End Computing facility
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>PPA</td>
<td>Particle Physics and Astrophysics</td>
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<tr>
<td>PSLB</td>
<td>Photon Science Laboratory Building</td>
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<tr>
<td>PV</td>
<td>Photovoltaic</td>
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<tr>
<td>PWFA</td>
<td>Plasma Wakefield Acceleration</td>
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<tr>
<td>QIS</td>
<td>Quantum Information Science</td>
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<tr>
<td>R&amp;D</td>
<td>Research and Development</td>
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<tr>
<td>RF</td>
<td>Radio Frequency</td>
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<tr>
<td>RIXS</td>
<td>Resonant Inelastic X-ray Scattering</td>
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<td>RN</td>
<td>Repair Needs</td>
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<td>RPAM</td>
<td>Real Property Asset Management</td>
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<td>RPV</td>
<td>Replacement Plant Value</td>
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<td>Radioactive Waste Management Facility</td>
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<td>Spring-8 Angstrom Compact free electron LAser</td>
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<td>SAXS</td>
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<td>SBIR</td>
<td>Small Business Innovation Research</td>
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<td>SC</td>
<td>Superconducting</td>
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<td>SDF</td>
<td>Science Data Facility</td>
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<td>SIMES</td>
<td>Stanford Institute for Materials and Energy Science</td>
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<td>SLAC</td>
<td>SLAC National Accelerator Laboratory</td>
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<td>SPEAR</td>
<td>Stanford Positron Electron Accelerating Ring, now SPEAR3</td>
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<td>Strategic Partnership Projects</td>
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<td>South Pole Telescope</td>
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<td>SRCF</td>
<td>Stanford Research Computer Facility</td>
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<td>SRCF-II</td>
<td>Stanford Research Computer Facility expansion</td>
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<td>SRF</td>
<td>Superconducting Radio Frequency</td>
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<td>SSRL</td>
<td>Stanford Synchrotron Radiation Lightsource</td>
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<td>Stanford</td>
<td>Stanford University</td>
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<td>SUNCAT</td>
<td>SUNCAT Center for Interface Science and Catalysis</td>
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<td>SuperCDMS</td>
<td>Super Cryogenic Dark Matter Search (CDMS)</td>
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<td>SUSB</td>
<td>Science and User Support Building</td>
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<td>TeV</td>
<td>Teraelectronvolt</td>
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<td>THz</td>
<td>Terahertz</td>
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<td>TIMES</td>
<td>Theory Institute for Materials and Energy Spectroscopies</td>
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<tr>
<td>TMO</td>
<td>Time Resolved AMO</td>
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<td>Time Projection Chamber</td>
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<td>TXI</td>
<td>Tender X-ray Instrument</td>
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<td>UED</td>
<td>Ultrafast Electron Diffraction</td>
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<td>UEM</td>
<td>Ultrafast Electron Microscopy</td>
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<td>UUIR</td>
<td>Underground Utilities Infrastructure Revitalization</td>
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<td>Voice over Internet Protocol</td>
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<td>VVS</td>
<td>Variable Voltage Substations</td>
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<tr>
<td>WIMP</td>
<td>Weakly Interacting Massive Particle</td>
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<td>XCS</td>
<td>X-ray Correlation Spectroscopy</td>
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<td>X-ray Free Electron Laser</td>
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