DOE/CF-0142
Volume 4

Department of Energy
FY 2019 Congressional Budget Request

Science

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Funding by Appropriation

Department of Energy Budget by Appropriation	FY 2017 Enacted	FY 2018 Annualized CR*	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted $	FY 2019 Request vs FY 2017 Enacted %
	($K)				
Energy and Water Development, and Related Agencies					
Energy Programs					
Energy Efficiency and Renewable Energy	2,034,582	2,040,249	695,610	-1,338,972	-65.8%
Electricity Delivery and Energy Reliability	229,585	228,026	0	-229,585	-100.0%
Electricity Delivery	0	0	61,309	+61,309	N/A
Cybersecurity, Energy Security, and Emergency Response	0	0	95,800	+95,800	N/A
Nuclear Energy	1,015,821	1,008,922	757,090	-258,731	-25.5%
Fossil Energy Programs					
Fossil Energy Research and Development	421,154	425,093	502,070	+80,916	+19.2%
Naval Petroleum and Oil Shale Reserves	12,005	14,848	10,000	-2,005	-16.7%
Strategic Petroleum Reserve	222,605	221,485	175,105	-47,500	-21.3%
Northeast Home Heating Oil Reserve	6,497	6,456	10,000	+3,503	+53.9%
Total, Fossil Energy Programs	**662,261**	**667,882**	**697,175**	**+34,914**	**+5.3%**
Uranium Enrichment Decontamination and Decommissioning (D&D) Fund	767,929	763,106	752,749	-15,180	-2.0%
Energy Information Administration	122,000	121,171	115,035	-6,965	-5.7%
Non-Defense Environmental Cleanup	246,762	245,324	218,400	-28,362	-11.5%
Science	5,390,972	5,354,362	5,390,972	0	N/A
Advanced Research Projects Agency - Energy	305,245	303,172	0	-305,245	-100.0%
Nuclear Waste Disposal (30M in DNWF 050)	0	0	90,000	+90,000	N/A
Departmental Administration	120,692	120,009	139,534	+18,842	+15.6%
Inspector General	44,424	44,122	51,330	+6,906	+15.5%
Title 17 - Innovative Technology Loan Guarantee Program	139	16,749	7,000	+6,861	+4,936.0%
Advanced Technology Vehicles Manufacturing Loan Program	3,883	4,966	1,000	-2,883	-74.2%
Tribal Energy Loan Guarantee Program	9,000	8,939	-8,500	-17,500	-194.4%
Total, Energy Programs	**10,953,295**	**10,926,999**	**9,064,504**	**-1,888,791**	**-17.2%**
Atomic Energy Defense Activities					
National Nuclear Security Administration					
Federal Salaries and Expenses	387,366	384,736	422,529	+35,163	+9.1%
Weapons Activities	9,240,739	9,241,675	11,017,078	+1,776,339	+19.2%
Defense Nuclear Nonproliferation	1,879,738	1,885,970	1,862,825	-16,913	-0.9%
Naval Reactors	1,419,792	1,410,455	1,788,618	+368,826	+26.0%
Total, National Nuclear Security Administration	**12,927,635**	**12,922,836**	**15,091,050**	**+2,163,415**	**+16.7%**
Environmental and Other Defense Activities					
Defense Environmental Cleanup	5,404,217	5,368,298	5,630,217	+226,000	+4.2%
Other Defense Activities	781,703	778,676	853,300	+71,597	+9.2%
Defense Nuclear Waste Disposal (90M in 270 Energy)	0	0	30,000	+30,000	N/A
Total, Environmental and Other Defense Activities	**6,185,920**	**6,146,974**	**6,513,517**	**+327,597**	**+5.3%**
Total, Atomic Energy Defense Activities	**19,113,555**	**19,069,810**	**21,604,567**	**+2,491,012**	**+13.0%**
Power Marketing Administrations					
Southeastern Power Administration	0	0	0	0	N/A
Southwestern Power Administration	11,057	10,982	10,400	-657	-5.9%
Western Area Power Administration	94,742	94,099	89,372	-5,370	-5.7%
Falcon and Amistad Operating and Maintenance Fund	232	230	228	-4	-1.7%
Colorado River Basins Power Marketing Fund	-23,000	-22,844	-23,000	0	N/A
Total, Power Marketing Administrations	**83,031**	**82,467**	**77,000**	**-6,031**	**-7.3%**
Federal Energy Regulatory Commission (FERC)	**0**	**0**	**0**	**0**	**N/A**
Subtotal, Energy and Water Development, and Related Agencies	**30,149,881**	**30,079,276**	**30,746,071**	**+596,190**	**+2.0%**
Uranium Enrichment D&D Fund Discretionary Payments	-563,000	-559,177	0	+563,000	+100.0%
Defense EM Funded Uranium Enrichment D&D Fund Contribution	563,000	559,177	0	-563,000	-100.0%
Excess Fees and Recoveries, FERC	-16,645	-9,000	-16,000	+645	+3.9%
Title XVII Loan Guarantee Program Section 1703 Negative Credit Subsidy Receipt	-37,000	-37,000	-44,000	-7,000	-18.9%
Sale of Northeast Gas Reserve	0	0	-77,000	-77,000	N/A
Defense Programs Rescission of Balances (Undistributed)	-43	-43	0	+43	+100.0%
Title 17 Loan Guarantee Program Rescission	-9,000	-8,939	0	+9,000	+100.0%
Total, Funding by Appropriation	**30,087,193**	**30,024,294**	**30,609,071**	**+521,878**	**+1.7%**

*Note.—A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115–56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

Science

Science

Science
Proposed Appropriation Language

For Department of Energy expenses including the purchase, construction, and acquisition of plant and capital equipment, and other expenses necessary for science activities in carrying out the purposes of the Department of Energy Organization Act (42 U.S.C. 7101 et seq.), including the acquisition or condemnation of any real property or facility or for plant or facility acquisition, construction, or expansion, and purchase of not more than 16 passenger motor vehicles and one airplane for replacement only, including one bus, $5,390,972,000 to remain available until expended: Provided, That of such amount, $180,000,000, shall be available until September 30, 2020, for program direction.

Note.—A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115–56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution.

Explanation of Change

Proposed appropriation language updates reflect the funding and replacement of passenger motor vehicle levels and one airplane replacement requested in FY 2019.

Public Law Authorizations

Science:

- Public Law 95-91, "Department of Energy Organization Act", 1977
- Public Law 102-486, "Energy Policy Act of 1992"
- Public Law 108-153, "21st Century Nanotechnology Research and Development Act 2003"
- Public Law 109-58, "Energy Policy Act of 2005"
- Public Law 110-69, "America COMPETES Act of 2007"
- Public Law 111-358, "America COMPETES Reauthorization Act of 2010"

Nuclear Physics:

- Public Law 101-101, "1990 Energy and Water Development Appropriations Act," establishing the Isotope Production and Distribution Program Fund
- Public Law 103-316, "1995 Energy and Water Development Appropriations Act," amending the Isotope Production and Distribution Program Fund to provide flexibility in pricing without regard to full-cost recovery

Workforce Development for Teachers and Scientists:

- Public Law 101-510, "DOE Science Education Enhancement Act of 1991"
- Public Law 103-382, "The Albert Einstein Distinguished Educator Fellowship Act of 1994"

Science
($K)

FY 2017 Enacted	FY 2018 Annualized CR	FY 2019 Request
5,390,972	5,354,362[a]	5,390,972

Overview

The Office of Science's (SC) mission is to deliver scientific discoveries and major scientific tools to transform our understanding of nature and advance the energy, economic and national security of the United States. SC is the Nation's largest Federal sponsor of basic research in the physical sciences and the lead Federal agency supporting fundamental scientific research for our Nation's energy future.

SC accomplishes its mission and advances national goals by supporting:

- *The frontiers of science*—exploring nature's mysteries from the study of fundamental subatomic particles, atoms, and molecules that are the building blocks of the materials of our universe and everything in it to the DNA, proteins, and cells that are the building blocks of life. Each of the programs in SC supports research probing the most fundamental disciplinary questions.
- *The 21st Century tools of science*—providing the nation's researchers with 26 state-of-the-art national scientific user facilities - the most advanced tools of modern science - propelling the U.S. to the forefront of science, technology development and deployment through innovation.
- *Science for energy and the environment*—paving the knowledge foundation to spur discoveries and innovations for advancing the Department's mission in energy and environment. SC supports a wide range of funding modalities from single principal investigators to large team-based activities to engage in fundamental research on energy production, conversion, storage, transmission, and use, and on our understanding of the earth systems.

SC is an established leader of the U.S. scientific discovery and innovation enterprise. Over the decades, SC investments and accomplishments in basic research and enabling research capabilities have provided the foundations for new technologies, businesses, and industries, making significant contributions to our nation's economy, national security, and quality of life. Select scientific accomplishments in FY 2017 enabled by the SC programs are described in the program budget narratives. Additional descriptions of recent science discoveries can be found at http://science.energy.gov/news/highlights.

Highlights and Major Changes in the FY 2019 Request

The FY 2019 Request for SC is $5,391.0 million, the same as the FY 2017 Enacted level, to implement the Administration's objectives for achieving overall reductions in civilian, discretionary spending and address the Administration's research and development priorities in American Security, Prosperity, and Energy Dominance[b]. The FY 2019 Request supports a balanced research portfolio of basic scientific research probing some of the most fundamental questions in areas such as: high energy, nuclear, and plasma physics; materials and chemistry; biological and environmental systems; applied mathematics; next generation high-performance computing and simulation capabilities; and basic research for advancement in new energy technologies. The Request supports SC's basic research portfolio, which includes extramural grants and contracts supporting over 22,000 researchers located at over 300 institutions and the 17 DOE national laboratories, spanning all fifty states and the District of Columbia. In FY 2019, SC's suite of 26 scientific user facilities will continue to provide unmatched tools and capabilities for nearly 32,000 users per year from universities, national laboratories, industry, and international partners. The Request will also support the construction of new user facilities and the R&D necessary for future facilities and facility

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).
[b] M-17-30, OMB Memo: *FY 2019 Administration Research and Development Budget Priorities*

upgrades to continue to provide world class research capabilities to U.S. researchers. SC allocates Working Capital Fund charges for common administrative services to the research programs and the program direction account.

Highlights of the FY 2019 Request by Program Office include:

- *Advanced Scientific Computing Research (ASCR)* supports research to discover, develop, and deploy computational and networking capabilities to analyze, model, simulate, and predict complex phenomena important to the DOE and the United States. The ASCR Request of $899.0 million, is an increase of $252.0 million, or 39.0 percent, above the FY 2017 Enacted level. The increase supports activities to accelerate the Department's Exascale Computing Initiative (ECI) and intends to enable delivery of at least one exascale-capable system in 2021—reasserting U.S. leadership in this critical area. Within ASCR, ECI consists of two components, Office of Science Exascale Project (SC-ECP), which supports the research and development focused on addressing the challenges of exascale and the second component, preparations for the deployment of at least one exascale system at an ASCR Leadership Computing Facility (LCF) in 2021. To ensure continued progress during and after the ECI, this Request also increases support for ASCR's fundamental research in Applied Mathematics and Computational Partnerships with a focus on advanced technologies such as quantum information science, including quantum computing and networking, and on new methods, software and tools for scientific machine learning for discovery and decision support. Funding for the LCF's is significantly increased to continue site preparations and non-recurring engineering investment with their vendors that will allow them to deploy at least one exascale-capable system as rapidly as possible. The Argonne Leadership Computing Facility (ALCF) will procure a large developmental testbed to test activities from non-recurring engineering investments and to provide ECP applications and software technology projects to test their codes. The FY 2019 Request also supports the operations of the 200 petaflop (pf) Summit system at the Oak Ridge Leadership Computing Facility and the 10 petaflop (pf) Mira and 8.5 pf Theta systems at the ALCF for existing users while the ALCF upgrade project continues. The National Energy Research Scientific Computing Center (NERSC) will operate the 30 pf Cori supercomputer. Funds will support continued operations of the Energy Sciences Network and for the ESnet upgrade to address the rapidly growing volume of scientific data transmission.

- *Basic Energy Sciences (BES)* supports fundamental research to understand, predict, and ultimately control matter and energy at the electronic, atomic, and molecular levels to provide foundations for new energy technologies. The BES Request of $1,850.0 million is a decrease of $21.5 million, or 1.1 percent, below the FY 2017 Enacted level. The FY 2019 Request focuses resources toward early-stage fundamental research, on the operation and maintenance of a complementary suite of scientific user facilities, and in the highest priority facility upgrades. The highest priorities in core research are quantum information science (QIS), ultrafast science, computational materials and chemical sciences as part of the ECI, and materials and chemistry for future nuclear energy. In the remaining core research activities, BES will place emphasis on basic science areas with the potential to transform the understanding and control of matter and energy including emphasis on emerging high priorities in quantum materials and chemistry, catalysis science, synthesis, instrumentation science, and materials and chemical research related to interdependent energy-water issues. The Request provides funding for the two BES-supported Energy Innovation Hubs, *Batteries and Energy Storage* and *Fuels from Sunlight*, and for the DOE Established Program to Stimulate Competitive Research. In the BES suite of facilities, the Request provides funds for operating the Linac Coherent Light Source (LCLS) in support of the priority on ultrafast science and to fully fund the last year of the LCLS-II construction project per the project plan. To allow installation activities for the LCLS-II construction project to proceed, LCLS will be shut down for one year, starting around second quarter of FY 2019. The four remaining x-ray facilities, both BES-supported neutron sources, and five nanoscience centers will continue operations. Funding for the Advanced Photon Source Upgrade (APS-U) project increases per the project plan. The request includes funds to initiate the Advanced Light Source Upgrade (ALS-U) project and the Linac Coherent Light Source-II High Energy (LCLS-II-HE) project.

- *Biological and Environmental Research (BER)* supports transformative science and scientific user facilities to achieve a predictive understanding of complex biological, earth, and environmental systems for energy and infrastructure security, independence, and prosperity. The BER Request of $500.0 million is a decrease of $112.0 million, or 18.3 percent, below the FY 2017 Enacted level. The FY 2019 Request implements Administration priorities for early-stage fundamental research focused on biological and earth and environmental systems. The Biological Systems Science subprogram implements priority-shifts to the core research areas of Genomic Sciences, adding new efforts in secure biosystems design to ongoing activities in systems biology and environmental genomics, and fully supports the second year of the recompeted four DOE Bioenergy Research Centers. Biomolecular Characterization and Imaging Science (formerly known as Mesoscale to Molecules and Structural Biology Infrastructure) research supports structural, spatial and temporal understanding of functional biomolecules and processes within living cells, including new efforts in characterization of QIS advanced sensors. In the Earth and Environmental Systems Sciences subprogram, the Request focuses on continuing to prioritize development of the DOE high-resolution earth system model and for model diagnostics and intercomparisons. The Request supports operations of BER's three scientific user facilities: the DOE Joint Genome Institute (JGI), the Environmental Molecular Sciences Laboratory (EMSL), and the Atmospheric Radiation Measurement Research Facility (ARM). BER also requests funding for the acquisition and replacement of the ARM aerial capability as a Major Item of Equipment (MIE).

- *Fusion Energy Sciences (FES)* supports research to expand the fundamental understanding of matter at very high temperatures and densities and to build the scientific foundation for fusion energy. The FES FY 2019 Request of $340.0 million is a decrease of $40.0 million, or 10.5 percent, below the FY 2017 Enacted level. FES investments in user facility operations focus on the completion of DIII-D facility improvements that began in FY 2018, followed by 12 weeks of research operation to exploit these new tools and address priority science areas identified by recent community workshops. In addition, the Request includes funding for NSTX-U at the Princeton Plasma Physics Laboratory to implement repairs and corrective actions required to obtain robust, reliable research operations, and enhanced collaborative research at other facilities to support NSTX-U research program priorities. Funding for high-performance scientific computing through the SciDAC partnership with ASCR increases to accelerate development of a whole-device modeling capability and increase readiness for the exascale era. The FY 2019 Request will continue support for leveraged research opportunities by U.S. scientists on international superconducting tokamak and stellarator facilities with unique capabilities. Funding will be provided for the Materials-Plasma Exposure eXperiment Major Item of Equipment (MIE) project; which will address critical fusion material science questions. FES will initiate scoping studies to evaluate plans for an upgrade to the Matter in Extreme Conditions end station at LCLS and to assess options for a neutron source to test materials in a fusion-like environment. The Request will emphasize support for core discovery plasma science experiments on intermediate-scale collaborative facilities. Support will continue for low-temperature plasma research and high energy density plasma research, with connections and spinoffs to U.S. industry. The FY 2019 Request includes funding for the ITER project focusing on the highest-priority, in-kind contributions.

- *High Energy Physics (HEP)* supports research to understand how the universe works at its most fundamental level by discovering the most elementary constituents of matter and energy, probing the interactions among them, and exploring the basic nature of space and time itself. The FY 2019 Request of $770.0 million is a decrease of $55.0 million, or 6.7 percent, below the FY 2017 Enacted level. The FY 2019 Request will focus support on the highest priority elements identified in the 2014 High Energy Physics Advisory Panel (HEPAP) Particle Physics Project Prioritization Panel (P5) Report. The P5 report identified the High-Luminosity Large Hadron Collider (HL-LHC) accelerator and A Toroidal LHC Apparatus (ATLAS) and Compact Muon Solenoid (CMS) Detector Upgrade Projects as the highest priority in the near-term, and Long-Baseline Neutrino Facility and Deep Underground Neutrino Experiment (LBNF/DUNE) as the highest-priority large project in its timeframe. To continue our strong international partnership with CERN, the FY 2019 Request will increase support to these high-priority projects. The Request will enhance support for the LBNF/DUNE far-site civil construction, including the excavation of the underground equipment caverns and connecting drift, and the continued design effort work for the near site, cryogenic systems, and DUNE detectors. The Request supports preliminary design and prototyping for the planned Proton Improvement Plan II (PIP-II) construction project. The Request will support most projects consistent with planned funding profiles: LBNF/DUNE, HL-LHC Accelerator Upgrade Project (HL-LHC AUP), Muon to Electron Conversion Experiment (Mu2e), the Large Underground Xenon (LUX)-ZonEd Proportional scintillation in LIquid Noble gases (ZEPLIN) experiment (LZ), Super Cryogenic Dark Matter Search at Sudbury Neutrino Observatory Laboratory (SuperCDMS-SNOLAB), and the Dark Energy Spectroscopic Instrument (DESI). The Mu2e and LZ projects will receive final funding needed to complete all remaining project deliverables. The Request provides funding for two new Major Items of Equipment (MIEs), the HL-LHC ATLAS Detector Upgrade and the HL-LHC CMS Detector Upgrade Projects. The Request will support the operation of the Fermi National Accelerator Laboratory (Fermilab) Accelerator Complex at 75% of optimal. The Request will also support design and fabrication for the Facility for Advanced Accelerator Experimental Tests II (FACET-II) project. R&D that requires long-term investments including Advanced

Technology R&D, Accelerator Stewardship, and QIS will also be given higher priority in order to sustain world-leading efforts and support Office of Science priorities.

- *Nuclear Physics (NP)* supports experimental and theoretical research to discover, explore, and understand all forms of nuclear matter. The FY 2019 Request of $600.0 million is a decrease of $22.0 million, or 3.5 percent, below the FY 2017 Enacted level. The FY 2019 Request will support the highest priority research and scientific user facilities to maintain U.S. leadership in nuclear science. The FY 2019 Request will provide for operations of the Relativistic Heavy Ion Collider (RHIC) to confirm the origin of intriguing new phenomena observed in quark gluon plasma formation, operations of the recently completed 12 GeV Upgrade at the Continuous Electron Beam Accelerator Facility (CEBAF) to unravel the mechanism of quark confinement, and operations of the Argonne Tandem Linac Accelerator System (ATLAS) to provide opportunities for research in nuclear structure and nuclear astrophysics. The Request will support the continued construction of the Facility for Rare Isotope Beams (FRIB) according to the performance baseline profile; FRIB will provide world-leading capabilities for nuclear structure and astrophysics. The Request also supports the Gamma-Ray Energy Tracking Array (GRETA) detector, which will exploit the world-leading science capabilities of FRIB, and the Stable Isotope Production Facility (SIPF) within available resources. The Request also supports the initiation of the Strongly Pioneering High Energy Nuclear Interaction eXperiment (sPHENIX) MIE, which will further explore the properties of the quark gluon plasma. The Request supports core research at universities and DOE national laboratories and the development of cutting-edge approaches for producing isotopes critical to the Nation.

Reorganization and Restructure Initiative

SC is currently reviewing all functions and the organizational structure to maximize efficiencies across all programs in an attempt to increase efficiencies and reduce the Federal footprint. Through workforce analysis and restructuring, we will continue to review, analyze and prioritize mission requirements and identify those organizations and functions most in line with the Administration and Department program objectives and SC strategic goals. Using available human capital workforce reshaping tools, we have focused on functional consolidation, elimination of positions, and hiring limitations to achieve necessary results. SC has completed two VERA/VSIP buyout exercises that have helped to streamline the organization. SC is reviewing the field operations to identify areas of efficiency and potential reductions for the Integrated Service Centers (ISC) and the site offices. SC is reviewing the potential to reorganize the ISCs by establishing functional centers of excellence under one manager. Also, there is currently one site office for each national laboratory. By combining some of the site offices, better efficiencies can occur. Other areas under review include consolidation of SC's Information Technology services with those of the Department to boost security and efficiency. Safety and Security Technical Services are being consolidated and moved to the ISCs for better management of resources. These actions are in the process of being reviewed and implemented within SC. The review process continues as SC looks for other areas to reorganize to become a more effective and efficient office.

Basic and Applied R&D Coordination

Coordination between the Department's basic research and applied technology programs is a high priority within DOE and is facilitated through joint planning meetings, technical community workshops, annual contractor/awardee meetings, joint research solicitations, focused DOE program office working groups in targeted research areas, and collaborative program management of DOE's Small Business Innovation Research and Small Business Technology Transfer programs. Co-funding of research activities and facilities at the DOE laboratories and partnership/collaboration-encouraging funding mechanisms facilitate research integration within the basic and applied research communities. SC's R&D coordination also occurs at the interagency level. Specific collaborative activities are highlighted in the "Basic and Applied R&D Coordination" sections of each individual SC program budget justification narrative.

High-Risk, High-Reward Research[a]

SC incorporates high-risk, high-reward, basic research elements in all of its research portfolios; each SC research program considers a significant proportion of its supported research as high-risk, high-reward. Because advancing the frontiers of science also depends on the continued availability of state-of-the-art scientific facilities, SC constructs and operates national scientific facilities and instruments that comprise the world's most sophisticated suite of research capabilities. SC's basic research is integrated within program portfolios, projects, and individual awards; as such, it is not possible to quantitatively

[a] In compliance with the reporting requirements in the America COMPETES Act of 2007 (P.L. 110-69, section 1008)

separate the funding contributions of particular experiments or theoretical studies that are high-risk, high-reward from other mission-driven research in a manner that is credible and auditable. SC incorporates high-risk, high-reward basic research elements in its research portfolios to drive innovation and challenge current thinking, using a variety of mechanisms to develop topics: Federal advisory committees, triennial Committees of Visitors, program and topical workshops, interagency working groups, National Academies' studies, and special SC program solicitations. Many of these topics are captured in formal reports, e.g., *Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global* Context, by the High Energy Physics Advisory Panel (HEPAP-P5) (2014)[a]; *Quantum Computing Testbed for Science,* ASCR workshop report (2017)[b]; *Basic Research Needs Workshop on Innovation and Discovery of Transformative Experimental Tools,* Basic Energy Sciences workshop report (2017) [c]; *Challenges at the Frontiers of Matter and Energy: Transformative Opportunities for Discovery Science*, by BES Advisory Committee (BESAC) (2015)[d]; *Basic Research Needs Workshop on Quantum Materials for Energy Relevant Technology,* BES workshop report (2016)[e]; *Grand Challenges for Biological and Environmental Research: Progress and Future* Vision, by the BER Advisory Committee (BERAC) (2017)[f]; *Technologies for Characterizing Molecular and Cellular Systems*, BER workshop report (2016)[g]; *Plasma: at the Frontier of Scientific Discovery*, FES workshop report (2017)[h]; *Isotope Research and Production Opportunities and Priorities*, by the Nuclear Science Advisory Committee (NSAC) (2015)[i]; and *Nuclear Physics Long Range Plan*, by the NSAC (2015)[j]

Scientific Workforce

SC and its predecessors have fostered the training of a skilled scientific workforce for more than 60 years. In addition to the undergraduate and graduate research opportunities provided through SC's Office of Workforce Development for Teachers and Scientists (WDTS), the six SC research program offices train undergraduates, graduate students, and postdoctoral researchers through sponsored research awards at universities and the DOE national laboratories. The research program offices also support targeted, undergraduate and graduate-level experimental training in areas associated with scientific user facilities and not readily available in university academic departments, such as particle accelerator and detector physics, neutron and x-ray scattering, nuclear chemistry, and computational sciences at the leadership computing level. Lastly, SC supports the Early Career Research Program, which funds individual research programs by outstanding Ph.D. scientists early in their careers in the disciplines supported by SC[k]. SC coordinates with other DOE offices and other agencies on best practices for training programs and program evaluation through internal DOE working groups and active participation in the National Science and Technology Council's Committee on Science, Technology, Engineering, and Mathematics Education. SC also participates in the American Association for the Advancement of Science's Science & Technology Policy Fellowships program and the Presidential Management Fellows Program to bring highly qualified scientists and professionals to DOE headquarters for a maximum term of two years.

Cybersecurity

DOE is engaged in two categories of cyber-related activities: protecting the DOE enterprise from a range of cyber threats that can adversely impact mission capabilities and improving cybersecurity in the electric power subsector and the oil and natural gas subsector. The cybersecurity crosscut supports central coordination of the strategic and operational aspects of cybersecurity and facilitates cooperative efforts such as the Joint Cybersecurity Coordination Center for incident response and the implementation of Department-wide Identity, Credentials, and Access Management.

[a] http://science.energy.gov/~/media/hep/hepap/pdf/May%202014/FINAL_P5_Report_Interactive_060214.pdf
[b] https://science.energy.gov/~/media/ascr/pdf/programdocuments/docs/2017/QTSWReport.pdf
[c] https://science.energy.gov/~/media/bes/pdf/brochures/2017/Electrical_Energy_Brochure.pdf
[d] http://science.energy.gov/~/media/bes/besac/pdf/Reports/CFME_rpt_print.pdf
[e] https://science.energy.gov/~/media/bes/pdf/reports/2016/BRNQM_rpt_Final_12-09-2016.pdf
[f] https://science.energy.gov/~/media/ber/berac/pdf/Reports/BERAC-2017-Grand-Challenges-Report.pdf
[g] http://science.energy.gov/~/media/ber/pdf/workshop%20reports/VirtualEcosystems.pdf
[h] https://science.energy.gov/~/media/fes/pdf/program-news/Frontiers_of_Plasma_Science_Final_Report.pdf
[i] https://science.energy.gov/~/media/ber/pdf/community-resources/Technologies_for_Characterizing_Molecular_and_Cellular_Systems.pdf
[j] https://science.energy.gov/np/nsac/reports/
[k] https://science.energy.gov/early-career/

Science
Funding by Congressional Control ($K)

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Advanced Scientific Computing Research				
Research	483,000	479,720	666,304	+183,304
17-SC-20 Office of Science Exascale Computing Project (SC-ECP)	164,000	162,886	232,706	+68,706
Total, Advanced Scientific Computing Research	**647,000**	**642,606**	**899,010**	**+252,010**
Basic Energy Sciences				
Research	1,681,500	1,670,081	1,635,700	-45,800
Construction				
13-SC-10 Linac Coherent Light Source-II, SLAC	190,000	188,710	139,300	-50,700
18-SC-10 Advanced Photon Source Upgrade, ANL	0	—	60,000	+60,000
19-SC-10 Advanced Light Source Upgrade, LBNL	0	—	10,000	+10,000
19-SC-11 Linac Coherent Light Source-II-High Energy, SLAC	0	—	5,000	+5,000
Total, Construction	**190,000**	**188,710**	**214,300**	**+24,300**
Total, Basic Energy Sciences	**1,871,500**	**1,858,791**	**1,850,000**	**-21,500**
Biological and Environmental Research	**612,000**	**607,844**	**500,000**	**-112,000**
Fusion Energy Sciences				
Research	330,000	327,759	265,000	-65,000
Construction				
14-SC-60 ITER	50,000	49,660	75,000	+25,000
Total, Fusion Energy Sciences	**380,000**	**377,419**	**340,000**	**-40,000**

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
High Energy Physics				
Research	731,500	726,532	627,000	-104,500
Construction				
11-SC-40 Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment, FNAL	50,000	49,660	113,000	+63,000
11-SC-41 Muon to Electron Conversion Experiment, FNAL	43,500	43,205	30,000	-13,500
Total, Construction	**93,500**	**92,865**	**143,000**	**+49,500**
Total, High Energy Physics	**825,000**	**819,397**	**770,000**	**-55,000**
Nuclear Physics				
Operation and Maintenance	522,000	520,576	525,000	+3,000
Construction				
14-SC-50 Facility for Rare Isotope Beams, Michigan State University	100,000	97,200	75,000	-25,000
Total, Construction	**100,000**	**97,200**	**75,000**	**-25,000**
Total, Nuclear Physics	**622,000**	**617,776**	**600,000**	**-22,000**
Workforce Development for Teachers and Scientists	**19,500**	**19,368**	**19,000**	**-500**
Science Laboratories Infrastructure				
Infrastructure Support				
Payment in Lieu of Taxes	1,764	1,752	1,513	-251
Oak Ridge Landlord	6,182	6,140	6,434	+252
Facilities and Infrastructure	32,603	32,382	30,724	-1,879
Oak Ridge Nuclear Operations	26,000	25,823	10,000	-16,000
Total, Infrastructure Support	**66,549**	**66,097**	**48,671**	**-17,878**

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Construction				
19-SC-71 Science User Support Center, BNL	0	—	2,000	+2,000
19-SC-72 Electrical Capacity and Distribution Capability, ANL	0	—	20,000	+20,000
18-SC-71 Energy Science Capability at PNNL	0	—	4,000	+4,000
17-SC-71 Integrated Engineering Research Center, FNAL	2,500	2,483	5,000	+2,500
17-SC-73 Core Facility Revitalization at BNL	1,800	1,788	13,632	+11,832
15-SC-76 Materials Design Laboratory at ANL	19,590	19,457	20,000	+410
15-SC-77 Photon Science Laboratory Building at SLAC	20,000	19,864	0	-20,000
15-SC-78 Integrative Genomics Building at LBNL	19,561	19,428	13,549	-6,012
Total, Construction	**63,451**	**63,020**	**78,181**	**+14,730**
Total, Science Laboratories Infrastructure	**130,000**	**129,117**	**126,852**	**-3,148**
Safeguards and Security	**103,000**	**102,301**	**106,110**	**+3,110**
Program Direction	**182,000**	**180,764**	**180,000**	**-2,000**
Subtotal, Science	**5,392,000**	**5,355,383**	**5,390,972**	**-1,028**
Rescission of prior year balances	**-1,028**	**-1,021**	**0**	**+1,028**
Total, Science	**5,390,972**	**5,354,362**	**5,390,972**	**0**
Federal FTEs	**870**	**825**	**835**	**-35**

SBIR/STTR:

- FY 2017 Enacted: SBIR $134,016,000; and STTR $18,845,000 (SC only)
- FY 2019 Request: SBIR $128,083,000; and STTR $18,096,000 (SC only)

Advanced Scientific Computing Research

Overview

The Advanced Scientific Computing Research (ASCR) program's mission is to advance applied mathematics and computer science; deliver the most advanced computational scientific applications in partnership with disciplinary science; advance computing and networking capabilities; and develop future generations of computing hardware and software tools for science and engineering, in partnership with the research community, including U.S. industry. The ASCR program gives the science and technology community, including U.S. industry, access to world-class supercomputers and the tools to use them for science and engineering. ASCR accomplishes this by developing and maintaining world-class computing and network facilities for science; and advancing research in applied mathematics, computer science, and advanced networking.

For over half a century, the U.S. maintained world-leading computing capabilities through sustained investments in research, development, and deployment of new computing systems along with the applied mathematics and software technologies to effectively use the leading edge systems. The benefits of U.S. computational leadership have been enormous – huge gains in increasing workforce productivity, accelerated progress in both science and engineering, advanced manufacturing techniques and rapid prototyping, stockpile stewardship without testing, and the ability to explore, understand and harness natural and engineered systems, which are too large, too complex, too dangerous, too small, or too fleeting to explore experimentally. As the Council on Competitiveness noted and documented in a series of case studies, "A country that wishes to out-compete in any market must also be able to out-compute its rivals."[a] U.S. dominance in computing is under threat from significant investments in Asia and Europe. This is happening at a time when advances in computing capabilities are becoming increasingly costly and risky. We cannot afford to fall further behind in an area that is critical to the American prosperity because computing impacts our national security, every sector of our economy, and every field of science and engineering. Therefore, this FY 2019 Request increases our investments in the Department of Energy (DOE) Exascale Computing Initiative (ECI) to lower the risk of the project and deliver at least one exascale-capable system in 2021 and a second system in the 2021-2022 timeframe. In addition, the FY 2019 Request includes support for long-term investments in future computing technologies such as quantum information systems and artificial intelligence, areas where Asia and Europe are also investing heavily.

The DOE and its predecessor organizations have long played a key role in advancing U.S. computing capabilities in partnership with U.S. computing vendors and researchers. Computing is a fast-paced industry, but sustained progress depends upon significant gains in numerous areas of fundamental research including: advanced lithography, nano-scale materials science, applied mathematics and computer science – areas where DOE has provided long-term investments and world-leading capabilities. Because DOE partners with High Performance Computing (HPC) vendors to accelerate and influence the development of commodity parts, these research investments will impact computing at all scales, ranging from the largest scientific computers and data centers to department-scale computing to home computers and laptops. Public-private partnership remains vital as we push our state-of-the-art fabrication techniques to their limit to develop an exascale-capable (a billion billion operations per second) system while simultaneously preparing for what follows at the end of the current technology.

Maximizing the benefits of U.S. leadership in computing in the coming decades will require an effective national response to increasing demands for computing capabilities and performance, emerging technological challenges and opportunities, and competition with other nations. As one of the leading Federal agencies in the National Strategic Computing Initiative (NSCI), DOE will sustain and enhance its support for HPC research, development, and deployment as part of a coordinated Federal strategy guided by five NSCI objectives:

- Accelerate delivery of a capable exascale computing system that integrates hardware and software capability to deliver approximately 100 times the performance of current 10 petaflop systems across a range of applications representing government needs.
- Increase coherence between the technology base used for modeling and simulation and the one used for data analytic computing.
- Establish, over the next 15 years, a viable path forward for future HPC systems even after the limits of current semiconductor technology are reached (the "post- Moore's Law era").

[a] Final report from the High Performance Computing Users Conference: Supercharging U.S. Innovation & Competitiveness, held in July 2004.

- Increase the capacity and capability of an enduring national HPC ecosystem by employing a holistic approach that addresses relevant factors such as networking technology, workflow, downward scaling, foundational algorithms and software, accessibility, and workforce development.
- Develop an enduring public-private collaboration to ensure that the benefits of the research and development (R&D) advances are maximized and to the greatest extent, shared between the United States Government and industrial and academic sectors.

Within the context of coordinated NSCI strategy, the DOE Office of Science (SC) initiated a long term research program in quantum information science to prepare for the "post-Moore's Law era." In addition, SC and the DOE National Nuclear Security Administration (NNSA) are partnering on the ECI to overcome key exascale challenges in parallelism, energy efficiency, and reliability, leading to deployment of a diverse set of exascale systems in the 2021-2022 timeframe. The ECI's goal for an exascale-capable system is a fifty-fold increase in sustained performance over today's Titan system at Oak Ridge National Laboratory (ORNL), with applications that address next-generation science, engineering, and data problems. The ECI focuses on delivering advanced simulation through an exascale-capable computing program, which emphasizes sustained performance on science and national security mission applications and increased convergence between exascale and large-data analytic computing.

The SC FY 2019 Request funds two components of the ECI: planning, site preparations, and non-recurring engineering (NRE) at the Leadership Computing Facilities (LCF) to prepare for deployment of at least one exascale system in 2021, and the ASCR-supported Office of Science Exascale Computing Project (SC-ECP), first proposed in the FY 2017 Request, which includes only the R&D activities required to develop exascale-capable computers.

The scope of the SC-ECP has three areas which are focused on increasing the convergence of big compute and big data and creating a holistic high performance computing ecosystem:

- *Hardware Technology and Integration:* The goal of the Hardware Technology and Integration focus area is to integrate the delivery of SC-ECP products on targeted systems at leading DOE computing facilities.
- *System Software Technology:* The goal of the System Software Technology focus area is to produce a vertically integrated software stack to achieve the full potential of exascale computing including the software infrastructure to support large data management and data science for the DOE at exascale; and
- *Application Development:* The goal of the Application Development focus area is to develop and enhance the predictive capability of applications critical to DOE that involves: working with scientific and data-intensive grand challenge application areas to address the challenges of extreme parallelism, reliability and resiliency, deep hierarchies of hardware processors and memory, scaling to larger systems.

The SC-ECP is managed following the principles of DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets*, which SC uses for the planning, design, and construction of all of its major projects, but tailored to address the challenges of this fast-paced, research focused, public-private, HPC project.

Overall project management for SC-ECP is conducted via a Project Office established at ORNL because of its considerable expertise in developing computational science and engineering applications; in managing HPC facilities, both for the Department and for other federal agencies; and experience in managing distributed, large-scale scientific research projects, such as the Spallation Neutron Source project. A Memorandum of Agreement is in place between the six DOE national laboratories participating in SC-ECP: Lawrence Berkeley National Laboratory (LBNL), ORNL, Argonne National Laboratory (ANL), Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL) and Sandia National Laboratories (SNL) and the Project Office is now executing the project and coordinating among partners.

Highlights of the FY 2019 Request

The FY 2019 Request for ASCR increases our investments in the ECI to lower project risk to deliver at least one exascale-capable system in 2021. To ensure ASCR is meeting the HPC mission needs of the Office of Science during and after the exascale project, this Request prioritizes basic research for data intensive science, including machine learning and future computing technologies, and increases support for ASCR's Computational Partnerships with a focus on developing new strategic partnerships in quantum computing and data intensive applications. Funding for the ASCR facilities supports continued operations of the Oak Ridge Leadership Computing Facility (OLCF), the Argonne Leadership Computing Facility

(ALCF), the National Energy Research Scientific Computing Center (NERSC), and the Energy Sciences Network (ESnet). Funding will also support site preparations and NRE activities at the LCFs in support of a 2021 delivery of at least one exascale computing system.

Mathematical, Computational, and Computer Sciences Research

Recognizing that Moore's Law, where microchip feature sizes reduces by a factor of two approximately every two years, is nearing an end due to limits imposed by fundamental physics, ASCR began new activities in FY 2017 to explore future computing, such as quantum information science, that are not based on silicon microelectronics. In FY 2019, ASCR will continue the research and computational partnerships with the other SC program offices aimed at understanding the challenges that quantum information science pose to DOE mission applications and to identify the hardware, software, and algorithms that will need to be developed for DOE mission applications to harness these emerging technologies.

Activities in Applied Mathematics and Computer Science provide the foundation for increasing the capability of the national HPC ecosystem. In FY 2019, these activities will continue to develop the methods, software, and tools to ensure DOE applications can fully exploit the most advanced computing systems available today and use HPC systems for data-intensive and computational science at the exascale and beyond. In addition, fundamental changes to experimental and observational sciences are presenting new data and computing challenges along with exciting opportunities to deliver transformative capabilities to researchers. These changes are brought about by a confluence of factors that include, for example, the tremendous increases in data volumes and streaming data rates from experimental and observational devices; opportunities to combine data sources for new insights; a need for real-time feedback or automated steering of experiments; and a need to find new ways to derive insights from increasingly complex, heterogeneous information resources. Potential solutions to address these challenges rely on providing researchers with efficient and timely access to data and computing resources; effective use of new computing hardware; and new tools for analysis of big data. The FY 2019 Request supports fundamental research in computer science and applied mathematics to address these challenges, as well as partnerships among computer scientists, applied mathematicians, networking specialists, and domain scientists to address end-to-end analysis needs. The Request places a particular emphasis on machine learning for discovery and decision support.

The Scientific Discovery through Advanced Computing (SciDAC) computational partnerships, which were recompeted in FY 2017, use the software, tools, and methods developed by these core research efforts. This allows the other scientific programs in SC to more effectively use the current and immediate next generation HPC facilities. The focus of the SciDAC portfolio will continue to be on developing the mission critical applications of the other SC programs. In addition, new strategic partnerships in quantum computing and data intensive applications will advance capabilities and broaden the impact of these efforts. SciDAC investments are informed by the research results emerging from the ECI and will, whenever possible, incorporate the software, methods, and tools developed by that initiative.

The Next Generation Networking for Science activity was combined with other activities in FY 2018. Collaboratory efforts previously supported by this activity are now supported by computational partnerships to strengthen the interconnectivity of these efforts. Other networking-related R&D is now supported within the Computer Science activity. In FY 2019, these efforts will include research in new efforts in quantum networking.

High Performance Computing and Network Facilities

In FY 2019, the LCFs will continue to deliver HPC capabilities for large scale applications to ensure that the U.S. research community and DOE's industry partners continue to have access to the most capable supercomputing resources in the world. The ALCF upgrade project will continue to focus on deployment of a system capable of delivering more than an exaflop performance in 2021. Site preparations continue along with NRE efforts with the vendor to develop features that meet ECI requirements. The OLCF will operate the IBM Summit system to allow users to harness up to 200 petaflops of sustained performance while beginning preparation for an exascale upgrade in the 2021-2022 timeframe that is architecturally diverse from the ALCF system.

The NERSC will continue operations of the NERSC-8 supercomputer, named Cori, which has expanded the capacity of the facility to approximately 30 petaflops. To address growing demand for capacity computing to meet mission needs, the FY 2019 Request supports activities for an upgrade to NERSC-9, which will have three to five times the capacity of NERSC-8 in

2020. The Request also supports site preparation activities for the NERSC-9 upgrade, such as increased power and cooling capacity, and NRE to ensure the new computing system meets the need of the diverse NERSC user community.

Given the significant external competition for trained workforce across the ASCR portfolio and the need to develop the workforce to support the accelerated timeline for the delivery of an exascale system, the Research and Evaluation Prototypes (REP) activity will continue to support the Computational Sciences Graduate Fellowship at $10,000,000. Experienced computational scientists who assist a wide range of users in taking effective advantage of the advanced computing resources are critical assets at both the LCFs and NERSC. To address this DOE mission need, ASCR continues to support the post-doctoral training program for high end computational science and engineering at the facilities through ASCR facilities funding. In addition, the three ASCR HPC user facilities will continue to prepare their users for future architectures.

ASCR will also continue to support the future computing technologies testbed activity through REP. This research activity is focused on exploring the challenges and opportunities of quantum computing, a promising but currently experimental computing architecture. These efforts are in partnership with industry and the quantum research community.

In FY 2019, ESnet will continue to provide networking connectivity for large-scale scientific data flows. The last significant upgrade of the ESnet was in 2010 and some links are reaching the end of their life-span. In addition, the near-term delivery of exascale and sharply increased data rates from several other SC facilities means that the demand for data movement will exceed the cost effective capabilities of ESnet's rapidly aging technology. Therefore, the ESnet has an approved Mission Need Statement (Critical Decision-0) for the ESnet-6 upgrade in FY 2019 that will incorporate new optical technologies and increase core capacity to more than one terabit (one trillion bits) per second—an increase of 2-10 times current capacity at significantly lower per-wave deployment costs. The ESnet-6 upgrade will also continue to identify all of the critical research necessary to deploy these technologies with continued 99.999% reliability and enhanced cyber security protections.

Exascale Computing

Exascale computing is a central component of a long-term collaboration between the SC's ASCR program and the NNSA's Advanced Simulation and Computing Campaign (ASC) program to maximize the benefits of the Department's investments, avoid duplication, and leverage the significant expertise across the DOE complex. The ASCR FY 2019 Request includes $472,706,000 for SC's contribution to DOE's Exascale Computing Initiative to support the development of an exascale computing software ecosystem, prepare mission critical applications to address the challenges of exascale, and deploy at least one Exascale system in 2021 to meet national needs.

Exascale computing systems, capable of at least one billion billion (1×10^{18}) calculations per second, are needed to advance science objectives in the physical sciences, such as materials and chemical sciences, high-energy and nuclear physics, weather and energy modeling, genomics and systems biology, as well as to support national security objectives and energy technology advances in DOE. Exascale systems' computational capabilities are also needed for increasing data-analytic and data-intense applications across the DOE science and engineering programs and other Federal organizations that rely on large-scale simulations, e.g., the Department of Defense and the National Institutes of Health. The importance of exascale computing to the DOE science programs is documented in individual requirements reviews for each SC program office. Because DOE partners with HPC vendors to accelerate and influence the development of commodity parts, the investments in ECI will impact computing at all scales, ranging from the largest scientific computers and data centers to Department-scale computing to home computers and laptops.

Partnerships with U. S. vendors will continue to build on previous DOE investments in the Design Forward and Fast Forward pre-exascale activities to provide opportunities to accelerate our exascale efforts to keep pace with foreign competition. However, significant risk remains in delivering on this potential. To reduce this risk, the Department will increase the site preparations and NRE investments, initiated in FY 2018, between LCFs and U.S. vendors. As shown in the following table, the $472,706,000 funds continue application, software, and hardware development in SC-ECP and the site preparations and NRE activities at the LCFs to support the deployment of an exascale computing system in 2021 at ANL, followed by a second exascale system with a different advanced architecture at ORNL:

- $232,706,000 for the ECP project to accelerate research and the preparation of applications, develop a software stack for both exascale platforms, and support additional co-design centers in preparation for exascale system deployment in 2021.
- $240,000,000 in LCF activity to support operations of Theta and NRE, and site preparations for deployment of an exascale system to be delivered to the ALCF in 2021 and an additional exascale system with a different architecture at Oak Ridge in the 2021-2022 timeframe. Deployment of exascale systems will be through the LCFs as part of their usual upgrade processes.

This approach will reduce the risk of the project and expand the range of applications able to effectively utilize these capabilities in 2021.

FY 2019 Crosscuts ($K)

	ECI
Advanced Scientific Computing Research	472,706

Advanced Scientific Computing Research
Funding ($K)

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Mathematical, Computational, and Computer Sciences Research				
Applied Mathematics	29,229	–	40,316	+11,087
Computer Science	29,296	–	38,296	+9,000
Computational Partnerships	32,596	–	62,667	+30,071
Next Generation Networking for Science	16,000	–	–	-16,000
SBIR/STTR	6,369	–	5,352	-1,017
Total, Mathematical, Computational, and Computer Sciences Research	**113,490**	–	**146,631**	**+33,141**
High Performance Computing and Network Facilities				
High Performance Production Computing	92,145	–	80,000	-12,145
Leadership Computing Facilities	190,000	–	340,000	+150,000
Exascale (non-add)	–	–	*(240,000)*	*(+240,000)*
Research and Evaluation Prototypes	26,293	–	24,452	-1,841
High Performance Network Facilities and Testbeds	45,000	–	56,435	+11,435
SBIR/STTR	16,072	–	18,786	+2,714
Total, High Performance Computing and Network Facilities	**369,510**	–	**519,673**	**+150,163**
Exascale Computing				
17-SC-20 Office of Science Exascale Computing Project (SC-ECP)	164,000	162,886	232,706	+68,706
Total, Advanced Scientific Computing Research	**647,000**	**642,606**	**899,010**	**+252,010**

SBIR/STTR funding:
- FY 2017 Enacted: SBIR $19,675,000; and STTR $2,766,000
- FY 2019 Request: SBIR $21,162,000; and STTR $2,976,000

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

Advanced Scientific Computing Research
Explanation of Major Changes ($K)

	FY 2019 Request vs FY 2017 Enacted
Mathematical, Computational, and Computer Sciences Research: The Computer Science and Applied Mathematics activities will increase their emphasis on data-intensive science and machine learning to increase the impact of data generated in extreme-scale simulations and by Office of Science user facilities. The Computational Partnerships activity will continue to infuse the latest developments in applied math and computer science into the strategic applications of the Office of Science to get the most out of the leadership computing systems. There is a particular emphasis within the partnerships portfolio focus on future computing technologies such as quantum information science in partnership with Basic Energy Sciences (BES), Biological and Environmental Research (BER), High Energy Physics (HEP), and Nuclear Physics (NP) and on data intensive science. The Next Generation Networking for Science activity was combined with other activities in FY 2018. Collaboratory efforts previously supported by this activity are supported by computational partnerships to strengthen the interconnectivity of these efforts. Other networking-related R&D is now supported within the Computer Science activity. This funding will include new efforts in quantum networking.	**+33,141**
High Performance Computing and Network Facilities: Increased facilities funding initiates activities to deploy an exascale system at the ALCF in 2021 and to begin preparations at the OLCF for an exascale system that is architecturally distinct to be deployed in the 2021-2022 timeframe. Funding also supports operations, including increased power costs, upgrading, planning, and long lead site preparations at ASCR's facilities. High Performance Network Facilities and Testbeds will support the ESnet-6 upgrade to significantly increase capacity and security to all sites.	**+150,163**
Exascale Computing: The FY 2019 Request will support efforts in SC-ECP for the continued acceleration of application and software development for both architectures, together with additional co-design centers, applications, partnerships with the vendors, and testbeds to ensure development of hardware and software keep pace.	**+68,706**
Total, Advanced Scientific Computing Research	**+252,010**

Basic and Applied R&D Coordination

Coordination across disciplines and programs is a cornerstone of the ASCR program. Partnerships within SC are mature and continue to advance the use of HPC and scientific networks for science. New partnerships with the other SC Programs have been established in quantum information science. Growing areas of collaboration will be in the area of data-intensive science and readying applications for exascale. ASCR continues to have a strong partnership with NNSA for achieving the Department's goals for exascale computing. In April 2011, ASCR and NNSA strengthened this partnership by signing a memorandum of understanding for collaboration and coordination of exascale research within the Department. Through the National Information Technology Research and Development Subcommittee of the National Science and Technology Council's (NSTC) Committee on Technology, the interagency networking and information technology R&D coordination effort, ASCR also coordinates with programs across the Federal Government. In FY 2019, cross-agency interactions and collaborations will continue in coordination with the Office of Science and Technology Policy.

Program Accomplishments

Leadership Computing Adds Predictive Power to New Nuclear Reactor. The largest time-dependent simulation of a nuclear power plant was run on the Oak Ridge Leadership Computing Facility to obtain accurate design predictions for the startup of Watts Bar Unit 2 nuclear power plant, the United States' first new nuclear reactor in 20 years. The simulation used data supplied by two Consortium for Advanced Simulation of Light Water Reactors (CASL) members—the Tennessee Valley Authority and the Westinghouse Electric Company. The simulations provided a detailed picture of the reactor's hour-by-hour behavior during power escalation when it came fully online in October 2016. In total, the CASL team calculated 4,128 state points, a task that required more than 2 million core-hours of compute time.

Finding New Ways to Remove Hazardous Chemicals from Mixtures. Removing hydrogen sulfide from natural gas is costly and energy-intensive, limiting the economical use of raw natural gas reserves. Researchers from the University of Minnesota and the ALCF developed new models to identify methods to remove hazardous chemicals from mixtures economically and without associated health risks. Using Mira, the researchers identified siliceous zeolites as the best candidates for removing hydrogen sulfide from mixtures of methane, ethanol, carbon dioxide, and nitrogen and simulated efficient processes that use them. The findings from these studies will provide the natural-gas industry access to untapped reserves at reduced cost and environment impact, and without health risks.

Interoperable Design of Extreme-scale Application Software. The ECP Interoperable Design of Extreme-scale Application Software project released the first version of its Extreme-scale Scientific Software Development Kit (xSDK) to improve ECP developer productivity and software sustainability while ensuring continued scientific success. The xSDK toolkit provides a superior solution for application developers using libraries by enabling turnkey installation, compatible builds, and interoperability, which is especially important for multi-scale and multi-physics projects that rely upon this functionality. The current xSDK packages include four numerical libraries, two domain components, and nine others being staged as part of future releases. The explicit ECP investment in developing, adapting, and adopting new and better software practices will improve developer productivity and software sustainability at a time when such improvements are essential for transforming capabilities for new platforms, coupling multiscale and multi-physics, and improving the effectiveness of DOE's highly skilled computational scientists.

How safe is your data? ASCR-supported researchers at the University of Wisconsin-Madison analyzed how modern distributed storage systems behave in the presence of file-system faults such as data corruption and read and write errors. They characterized eight popular distributed storage systems and uncover numerous bugs related to file-system fault tolerance. According to their findings, modern distributed systems do not consistently use redundancy to recover from file-system faults thus a single file-system fault can cause catastrophic outcomes such as data loss, corruption, and unavailability. These research findings have led to numerous bug fixes by major storage vendors.

Largest ever simulation of a quantum computer. Quantum computing uses computational elements that obey quantum mechanical laws to potentially provide transformative changes in computational power for certain high-impact tasks such as the simulation of highly complex physical systems for applications of strategic importance to DOE and SC. Although a working prototype of a universal quantum computer has not been realized yet, it is generally thought that a quantum computer deploying 49 qubits—a unit of quantum information—will be able to match the computing power of today's most powerful supercomputers. Both emulation and simulation are important for calibrating, validating and benchmarking emerging quantum computing hardware and architectures. Simulation of quantum circuits is a general method that also allows the inclusion of the effects of noise but such simulations can be very challenging even on today's fastest supercomputers. In April 2017, two researchers from the Swiss Federal Institute of Technology (ETH Zurich) have nevertheless successfully run the largest ever simulation of a quantum computer by using 8,192 of 9,688 Intel Xeon Phi processors on NERSC's newest supercomputer, Cori. The 45-qubit simulation was made possible by the performance boost gained through the use of LBNL's Roofline model during the optimization process. The Roofline model was developed by the collaboration of 2 SciDAC Institutes (SUPER and FASTMath) between 2013 and 2017. It has quickly become a broadly used performance modeling methodology across the DOE community and recently Intel has embraced the approach and integrated it into its production Intel® Advisor.

X-ray science breakthroughs enabled by advanced mathematical algorithms. An international team of researchers is gaining insights into the three-dimensional structure and behavior of nanoscale viruses using newly-developed computational tools. The breakthrough capitalized on new Multi-Tiered Iterative Phasing algorithms developed by LBNL's Center for Advanced Mathematics for Energy Applications. The algorithms and mathematics provide a new set of tools and building blocks for data analyses of single-particle imaging experiments performed at X-ray free electron laser facilities such as the DOE Linac Coherent Light Source at SLAC. In overcoming long-standing technical barriers, the mathematical developments have immediate practical benefit for accelerating research discoveries using the most advanced x-ray light sources.

How to handle vast amounts of simulation data. Today's supercomputers are capable of generating more data than they can write to disk. For traditional workflows that rely on exporting the full state of the simulation every few time steps for post-hoc analysis, this is a major hurdle that will become even more entrenched as the ability to export data does not keep pace with the ability to generate data on future computing platforms. That's one reason why scientists are now looking to do more of the analysis of the simulation data inside the supercomputer—a technique referred to as *in situ* analysis. In situ analysis, however, comes with its own challenges, for example, analysis calculations perform differently from the simulation calculations. Novel computer science techniques are needed to balance the workloads of the different calculations within the machine and manage the sharing of data between the types of calculations. Two in situ methods are used, often in combination: the first does some portion of the analysis calculation within the simulation routine; the second does a portion of the analysis alongside the simulation, but shares data with the simulation as needed. Challenges of the in situ workflow include determining which analysis tasks can be done within the simulation and which have to be done alongside it, and how to allocate resources to each. In situ technologies for HPC applications have developed largely through long-term ASCR support for basic computer science research and are being deployed in current HPC codes, enabling the science to continue despite the data output limitations of current and expected HPC machines, often while gaining better time resolution of the saved data, and more efficient use of computing and storage resources. For example, researchers at LBNL have developed such in situ techniques with support from the ASCR basic research program and, in collaboration with SciDAC activities, deployed these techniques for cosmology simulations. By saving only the analysis results rather than the full simulation data, the application saw a one thousand fold decrease in data volume exported from the simulation without loss of scientifically valuable information.

Advanced Scientific Computing Research
Mathematical, Computational, and Computer Sciences Research

Description

The Mathematical, Computational, and Computer Sciences Research subprogram supports research activities to effectively meet the Office of Science HPC mission needs, including both data intensive and computationally intensive science. Computational science is increasingly central to progress at the frontiers of science and to our most challenging engineering problems. Accordingly, the subprogram delivers:

- new mathematics required to more accurately model systems involving processes taking place across a wide range of time and length scales;
- software, tools, and workflows to efficiently and effectively harness the potential of today's HPC systems and advanced networks for science and engineering applications;
- new mathematics and software for data management and analysis, including machine learning, required for the complex data-intensive workflows that are increasingly reliant on HPC capabilities.
- operating systems, data management, analyses, machine learning, representation model development, and other tools required to make effective use of future-generation supercomputers and the data sets from current and future scientific user facilities;
- computer science and algorithm innovations that increase the productivity, energy efficiency, and usability of future-generation supercomputers; and
- collaboration tools to make scientific resources readily available to scientists, in university, national laboratory, and industrial settings.

The research program supports long-term, basic research to develop methods, software, and tools to use HPC systems for data-intensive and computationally intensive science at the exascale and beyond. This requires a focus on increased parallelism, data movement, usability, and machine learning as well as exploratory research to prepare for computing paradigms in post exascale era including extremely heterogeneous architectures and beyond Moore's Law technologies such as quantum, neuromorphic, and probabilistic computing, which has the potential to revolutionize scientific computing.

Deriving scientific insights from the vast amounts of data flowing from SC user facilities as well as the output of extreme-scale simulations will require a seamless integration of HPC and data and a sophisticated tool suite for data management, analysis, and curation. In FY 2019, ASCR's research program will increase its emphasis on data-intensive science, including new efforts to exploit machine learning for discovery and decision support.

<u>Applied Mathematics</u>

The Applied Mathematics activity supports basic research leading to fundamental mathematical advances and computational breakthroughs across DOE and Office of Science missions. Basic research in scalable algorithms, multiscale modeling, and efficient data analysis underpin all of DOE's computational and data-intensive science efforts. More broadly, this activity includes support for foundational research in problem formulation, multiscale modeling and coupling, mesh discretization, time integration, advanced solvers for large-scale linear and nonlinear systems of equations, methods that use asynchrony or randomness, uncertainty quantification, and optimization. Forward-looking efforts by this activity anticipate DOE mission needs from the closer coupling and integration of scientific data with advanced computing, and for enabling greater capabilities for scientific discovery, design, and decision-support.

<u>Computer Science</u>

The Computer Science activity supports long-term, basic research on the software, tools, and techniques that allow scientists to harness the potential of advanced computing and smart networking technologies and extreme-scale data, including machine learning.

ASCR Computer Science research leads the way in the R&D of the software infrastructure that is essential for the effective use of the most powerful high performance computing systems in the country, tools to manage and analyze data at scale, and cybersecurity innovation that can enable the scientific integrity of extreme scale computation, networks, and scientific data. ASCR Computer Science plays the role of reducing risk when industry will not invest in the specialized software required for future Leadership Computers. Supercomputer vendors often take software developed with ASCR Computer Science investments and integrate it with their own software.

It is widely acknowledged that the computing industry is currently entering an era of unprecedented hardware architecture diversity — a veritable explosion of technology innovation that will greatly increase the complexity of Leadership Computing. Such diversity and complexity will be accompanied by major challenges at all levels of systems software, data management and analytics tools, the cybersecurity environment, and applications software. To have Leadership Computing systems that are useful for science applications at the time of delivery, ASCR Computer Science research focuses its investments on software needed for emerging technologies long before they are in operational use. These efforts are essential to ensure DOE mission applications including data-intensive applications, are able to use commercially available HPC through the exascale era and beyond Moore's law.

Computational Partnerships

The Computational Partnerships activity supports the SciDAC program, which accelerates progress in scientific computing through partnerships among applied mathematicians, computer scientists, and scientists in other disciplines. SciDAC focuses on the high-end of high-performance computational science and engineering and addresses two challenges: to broaden the community and thus the impact of HPC, particularly to address the Department's missions, and to ensure that progress at the frontiers of science is enhanced by advances in computational technology, most pressingly, the emergence of the hybrid and many-core architectures and machine learning techniques.

SciDAC partnerships enable scientists to conduct complex scientific and engineering computations on leadership-class and high-end computing systems at a level of fidelity needed to simulate real-world conditions. The SciDAC institutes bridge core research efforts in algorithms, methods, software, and tools with the need of the SciDAC applications supported in partnership with the other SC programs. Current SciDAC applications include chemistry, materials science, fusion research, high energy physics, nuclear physics, astrophysics, earth systems modeling, and accelerator physics. Starting in FY 2018, these efforts also include the collaboratory partnerships previously supported by the Next Generation of Networking for Science. These efforts enable large distributed research teams to share data and develop tools for real-time analysis of the massive data flows from Office of Science scientific user facilities.

In addition to SciDAC, the Computational Partnerships activity will support interdisciplinary teams in partnership with BES, BER, HEP, and NP to develop algorithms and applications targeted for future computing platforms, including quantum information systems.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Mathematical, Computational, and Computer Sciences Research $113,490,000	**$146,631,000**	**+$33,141,000**
Applied Mathematics $29,229,000	**$40,316,000**	**+$11,087,000**
Applied Mathematics continued its core programs in new algorithmic techniques and strategies that extract scientific advances and engineering insights from massive data for DOE missions. Adaptive algorithms and machine learning were added to the suite of tools under development for optimizing the scientific output of data-intensive programs across SC.	Applied Mathematics will continue its core programs in new algorithmic techniques and strategies that extract scientific advances and engineering insights from massive data for DOE missions. Applied Mathematics will also continue to focus on the development of adaptive algorithms and machine learning in recognition of the increased interest in these technologies across SC application areas.	The Request increases core research efforts in applied mathematics. Priorities within the portfolio are focused on addressing opportunities for applied mathematics research to improve the rigor, robustness, and reliability of machine learning for DOE mission requirements.
Computer Science $29,296,000	**$38,296,000**	**+$9,000,000**
Computer Science continued efforts to develop software, new programming models, new operating systems, and efforts to promote ease of use. Activities to support development of future computing technologies also continued, and a new effort was initiated to exploit machine learning techniques to better understand data generated both by HPC simulations and SC facilities.	Computer Science will continue efforts to develop software, new programming models, new operating systems, and efforts to promote ease of use. In addition, efforts in quantum networking, transferred from the Next Generation Networking for Science activity, will continue at FY 2018 levels. There will also be an emphasis on preparing for the "extremely heterogeneous" post-exascale era.	The Request increases core research efforts in Computer Science. Priorities within the portfolio include quantum networking and future computing technologies such as quantum, neuromorphic, or probabilistic computing.

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Computational Partnerships $32,596,000	**$62,667,000**	**+$30,071,000**
The SciDAC institutes continued to play a key role in assisting DOE mission critical applications to effectively use ASCR's existing production and LCFs while the newly-awarded fourth-generation SciDAC partnerships focused on preparing applications to harness the potential of ASCR's planned upgrades to its computing facilities. Partnerships continued to explore potential impacts of future computing technologies across SC.	In addition to continued support for the SciDAC institutes and partnerships awarded in FY 2017-18, this activity will increase efforts in quantum information science in partnership with the other SC programs, and efforts to bring the power of HPC to data intensive science.	Request supports expanded basic research efforts in quantum information science in partnership with other SC Programs such as BES, BER, HEP, and NP and data intensive science efforts, including collaboratory partnerships.
Next Generation Networking for Science $16,000,000	**$0**	**-$16,000,000**
The Next Generation Networking for Science activity continued to work closely with SC user facilities and applications, to develop the necessary tools—networking software, middleware and hardware—to address the challenges of moving, sharing, and validating massive quantities of data via next generation optical networking technologies.	The Next Generation Networking for Science activity was combined with other activities in FY 2018. Collaboratory efforts previously supported by this activity are supported by computational partnerships to strengthen the interconnectivity of these efforts. Other networking-related R&D is now supported within the Computer Science activity.	The Next Generation Networking for Science activity was combined with other activities in FY 2018.
SBIR/STTR $6,369,000	**$5,352,000**	**-$1,017,000**
In FY 2017, SBIR/STTR funding was set at 3.65% of non-capital funding.	In FY 2019, SBIR/STTR funding is set at 3.65% of non-capital funding.	

Advanced Scientific Computing Research
High Performance Computing and Network Facilities

Description
The High Performance Computing and Network Facilities subprogram delivers forefront computational and networking capabilities. These include high performance production computing at NERSC at LBNL and Leadership Computing Facilities (LCFs) at ORNL and ANL. These computers and the other SC research facilities generate many petabytes of data each year. Moving data to where it is needed requires advanced scientific networks and related technologies provided through High Performance Network Facilities and Testbeds, which includes the ESnet. Finally, operation of the facilities also includes investments to ensure the facilities remain state-of-the-art and can accept future systems, such as electrical and mechanical system enhancements.

The Research and Evaluation Prototypes (REP) activity addresses the challenges of next generation computing systems. By actively partnering with the research community, including industry and other Federal agencies, on the development of technologies that enable next-generation machines, ASCR ensures that commercially available architectures serve the needs of the scientific community. The REP activity also prepares researchers to effectively use future generations of scientific computers, including novel technologies, and seeks to reduce risk for future major procurements. In addition, the REP activity supports the Computational Sciences Graduate Fellowship to prepare the next generation of computational scientists and engineers for advanced computing systems in support of DOE workforce needs.

The facilities regularly gather requirements from the other SC research programs through a robust process to inform upgrade plans. These requirements activities are also vital to planning for SciDAC and other ASCR efforts to prioritize research directions and inform the community of new computing trends, especially as the computing industry moves toward exascale computing. Allocation of computer time at ASCR facilities follows the peer-reviewed and public-access model used by other SC scientific user facilities. To help address the workforce issues at the ASCR facilities, each facility established a postdoctoral training program in FY 2015 for high-end computational science and engineering. These programs teach PhD scientists with limited experience in HPC the skills to be computational scientists adept at using high performance production and leadership systems.

<u>High Performance Production Computing</u>
This activity supports NERSC, which delivers high-end production computing services for the SC research community. Approximately 7,000 computational scientists in about 700 projects use NERSC annually to perform scientific research across a wide range of disciplines including astrophysics, chemistry, earth systems modeling, materials, high energy and nuclear physics, fusion, and biology. NERSC users come from nearly every state in the U.S., with about 49% based in universities, 46% in DOE laboratories, and 5% in other government laboratories and industry. NERSC's large and diverse user base requires an agile support staff to aid users entering the HPC arena for the first time, as well as those preparing codes to run on the largest machines available at NERSC and the LCFs.

NERSC currently operates the 30 pf Intel/Cray system (Cori, after Nobel Laureate Gerty Cori) to support the SC research community. NERSC is a vital resource for the SC research community and is consistently oversubscribed, with requests exceeding capacity by a factor of 3–10. This gap between demand and capacity exists despite upgrades to the primary computing systems approximately every three to five years.

<u>Leadership Computing Facilities</u>
The LCFs enable open scientific applications, including industry applications, to harness the potential of leadership computing to advance science and engineering. The success of this effort is built on the gains made in Research and Evaluation Prototypes and ASCR research efforts. Another LCF strength is the staff, which operate and maintain the forefront computing resources and provide support to Innovative and Novel Computational Impact on Theory and Experiment (INCITE) projects, ASCR Leadership Computing Challenge (ALCC) projects, scaling tests, early science applications, and tool and library developers. Support staff experience is critical to the success of industry partnerships to address the challenges of next-generation computing.

The Oak Ridge Leadership Computing Facility's (OLCF) 27 petaflop (pf) Cray system (Titan) has been one of the most powerful computers in the world for scientific research since it began operations in October of 2012 and was ranked number five on the November 2017 Top 500 list, just below the most powerful supercomputers in China, Switzerland, and Japan.[a] The FY 2018 upgrade of this facility to a 200 pf IBM/NVIDIA system (Summit) challenges the leadership of the world's fastest systems. Early science applications at the OLCF, including large eddy simulation of turbulent combustion in complex geometries, quantum Monte Carlo simulations for the study and prediction of materials properties, heavy element chemistry, models of astrophysical explosions, dynamical simulations of magnetic fields in high-energy-density plasmas, molecular design of next-generation nanochemistry for atomically precise manufacturing, simulation of cellular and neural signaling, simulations of neutron transport in fast-fission reactor cores, and earthquake simulations, are scaling to make effective use of the new capability. OLCF staff shares its expertise with industry to broaden the benefits of petascale computing for the nation. For example, OLCF works with industry to reduce the need for costly physical prototypes and physical tests in the development of high-technology products. These efforts often result in upgrades to in-house computing resources at these U.S. companies.

The Argonne Leadership Computing Facility (ALCF) operates a 10-pf IBM system (Mira), developed through a joint research project with support from the NNSA, industry, and ASCR's REP activity. This HPC system achieves high performance with relatively lower electrical power consumption than other current petascale computers. The ALCF also operates an 8.5 pf Intel/Cray system (Theta) to prepare their users for the ALCF-3 upgrade in 2021.

The ALCF and OLCF systems are architecturally distinct, consistent with DOE's strategy to foster a diversity of capabilities that provides the Nation's HPC user community with the most effective resources. ALCF supports many applications, including molecular dynamics and materials, for which it is better suited than OLCF or NERSC. Through INCITE, ALCF also transfers its expertise to industry, for example, helping scientists and engineers to understand the fundamental physics of turbulent mixing to transform product design and to achieve improved performance, lifespan, and efficiency of aircraft engines.

The demand for 2018 INCITE allocations at the LCFs outpaced the available resources by a factor of two with growth expected to sharply increase upon the availability of upgrades.

Research and Evaluation Prototypes

REP has a long history of partnering with U.S. vendors to develop future computing technologies and testbeds that push the state-of-the-art and enabled DOE researchers to better understand the challenges and capabilities of emerging technologies. This activity supports testbeds for next-generation systems and for future computing technologies beyond Moore's law, specifically in the area of quantum computing testbeds and prototypes.

In addition, this activity partners with the NNSA on the Computational Sciences Graduate Fellowship (CSGF).

High Performance Network Facilities and Testbeds

The Energy Sciences Network (ESnet) is the Office of Science's high performance network user facility, delivering highly-reliable data transport capabilities optimized for the requirements of large-scale science. In essence, ESnet is the circulatory system that enables the DOE science mission. ESnet currently maintains one of the fastest and most reliable science networks in the world with a 100 gigabit per second (Gbps) "backbone" network that spans the continental United States and the Atlantic Ocean. ESnet interconnects the DOE's national laboratory system, dozens of other DOE sites, and ~200 research and commercial networks around the world—enabling tens of thousands of scientists at DOE laboratories and academic institutions across the country to transfer vast data streams and access remote research resources in real-time. ESnet also supports the data transport requirements of all SC user facilities. ESnet's traffic continues to grow exponentially—roughly 66% each year since 1990—a rate more than double the commercial internet. Costs for ESnet are dominated by operations and maintenance, including continual efforts to maintain dozens of external connections, benchmark future needs, expand capacity, and respond to new requests for site access and specialized services. As a user facility, ESnet engages directly in efforts to improve end-to-end network performance between DOE facilities and U.S. universities. ESnet is recognized as a global leader in innovative network design and operations, and is heavily engaged in planning a complete upgrade of its backbone network (the ESnet-6 upgrade).

[a] http://www.top500.org/lists/2017/11/

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
High Performance Computing and Network Facilities $369,510,000	**$519,673,000**	**+$150,163,000**
High Performance Production Computing $92,145,000	**$80,000,000**	**-$12,145,000**
The NERSC-8 system continued production operations. Demand for production computing for the SC programs continued to grow along with system capability and the rapid increase in data from experiments. In FY 2017, preparation for the 2020 delivery of NERSC-9, which will provide three to five times the capacity of NERSC-8, continued.	Support will continue operations and user support at the NERSC facility–including power, space, leases and staff. Funding will also support site preparation activities for the NERSC-9 upgrade, such as increased power and cooling capacity, and NRE efforts to ensure the new computing system meets the needs of the diverse NERSC user community.	FY 2019 funding supports site preparations and NRE activities to maintain deployment of the upgrade in the 2020 timeframe.
Leadership Computing Facilities $190,000,000	**$340,000,000**	**+$150,000,000**
Operation continued at both LCF facilities while upgrades will proceeded. The OLCF began installation and testing, the new IBM hybrid supercomputer, called Summit. This upgrade will provide 200 pf of computing capability, or approximately five times the capability of the previous system, Titan. OLCF also began site preparations to enable deployment of an exascale system in the 2021-2022 timeframe. The ALCF continued to provide access to the 8.5-pf Intel Xeon interim system, called Theta, to prepare ALCF users for the proposed 2021 exascale system. The ALCF began site preparations and significant NRE efforts to deploy a novel architecture capable of delivering more than an exaflop of computing capability in 2021.	Support will continue operations and user support at the LCF facilities –including power, space, leases, and staff. Long-lead site preparations for planned upgrades, such as increased power and cooling capacity and significant NRE efforts, will also be supported. The OLCF will continue operation and allocation of Summit. In support of ECP, the OLCF will provide access to Summit for the application and software projects to scale and test their codes. The OLCF will also continue activities to enable deployment of an exascale system in the 2021-2022 timeframe under the CORAL II. The ALCF will continue operation of Theta. The ALCF will continue site preparations and significant NRE efforts to deploy a novel architecture capable of delivering more than an exaflop of computing capability in the 2021 timeframe as part of ECI.	Increase supports significant NRE efforts and site preparation activities at both LCFs to lower the risk and support the accelerated delivery of exascale capable computing systems beginning in 2021.

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
	In addition, the ALCF will procure a large developmental testbed to test activities from NRE investments and to provide ECP applications and software technology projects to test their codes.	
Leadership Computing Facility at ANL: $80,000,000	$140,000,000	+$60,000,000
Leadership Computing Facility at ORNL: $110,000,000	$200,000,000	+$90,000,000
Research and Evaluation Prototypes $26,293,000	**$24,452,000**	**-$1,841,000**
Availability of experienced and knowledgeable workforce issues continued to be of vital importance to ASCR's current and planned facilities. The CSGF program plays an increasingly important role as the Exascale Initiative progresses and future computing technologies mature. Therefore, support for the CSGF within REP continued at $10,000,000 in FY 2017. Funding also established support for the future computing technology testbed focused on quantum computing.	The Request will provide continued support for the CSGF fellowship at $10,000,000 in partnership with the NNSA to increase availability of a trained workforce for exascale and beyond Moore's Law capabilities. In addition, funding will provide continued support for quantum testbed efforts to provide resources for the researchers supported through the quantum information science partnerships with the other SC programs.	Continues support for the CSGF fellowship and quantum testbed activities. The decrease reflects the completion of a data storage and memory project.
High Performance Network Facilities and Testbeds $45,000,000	**$56,435,000**	**+$11,435,000**
Funding supported operations and maintenance of the network and continued development of tools now widely deployed through the DOE and university systems in the U.S.: Science DMZ, perfSONAR, Data Transfer Nodes, and OSCARS. ESnet was last upgraded in 2010 and some technology is no longer supported by the vendor. Additional funds were used to support planning for an upgrade to ESnet-6, which will provide a network for scientific data transfer with the capacity, reliability and resilience, and flexibility to meet the needs of the Office of Science facilities and research community through the mid-2020s.	The Request will support operations of the ESnet at 99.999% reliability. In addition, funding will support the ESnet-6 upgrade to increase network capacity and modernize the network architecture.	The Request supports the continued operations of ESnet and the ESnet-6 upgrade.
SBIR/STTR $16,072,000	**$18,786,000**	**+$2,714,000**
In FY 2017, SBIR/STTR funding was set at 3.65% of non-capital funding.	In FY 2019, SBIR/STTR funding is set at 3.65% of non-capital funding.	

Description

SC and NNSA will continue to execute the Exascale Computing Initiative (ECI), which is an effort to develop and deploy an exascale-capable computing system with an emphasis on sustained performance for relevant applications and analytic computing to support DOE missions.

The SC Exascale Computing Project (SC-ECP) in the Exascale Computing subprogram captures the research aspects of ASCR's participation in the U. S. DOE's ECI, to ensure the hardware and software R&D, including applications software, for a exascale system is completed in time to meet the scientific and national security mission needs of the DOE in 2021. The deployment of these systems, funded under ECI, includes necessary site preparations and NRE, is supported by the Leadership Computing Facilities activity that will ultimately house and operate the exascale systems. The ECI will execute a program, joint between SC and NNSA, to develop and deploy an exascale-capable computing system with an emphasis on sustained performance for relevant applications and analytic computing to support DOE missions.

The SC-ECP is managed following the principles of DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets*, tailored for this fast-paced research effort and similar to that which has been used by SC for the planning, design, and construction of all of its major computing projects, including the LCFs at Argonne and Oak Ridge National Laboratories and NERSC at LBNL.

The FY 2019 Request includes $232,706,000 for the SC-ECP. These funds will support the preparation of mission critical applications and the development of a software stack for exascale platforms. Funding will also support additional co-design centers, vendor partnerships in preparation for an exascale system deployment in 2021, and integration between SC-ECP and the LCFs. Deployment of exascale systems will be through the LCFs as part of their usual upgrade processes. $240,000,000 of ECI funding is provided in the LCF activity to continue planning, NRE activities, and site preparations for at least two exascale systems, with the first to be delivered as early as 2021.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
17-SC-20 Office of Science Exascale Computing Project (SC-ECP) $164,000,000[a]	**$232,706,000**	**+$68,706,000**
FY 2017 funding accelerated application and software stack development in preparation for delivery of an exascale system in 2021.	Funding will continue the acceleration of application and software stack development in preparation for delivery of an exascale system in 2021.	Request supports expanded application and software efforts and accelerations of the Pathforward vendor partnerships.

[a] In addition, $150,000,000 of ECI funding is requested within the Leadership Computing Facilities activity in FY 2018 and $240,000,000 in FY 2019 to begin planning, non-recurring engineering, and site preparations for at least one exascale system to be delivered in 2021.

Advanced Scientific Computing Research
Performance Measures

In accordance with the GPRA Modernization Act of 2010, the Department sets targets for, and tracks progress toward, achieving performance goals for each program.

	FY 2017	FY 2018	FY 2019
Performance Goal (Measure)	**ASCR Facility Operations - Average achieved operation time of ASCR user facilities as a percentage of total scheduled annual operation time**		
Target	≥ 90 %	≥ 90 %	≥ 90 %
Result	Met	TBD	TBD
Endpoint Target	Many of the research projects that are undertaken at the SC's scientific user facilities take a great deal of time, money, and effort to prepare and regularly have a very short window of opportunity to run. If the facility is not operating as expected the experiment could be ruined or critically setback. In addition, taxpayers have invested millions or even hundreds of millions of dollars in these facilities. The greater the period of reliable operations, the greater the return on the taxpayers' investment.		
Performance Goal (Measure)	**ASCR Research - Discovery of new applied mathematics and computer science tools and methods that enable DOE applications to deliver scientific and engineering insights with a significantly higher degree of fidelity and predictive power**		
Target	Identify at least one multi-institutional team to develop new mathematics for DOE mission focused grand challenges at the nexus of multiple computational sub-domains such as data-driven discovery, multiscale modeling, uncertainty quantification, and adaptive algorithms.	Support at least two machines learning efforts in both applied mathematics and computer science.	Support at least two partnerships in quantum information science.
Result	Met	TBD	TBD
Endpoint Target	Develop and deploy high-performance computing hardware and software systems through exascale platforms		

Capital Summary ($K)

	Total	Prior Years	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Capital operating expenses						
Capital equipment	n/a	n/a	5,000	–	5,000	–

Funding Summary ($K)

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Research	319,855	–	422,575	+102,720
Scientific user facility operations	327,145	–	476,435	+149,290
Total, Advanced Scientific Computing Research	**647,000**	**642,606**	**899,010**	**+252,010**

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

Advanced Scientific Computing Research
Scientific User Facility Operations ($K)

The treatment of user facilities is distinguished between two types: TYPE A facilities that offer users resources dependent on a single, large-scale machine; TYPE B facilities that offer users a suite of resources that is not dependent on a single, large-scale machine.

Definitions:
Achieved Operating Hours – The amount of time (in hours) the facility was available for users.

Planned Operating Hours –
- For Past Fiscal Year (PY), the amount of time (in hours) the facility was planned to be available for users.
- For Current Fiscal Year (CY), the amount of time (in hours) the facility is planned to be available for users.
- For the Budget Fiscal Year (BY), based on the proposed budget request the amount of time (in hours) the facility is anticipated to be available for users.

Optimal Hours – The amount of time (in hours) a facility would be available to satisfy the needs of the user community if unconstrained by funding levels.

Percent of Optimal Hours – An indication of utilization effectiveness in the context of available funding; it is not a direct indication of scientific or facility productivity.
- For BY and CY, Planned Operating Hours divided by Optimal Hours expressed as a percentage.
- For PY, Achieved Operating Hours divided by Optimal Hours.

Unscheduled Downtime Hours - The amount of time (in hours) the facility was unavailable to users due to unscheduled events. NOTE: For type "A" facilities, zero Unscheduled Downtime Hours indicates Achieved Operating Hours equals Planned Operating Hours.

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
TYPE A FACILITIES				
NERSC	**$92,145**	**-**	**$80,000**	**-12,145**
Number of Users	6,000		6,000	–
Achieved operating hours	N/A	-	N/A	N/A
Planned operating hours	8,585		8,585	–
Optimal hours	8,585	-	8,585	–
Percent optimal hours	N/A		N/A	N/A
Unscheduled downtime hours	N/A	-	N/A	N/A

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
OLCF	**$110,000**	**-**	**$200,000**	**+90,000**
Number of Users	1,064		1,064	–
Achieved operating hours	N/A	-	N/A	N/A
Planned operating hours	7,008		7,008	–
Optimal hours	7,008	-	7,008	–
Percent optimal hours	N/A		N/A	N/A
Unscheduled downtime hours	N/A	-	N/A	N/A
ALCF	**$80,000**	**-**	**$140,000**	**+60,000**
Number of Users	1,434		1,434	–
Achieved operating hours	N/A	-	N/A	N/A
Planned operating hours	7,008		7,008	–
Optimal hours	7,008	-	7,008	–
Percent optimal hours	N/A		N/A	N/A
Unscheduled downtime hours	N/A	-	N/A	N/A
ESnet	**$45,000**	**-**	**$56,435**	**+11,435**
Number of users[b]	N/A		N/A	N/A
Achieved operating hours	N/A	-	N/A	N/A
Planned operating hours	8,760		8,760	–
Optimal hours	8,760	-	8,760	–
Percent optimal hours	N/A		N/A	N/A
Unscheduled downtime hours	N/A	-	N/A	N/A

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

[b] ESnet is a high performance scientific network connecting DOE facilities to researchers around the world; user statistics are not collected.

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Total Facilities	**$327,145**	**-**	**$476,435**	**+149,290**
Number of Users[b]	8,498		8,498	–
Achieved operating hours	N/A	-	N/A	N/A
Planned operating hours	31,361		31,361	–
Optimal hours	31,361	-	31,361	–
Percent of optimal hours[c]	N/A		N/A	N/A
Unscheduled downtime hours	N/A	-	N/A	N/A

Scientific Employment

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Number of permanent Ph.D.'s (FTEs)	470	–	630	+160
Number of postdoctoral associates (FTEs)	160	–	223	+63
Number of graduate students (FTEs)	360	–	545	+185
Other scientific employment (FTEs)[d]	225	–	274	+49

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

[b] Total users only for NERSC, OLCF, and ALCF.

[c] For total facilities only, this is a "funding weighted" calculation FOR ONLY TYPE A facilities: $\frac{\sum_1^n[(\%OH\ for\ facility\ n)\times(funding\ for\ facility\ n\ operations)]}{Total\ funding\ for\ all\ facility\ operations}$

[d] Includes technicians, engineers, computer professionals and other support staff.

17-SC-20, Office of Science Exascale Computing Project (SC-ECP)

1. Significant Changes and Summary

Significant Changes

This Project Data Sheet (PDS) is an update of the FY 2018 PDS and does not include a new start for FY 2019.

The FY 2019 Request for SC-ECP is $232,706,000 and is an increase of $36,126,000 over the FY 2018 Request. The FY 2019 Request supports investments in application development, software technology and hardware and integration focus areas to create an exascale eco-system that supports the delivery of the first exascale-capable system in 2021 timeframe. In addition, the preliminary estimate for the total project cost was revised from $1,153,524 to $1,233,965, an increase of $80,441, which is based on updated cost information from selected application, software and hardware activities selected to participate in the project. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-1/3A, Approve Alternative Selection and Cost Range and Approve Phase One Funding of Hardware and Software Research Projects and Application Development, was approved on January 3, 2017. The estimated Total Project Cost (TPC) range of the SC-ECP is $1.0 billion to $2.7 billion.

Summary

In FY 2016, the Budget Request included funding to initiate research, development, and computer-system procurements to deliver an exascale (10^{18} operations per second) computing capability by the mid-2020s. This activity, referred to as the Exascale Computing Initiative (ECI), is a partnership between the Office of Science (SC) and the National Nuclear Security Administration (NNSA) and addresses Department of Energy's (DOE) science and national security mission requirements.

In FY 2017, SC initiated the Office of Science Exascale Computing Project (SC-ECP) within Advanced Scientific Computing Research (ASCR) to support a large research and development (R&D) co-design project between domain scientists, application and system software developers and hardware vendors to develop a exascale ecosystem as part of the ECI. Other activities included in the ECI but not the SC-ECP include $240,000,000 to support the initiation of planning, site preparations, and non-recurring engineering at both the Argonne and Oak Ridge Leadership Computing Facilities (LCFs) where the exascale machines will be housed and operated. Moreover, the LCF ECI funding will accelerate delivery of at least one exascale-capable system in 2021 timeframe. Supporting parallel development at both LCFs will reduce the overall risk of ECI and broaden the range of applications able to utilize this new capability. Procurement of exascale systems, which is not included in the ECP, will be funded within the ASCR facility budgets in the outyears. This PDS is for the SC-ECP only; prior-year activities related to the SC-ECP are also included.

In FY 2019, SC-ECP funding will support project management; continue the co-design activities between application, software, and hardware technologies; R&D of exascale systems software and tools needed for exascale programming; increased engagement and integration between SC-ECP and the LCF's upgrade projects to provide continuous testing of the ECP funded applications and software; and vendor partnerships.

2. Critical Milestone History and Schedule

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1/3A	CD-2	Final Design Complete	CD-3B	D&D Complete	CD-4
FY 2017	3Q FY 2016	TBD	TBD	TBD	TBD	TBD	N/A	TBD
FY 2018	07/28/2016	2Q FY 2019	01/03/2017	4Q FY 2019	3Q FY 2019	4Q FY 2019	N/A	4Q FY 2023
FY 2019	07/28/2016	2Q FY 2019	01/03/2017	4Q FY 2019	3Q FY 2019	4Q FY 2019	N/A	4Q FY 2023

CD-0 – Approve Mission Need
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline

CD-3A – Approve phase one funding of hardware and software research projects and application development.
CD-3B – Approve phase two funding of hardware and software development, and exascale system contract options.
CD-4 – Approve Project Completion

3. Project Cost History

The preliminary cost range for the SC-ECP is estimated to be between $1.0 billion and $2.7 billion. The cost range will be updated and a project baseline (scope, schedule, and cost) will be established at CD-2.

4. Project Scope and Justification

Scope
Four well-known challenges[a] determine the requirements of the SC-ECP. These challenges are:

- *Parallelism:* Systems must exploit the extreme levels of parallelism that will be incorporated in an exascale-capable computer;
- *Resilience:* Systems must be resilient to permanent and transient faults;
- *Energy Consumption:* System power requirements must be no greater than 20-30 MW; and
- *Memory and Storage Challenge*: Memory and storage architectures must be able to access and store information at anticipated computational rates.

The realization of an exascale-capable system that addresses parallelism, resilience, energy consumption, and memory/storage will involve tradeoffs among hardware (processors, memory, energy efficiency, reliability, interconnectivity); software (programming models, scalability, data management, productivity); and algorithms. To address this, the scope of the SC-ECP has three focus areas:

The realization of an exascale-capable system that addresses parallelism, resilience, energy consumption, and memory/storage will involve tradeoffs among hardware (processors, memory, energy efficiency, reliability, interconnectivity); software (programming models, scalability, data management, productivity); and algorithms. To address this, the scope of the SC-ECP has three focus areas:

- *Hardware and Integration:* The Hardware and Integration focus area supports vendor-based research and the integrated deployment of specific ECP application milestones and software products on targeted systems at computing facilities, including the completion of PathForward projects transitioning to facility non-recurring engineering (where appropriate), and the integration of software and applications on pre-exascale and exascale system resources at facilities.
- *Software Technology:* The Software Technology focus area spans low-level operational software to programming environments for high-level applications software development, including the software infrastructure to support large data management and data science for the DOE at exascale and will deliver a high quality, sustainable product suite.
- *Application Development:* The Application Development focus area supports co-design activities between DOE mission critical applications and the software and hardware technology focus areas to address the exascale challenges: extreme parallelism, reliability and resiliency, deep hierarchies of hardware processors and memory, scaling to larger systems, and data-intensive science. As a result of these efforts, a wide range of applications will be ready to effectively use the exascale systems deployed in the 2021 timeframe under ECI.

The SC-ECP will be managed in accordance with the principles of DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets*, which SC uses for the planning, design, and construction of all of its major projects, including the LCFs at Argonne and Oak Ridge National Laboratories and NERSC at Lawrence Berkeley National Laboratory. Computer acquisitions use a tailored version of Order 413.3B. The first four years of SC-ECP will be focused on research in software (new algorithms and methods to support application and system software development) and hardware (node and

[a] http://www.isgtw.org/feature/opinion-challenges-exascale-computing

system design), and these costs will be reported as Other Project Costs. During the last three years of the project, project activities will focus on hardening the application and the system stack software, and on additional hardware technologies investments, and these costs will be included in the Total Estimated Costs for the project.

5. Financial Schedule

	(dollars in thousands)		
	Appropriations	Obligations	Costs
Total Estimated Cost (TEC)			
(Hardening of Applications Development System Software Technology, Hardware Technology)			
FY 2016[a]	0	0	0
FY 2020– FY 2023	426,735	426,735	426,735
Total, TEC	426,735	426,735	426,735
Other project costs (OPC)			
(Research for Application Development, System Software Technology, and Hardware Technology)			
FY 2016[a]	157,944	157,944	15,615
FY 2017	164,000	164,000	100,000
FY 2018	196,580	196,580	402,909
FY 2019	232,706	232,706	232,706
FY 2020 – FY 2023	56,000	56,000	56,000
Total, OPC	807,230	807,230	807,230
Total Project Costs (TPC)			
FY 2016[a]	157,944	157,944	15,615
FY 2017	164,000	164,000	100,000
FY 2018	196,580	196,580	402,909
FY 2019	232,706	232,706	232,706
FY 2020 – FY 2023	482,735	482,735	482,735
Total, TPC	1,233,965	1,233,965	1,233,965

6. Project Cost Estimate

The SC-ECP will be baselined at CD-2. The estimated Total Project Cost for the SC-ECP is represented in the table below.

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Application Development	255,125	225,000	N/A
Production Ready Software	157,870	86,000	N/A
Hardware Partnerships	13,740	79,000	N/A
Total, TEC	426,735	390,000	N/A

[a] Funding was provided to ASCR in FY 2016 to support the Department's ECI efforts. For completeness, that information is shown here.

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Other Project Costs (OPC) (Research)			
Planning/Project Mgmt	109,715	118,000	N/A
Application Development	295,062	269,630	N/A
Software Research	179,303	121,423	N/A
Hardware Research	223,150	254,471	N/A
Total OPC	807,230	763,524	N/A
Total, TPC	1,233,965	1,153,524	N/A

7. Schedule of Appropriation Requests

Request Year		FY 2016[a]	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	Outyears	Total
FY 2017	TEC	0	0	TBD	TBD	TBD	TBD	TBD	TBD
	OPC	157,894	154,000	TBD	TBD	TBD	TBD	TBD	TBD
	TPC	157,894	154,000	TBD	TBD	TBD	TBD	TBD	TBD
FY 2018	TEC	0	0	0	0	175,000	145,000	70,000	390,000
	OPC	157,944	164,000	196,580	189,000	14,000	14,000	28,000	763,524
	TPC	157,944	164,000	196,580	189,000	189,000	159,000	98,000	1,153,524
FY 2019	TEC	0	0	0	0	174,735	146,000	106,000	426,735
	OPC	157,944	164,000	196,580	232,706	14,000	14,000	28,000	807,230
	TPC	157,944	164,000	196,580	232,706	188,735	160,000	134,000	1,233,965

8. Related Operations and Maintenance Funding Requirements

System procurement activities for the exascale-capable computers are not part of the SC-ECP. The exascale-capable computers will become part of existing facilities and operations and maintenance funds and will be included in the ASCR facilities' operations budget. In the FY 2019 Budget Request, $240,000,000 is included in the LCF's at Argonne and Oak Ridge National Laboratories facilities' budgets to begin planning non-recurring engineering and site preparations for the delivery and deployment for the exascale systems. These funds are included in ECI but not in SC-ECP.

Start of Operation	2022
Expected Useful Life (number of years)	5
Expected Future start of D&D for new construction (fiscal quarter)	4Q 2030

9. D&D Funding Requirements

N/A, no construction.

10. Acquisition Approach

The early years of the SC-ECP, approximately four years in duration, will support R&D directed at achieving system performance targets for parallelism, resilience, energy consumption, and memory and storage. The second phase of approximately three years duration will support finalizing applications and system software.

[a] Funding was provided to ASCR in FY 2016 to support the Department's ECI efforts. For completeness, that information is shown here.

Basic Energy Sciences

Overview

The mission of the Basic Energy Sciences (BES) program is to support fundamental research to understand, predict, and ultimately control matter and energy at the electronic, atomic, and molecular levels in order to provide the foundations for new energy technologies and to support Department of Energy (DOE) missions in energy, environment, and national security.

The research disciplines that BES supports—condensed matter and materials physics, chemistry, geosciences, and aspects of biosciences—are those that discover new materials and design new chemical processes that touch virtually every important aspect of energy resources, production, conversion, transmission, storage, efficiency, and waste mitigation. BES research provides a knowledge base to help understand, predict, and ultimately control the natural world and helps build the foundation for achieving a secure and sustainable energy future. BES also supports world-class, open-access scientific user facilities consisting of a complementary set of intense x-ray sources, neutron sources, and research centers for nanoscale science. Capabilities at BES facilities probe materials and chemical systems with ultrahigh spatial, temporal, and energy resolutions to investigate the critical functions of matter—transport, reactivity, fields, excitations, and motion—and answer some of the most challenging grand science questions. BES-supported activities are entering a new era in which materials can be built with atom-by-atom precision, chemical processes at the molecular scale can be controlled with increasing accuracy, and computational models can predict the behavior of materials and chemical processes before they exist.

As history has shown, basic research advances provide the foundation for breakthroughs in new energy technologies. Key to exploiting such discoveries is the ability to create new materials using sophisticated synthesis and processing techniques, to precisely define the atomic arrangements in matter, and to design chemical processes, which will enable control of physical and chemical transformations. The energy systems of the future will revolve around materials and chemical processes that convert energy from one form to another. Such materials will need to be more functional than today's energy materials. The new chemical processes will require ever increasing control to the levels of electrons. Such advances are not found in nature; they must be designed and fabricated to exacting standards using principles revealed by basic science.

Highlights of the FY 2019 Budget Request

The BES FY 2019 Request of $1,850.0 million focuses resources toward the highest priorities in early-stage fundamental research, in operation and maintenance of scientific user facilities, and in facility upgrades. Core research priorities in the FY 2019 Request include quantum information science (QIS), ultrafast science, and computational materials and chemical sciences related to the Exascale Computing Initiative, as well as research in support of future nuclear energy systems. In the remaining core research activities, BES emphasizes basic scientific areas with potential to transform the understanding and control of matter and energy. The 2015 Basic Energy Sciences Advisory Committee (BESAC) report, "Challenges at the Frontiers of Matter and Energy: Transformative Opportunities for Discovery Science," and the follow-on Basic Research Needs workshop reports outline specific topical areas.[a] The Request continues to support the Energy Frontier Research Centers (EFRCs), which will enable basic energy-relevant research with a scope and complexity beyond that possible in standard single-investigator or small-group awards. Both the core research and the EFRCs will emphasize emerging high priorities in quantum materials and chemistry, catalysis science, synthesis, instrumentation science, materials and chemical research related to interdependent energy-water issues, future nuclear energy systems, and next-generation electrical energy storage. The Request also supports the two BES-supported Energy Innovation Hubs, and the DOE Established Program to Stimulate Competitive Research (EPSCoR).

In the Scientific User Facilities subprogram, BES maintains a balanced suite of complementary tools. The Linac Coherent Light Source (LCLS) continues operations in support of the BES priority in ultrafast science and also in preparation for completion of the LCLS-II construction project. To allow installation activities for the LCLS-II construction project to proceed, LCLS will be shut down for one year, starting around the second quarter of FY 2019. The Advanced Light Source, Advanced Photon Source, National Synchrotron Light Source-II, and the Stanford Synchrotron Radiation Lightsource will continue operations and are supported at 95% of optimum. Both BES-supported neutron sources, the Spallation Neutron Source and the High Flux Isotope Reactor, will be operational in FY 2019 and funded at approximately 95% of optimum. All five

[a] All reports are available at https://science.energy.gov/bes/community-resources/reports/.

Nanoscale Science Research Centers will be supported, with part of the funding designated for tool development for QIS. The BES commitment for long term surveillance and maintenance ends in FY 2018. No funding is requested for these activities in FY 2019.

In the Construction subprogram, the LCLS-II project remains the highest priority construction project in BES and is fully supported for the last year of funding for the project. The Request provides continued support for the Advanced Photon Source Upgrade (APS-U) project, and funds to initiate the Advanced Light Source Upgrade (ALS-U) project at Lawrence Berkeley National Laboratory and the Linac Coherent Light Source-II High Energy (LCLS-II-HE) project at SLAC National Accelerator Laboratory.

Basic Energy Sciences
Funding ($K)

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Materials Sciences and Engineering				
Scattering and Instrumentation Sciences Research	76,598	—	60,925	-15,673
Condensed Matter and Materials Physics Research	101,645	—	123,790	+22,145
Materials Discovery, Design, and Synthesis Research	61,931	—	62,551	+620
Established Program to Stimulate Competitive Research (EPSCoR)	14,452	—	7,708	-6,744
Energy Frontier Research Centers (EFRCs)	55,800	—	55,800	0
Energy Innovation Hubs—Batteries and Energy Storage	24,088	—	24,088	0
Computational Materials Sciences	12,000	—	13,000	+1,000
SBIR/STTR	13,127	—	13,178	+51
Total, Materials Sciences and Engineering	**359,641**	**—**	**361,040**	**+1,399**
Chemical Sciences, Geosciences, and Biosciences				
Fundamental Interactions Research	62,606	—	69,581	+6,975
Chemical Transformations Research	81,687	—	88,869	+7,182
Photochemistry and Biochemistry Research	89,168	—	74,386	-14,782
Energy Frontier Research Centers (EFRCs)	54,200	—	54,200	0
Energy Innovation Hubs—Fuels from Sunlight	15,000	—	15,000	0
Computational Chemical Sciences (CCS)	13,489	—	13,000	-489
General Plant Projects (GPP)	1,000	—	1,000	0
SBIR/STTR	11,977	—	11,934	-43
Total, Chemical Sciences, Geosciences, and Biosciences	**329,127**	**—**	**327,970**	**-1,157**
Scientific User Facilities				
X-Ray Light Sources	489,059	—	491,059	+2,000
High-Flux Neutron Sources	266,000	—	265,000	-1,000
Nanoscale Science Research Centers (NSRCs)	122,272	—	122,272	0
Other Project Costs	5,000	—	10,100	+5,100
Major Items of Equipment	42,500	—	0	-42,500
Research	34,618	—	25,000	-9,618
SBIR/STTR	33,283	—	33,259	-24
Total, Scientific User Facilities	**992,732**	**—**	**946,690**	**-46,042**
Subtotal, Basic Energy Sciences	**1,681,500**	**1,670,081**	**1,635,700**	**-45,800**

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Construction				
13-SC-10, Linac Coherent Light Source-II (LCLS-II), SLAC	190,000	188,710	139,300	-50,700
18-SC-10, Advanced Photon Source Upgrade (APS-U), ANL	0	—	60,000	+60,000
19-SC-10, Advanced Light Source Upgrade (ALS-U), LBNL	0	—	10,000	+10,000
19-SC-11, Linac Coherent Light Source-II-HE (LCLS-II-HE), SLAC	0	—	5,000	+5,000
Total, Construction	**190,000**	**188,710**	**214,300**	**+24,300**
Total, Basic Energy Sciences	**1,871,500**	**1,858,791**	**1,850,000**	**-21,500**

SBIR/STTR Funding:

- FY 2017 Enacted: SBIR $51,189,000; and STTR $7,198,000
- FY 2019 Request: SBIR $51,175,000; and STTR $7,196,000

Explanation of Major Changes ($K)

	FY 2019 Request vs FY 2017 Enacted
Materials Sciences and Engineering: Research will continue to support fundamental scientific opportunities, including those identified as high priorities in the BESAC report on transformative opportunities for discovery science and Basic Research Needs workshops, with a special emphasis on quantum materials. Research priorities include ultrafast science to understand the initial stages of materials phenomena and dynamics, materials science theory for computational applications that take full advantage of exascale computing, and materials under extreme environments for future nuclear energy. The Request emphasizes research on novel materials and theory for QIS. Funding is requested for continued support of the Batteries and Energy Storage Energy Innovation Hub and the DOE Established Program to Stimulate Competitive Research (EPSCoR).	**+1,399**
Chemical Sciences, Geosciences, and Biosciences: Research will continue to support fundamental science, including grand challenge science and opportunities identified in the BESAC report on transformative opportunities for discovery science and Basic Research Needs workshops on synthesis science, instrumentation, energy-water issues, catalysis science, and future nuclear energy. Ultrafast science research will continue to be emphasized to probe the dynamics of electrons that control chemical bonding and reactivity; to investigate energy flow underlying energy conversions; and to elucidate structural dynamics accompanying bond breaking and bond making in chemical transformations. Research on QIS remains a priority to understand the quantum nature of atomic and molecular systems important for developing quantum information systems and to exploit recent advances in quantum computing to address scientific challenges that are beyond the capabilities of classical computers. Funding is requested for continued support of the Fuels from Sunlight Energy Innovation Hub.	**-1,157**
Scientific User Facilities: The Linac Coherent Light Source (LCLS) continues operations in support of ultrafast science and also in preparation for completion of the LCLS-II construction project. To allow installation activities for the LCLS-II construction project to proceed, LCLS will be shut down for one year, starting around the second quarter of FY 2019. All remaining scientific user facilities will operate at approximately 95% of optimum. Funding for the Nanoscale Science Research Centers will include support for QIS-related tools development. No funding is requested for the disposition of unused equipment for the Lujan Neutron Scattering Center. The BES commitment for long term surveillance and maintenance ends in FY 2018. No funding is requested for these activities in FY 2019.	**-46,042**
Construction: LCLS-II is fully supported for the last year of funding for the project. Support for the APS-U project continues. The Request includes funds to initiate the Advanced Light Source Upgrade (ALS-U) project at LBNL and the Linac Coherent Light Source-II High Energy (LCLS-II-HE) project at SLAC.	**+24,300**
Total, Basic Energy Sciences	**-21,500**

Basic and Applied R&D Coordination
As a program that supports fundamental scientific research relevant to many DOE mission areas, BES strives to build and maintain close connections with other DOE program offices. The Department facilitates coordination between DOE R&D programs through a variety of Departmental activities, including joint participation in research workshops, strategic planning activities, solicitation development, and program review meetings. BES also coordinates with DOE technology offices in the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) program, including topical area planning, solicitations, reviews, and award recommendations.

BES program managers regularly participate in intra-departmental meetings for information exchange and coordination on solicitations, program reviews, and project selections in the research areas of biofuels derived from biomass; solar energy utilization; building technologies, including solid-state lighting; advanced nuclear energy systems and advanced fuel cycle technologies; vehicle technologies; improving efficiencies in industrial processes; and superconductivity for grid applications. These activities facilitate cooperation and coordination between BES and the DOE technology offices and defense programs. DOE program managers from basic and applied programs have also established formal technical coordination working groups that meet on a regular basis to discuss R&D activities with wide applications. Additionally, DOE technology office personnel participate in reviews of BES research, and BES personnel participate in reviews of research funded by the technology offices.

Co-funding and co-siting of research by BES and DOE technology programs at the same institutions has proven to be a valuable approach to facilitate close integration of basic and applied research. In these cases, teams of researchers benefit by sharing expertise and knowledge of research breakthroughs and program needs. The Department's national laboratory system plays a crucial role in achieving integration of basic and applied research.

Program Accomplishments
Ultrafast Chemistry. Controlling chemical transformations requires knowledge of the fundamental processes that direct energy flow and bond rearrangement in chemical reactions. New capabilities to probe ultrafast phenomena, such as light-activated processes occurring on timescales of attoseconds to nanoseconds, allow unprecedented insight into chemical transformations underlying energy technologies.

- Femtosecond-duration soft x-ray pulses from a free-electron laser revealed the ultrafast relaxation of thymine, a DNA building block, following absorption of ultraviolet light. The new understanding of this protective ultrafast mechanism, which dissipates the absorbed energy before harmful chemical reactions can affect the thymine molecules, settles a long-standing scientific quest. The new experimental technique promises to lead to insights on the ultrafast response of other organic molecules to light, including processes relevant to photosynthesis as well as human vision.
- By transient absorption of femtosecond soft x-ray pulses from a laboratory-scale table-top source in combination with theoretical simulations, scientists made an x-ray spectroscopic "movie" of the electrons in cyclohexadiene as it opens from a ring to a linear shape in hundreds of femtoseconds after exposure to ultraviolet light. This approach uncovers details of the ultrafast exchange of energy in coupled electronic and nuclear dynamics leading to ring opening in cyclohexadiene, and is applicable to a wide range of light-activated chemical reactions that are ubiquitous in photobiology and in optoelectronic technologies.
- During photosynthesis, the Photosystem II (PSII) protein complex uses light energy to extract electrons from water, splitting water into oxygen and hydrogen. Scientists combined femtosecond pulses from a free electron laser and a new sample delivery method to obtain the first high-resolution, 3D view of PSII in action at room temperature. These images provide new insights into the chemistry of natural photosynthetic water splitting and could aid development of artificial photosynthesis approaches for renewable energy production.

Probing the Ultrasmall World through Unprecedented Precise Measurements. Much of modern science and technology relies on highly complex materials where defects and disorder disrupt ordered, periodic crystallinity to create internal boundaries between small regions called grains. Researchers are gaining insight into the behavior of a wide variety of such materials through a range of new high-precision measurement techniques that elucidate the defect or grain structure. This information can then be correlated to functional material properties, with the potential for controlled design of improved energy materials.

- In an iron-platinum nanoparticle, the 3D coordinates of 6,569 iron and 16,627 platinum atoms were determined with 22 picometer precision by a new imaging technique, atomic electron tomography. Further, the chemical order/disorder were correlated with material properties at the single-atom level. Similar "single-atom" correlations of properties for a wide range of nanostructured materials could transform our understanding of structure-property relationships at the most fundamental level.
- A new x-ray technique, Bragg coherent diffraction imaging, characterized the dynamics of crystal defects in individual, nanoscale grains of gold during annealing. The technique provided 3D detailed structure with extraordinary resolution (10 nm spatial and sub-angstrom displacement field resolution). The approaches could shed light on the response of many polycrystalline materials under external stimuli, such as stress, temperature, or exposure to chemicals common to materials used for energy applications.
- Two-dimensional (2D) materials, such as graphene, have electronic and chemical properties that are sensitive to atomic defects. In "MXene" phases, a 2D transition metal carbide, high-resolution electron microscopy revealed that the concentration of an important defect in the structure – missing atoms called vacancies – could be controlled during chemical processing. Coupled theoretical results demonstrated that vacancies influence the surface morphology and chemistry of the 2D material. Such advances could lead to new catalytic substrates and electrodes for energy storage.

Chemistry at Complex Interfaces. Complex environments created at interfaces (characterized by structural and functional disorder and dynamic behavior) influence chemical phenomena such as reactivity and transport that are important in photochemical, catalytic, separation, biochemical, and geochemical systems. Manipulating non-covalent interactions holds the promise of gaining control over chemical processes at these complex interfaces.

- At mineral-water interfaces, a quantitative description of ion exchange with the surrounding fluids can aid in the design of chemical processes such as solid nucleation, growth, and water purification. This exchange depends in part on the rates of adsorption and desorption to and from the surface. With time-resolved x-ray reflectivity measurements at a mica-water interface, scientists demonstrated that rubidium cations adsorb at a greater rate than they desorb, because of direct adsorption from solution to the surface and an additional resistance to full hydration from the surface back into solution.
- The by-products of electrochemical reduction of carbon dioxide are typically mostly hydrogen and carbon monoxide, with a minor fraction of desirable multi-carbon compounds. Scientists discovered several chemical additives that can greatly increase the yield of multi-carbons; for instance, adding specific nitrogen-containing aromatics increased ethylene and ethanol output to more than 75% of the total. This research provides new insights into how additives impact the composition of the interfaces, influencing selectivity, and can inform our understanding of the role of non-covalent interactions on these processes.
- The activity and selectivity of heterogeneous catalysis depends on the stability of reaction intermediates at the catalyst interfaces. For oxidative coupling of alcohols catalyzed by gold, scientists combined experiment with theory to demonstrate the critical further dependence of stability of intermediates on non-covalent interactions. For alkoxide intermediates, they found that the influence of non-covalent interactions on stability of intermediates depended on the internal molecular structure of the intermediates, affecting the selectivity of catalysis differently for the different intermediates.

The Science of Spin. The spin of an electron plays a prominent role in materials properties and functionality. Common examples are magnetism, computer memory, and electronics. For the future, isolated spins in materials are candidates for the development of quantum information and quantum sensing technologies. In addition, the collective behavior of spins is producing new, emergent behavior that could lead to the development of next-generation energy-relevant technologies.

- Next-generation quantum-based electronics requires long-range, efficient control of spin states of the electrons and associated atomic structures. This may be possible with hybrid architectures combining different properties, such as nanodiamond particles on top of a ferromagnetic thin film. Research found that microwaves could generate spin waves in the film that excited single electron spins in the particles at distances approaching millimeter-scale, a two-orders-of-magnitude increase. This is a notable step toward ultra-efficient control of solid-state qubits for quantum information processing and nanoscale sensing.

- Under certain conditions, atoms in a material can be oriented such that the electron spins find so many stable orientations that a randomly oriented spin structure or "spin ice" is formed. However, it is difficult to achieve tailored long-range ordering of these configurations. This was solved by using a magnetic force microscope to control the magnetic charge orientations and produce localized regions of aligned spin. This nanoscale control could create novel phenomena associated with the spin orientation and may enable write-read-erase multi-functionality for information storage on a nanometer length scale.
- In spintronics, extreme-low-power transmission of electrical information uses the spin of the electron, rather than moving electrons as in conventional electronics. However, spin currents are harder to detect and to amplify. Researchers demonstrated the ability to manipulate and amplify the spin current in a material, similar to amplifying a conventional electrical current with a transistor, using layered structures of an antiferromagnetic and an insulating material. The layered structure showed a factor of ten increase in the spin polarized current, laying the path to use in computing and high-efficiency electronics.

BES user facilities contribute to world leading science and help U.S. industries advance the technology frontiers.

- The advanced imaging capabilities at BES synchrotron facilities have assisted the aviation industry to gain insights into the components of their engines. The 3D micro-structure information about these engine materials under operating environments provides understanding of the features and the interaction between micro-structures, and of damage evolution of the materials. This will allow the industry to develop safer and more fuel-efficient engines.
- The VISION inelastic scattering instrument at the Spallation Neutron Source (SNS) has been employed by a commercial research laboratory (Toyota Research Institute) to study the fundamental internal chemical reactions taking place in a new type of electrolyte material called "molten redox" that may lead to improved performance of future batteries.
- Researchers at the Center for Nanoscale Materials invented a new nano-enabled foam called the Oleo Sponge that not only easily adsorbs oil from water, but is also reusable and can pull dispersed oil from an entire water column, not just the surface. Successful tests in New Jersey's Ohmsett—The National Oil Spill Response Research and Renewable Energy Test Facility—giant seawater tank indicate that this new technology could have significant impact in oil and other contaminant remediation.

New advanced capabilities and instrumentations at BES user facilities enable ground breaking science.

- The NSLS-II Experimental Tools (NEXT) project has delivered five world-class scientific instruments at NSLS-II. These new instruments provide the researchers the most advanced scientific research capabilities to resolve fundamental scientific problems, to examine materials under various environmental conditions, and to conduct in situ and operando studies of reactions. This will facilitate the discovery of new materials and the development of new devices that address national challenges.
- Experiments using SLAC's Ultrafast Electron Diffraction system demonstrated that light whirls atoms around in perovskites, possibly facilitating the transport of electric charge through the composite, and potentially explaining the high efficiency of these next-generation solar cell materials. Perovskites are cheap, easy to produce and very efficient at converting light into electricity.
- Using the Oak Ridge Leadership Computing Facility, SNS scientists and the ORNL Applied Math Group have developed the capability for real-time theoretical modeling of inelastic neutron scattering results. This development has enabled researchers to instantly compare experimental data to relevant theory and to determine if the theoretical and experimental results are demonstrating equivalent physical phenomena. This comparison allows researchers to adjust parameters in the theory in real-time based on the scattering data results and likewise to determine aspects of the experimental data that need more statistical detail.
- The Molecular Foundry scientists developed a new electron microscopy imaging technique that greatly improves images of light elements while using fewer electrons. The MIDI-STEM method may solve the challenge of seeing structures with a mixture of heavy and light elements in close proximity, thereby allowing scientists to use high-resolution electron microscopy on a broader set of hard and soft material combinations. The high resolution, speed, and non-invasiveness could transform the way key biomolecular interactions are studied for sensors, biology, and biomedicine.

Basic Energy Sciences
Materials Sciences and Engineering

Description
Materials are critical to nearly every aspect of energy generation and end-use. Materials limitations are often a significant barrier to improved energy efficiencies, longer lifetimes of infrastructure and devices, or the introduction of new energy technologies. The latest BESAC report on transformative opportunities for discovery science, coupled with the Basic Research Needs workshop reports on quantum materials, provide further documentation of the importance of materials sciences in forefront research for next generation scientific and technological advances.

The Materials Sciences and Engineering subprogram supports research to provide the fundamental understanding of materials synthesis, behavior, and performance that will enable solutions to wide-ranging energy generation and end-use challenges as well as opening new directions that are not foreseen based on existing knowledge. The research explores the origin of macroscopic material behaviors; their fundamental connections to atomic, molecular, and electronic structures; and their evolution as materials move from nanoscale building blocks to mesoscale systems. At the core of the subprogram is experimental, theory/computational, and instrumentation research that will enable the predictive design and discovery of new materials with novel structures, functions, and properties. A growing area for insight on materials behavior is the understanding of dynamic processes, especially those in the ultrafast regime that only recently has been accessible for materials research. Such understanding and control are critical to science-guided design of highly efficient energy conversion processes, multi-functional nanoporous and mesoporous structures for optimum ionic and electronic transport in batteries and fuel cells, materials with longer lifetimes in extreme environments through better materials design and self-healing processes, and new materials with novel, emergent properties that will open new avenues for technological innovation.

To accomplish these goals, the portfolio includes three integrated research activities:

- **Scattering and Instrumentation Sciences**—Advancing science using new tools and techniques to characterize materials structure and dynamics across multiple length and time scales, including ultrafast science, and to correlate this data with materials performance under real world conditions.

- **Condensed Matter and Materials Physics**—Understanding the foundations of material functionality and behavior including electronic, thermal, optical, and mechanical properties, and quantum materials whose properties arise from the effects of quantum mechanics.

- **Materials Discovery, Design, and Synthesis**—Developing the knowledge base and synthesis strategies to design and precisely assemble structures to control properties and enable discovery of new materials with unprecedented functionalities, including rare earth and other critical materials.

The portfolio emphasizes understanding of how to direct and control energy flow in materials systems over multiple time (from femtoseconds to seconds) and length scales (from the nanoscale to mesoscale), and translation of this understanding to prediction of material behavior, transformations, and processes in challenging real-world systems. An example of this research is examination of the transformations that take place in materials with many atomic constituents, complex structures, and a broad range of defects when these materials are exposed to extreme environments, including extremes in temperature, pressure, stress, photon and radiation flux, electromagnetic fields, and chemical exposures – such as those found in fossil energy, nuclear energy, and most industrial settings. To maintain leadership in materials discovery, the research explores new frontiers of unpredicted, emergent materials behavior; utilization of nanoscale control; and materials systems that are metastable or far from equilibrium. The research includes investigation of the interfaces between physical and biological sciences to explore new approaches to novel materials design. Also essential is development of advanced characterization tools, instruments and techniques that can assess a wide range of space and time scales, especially in combination and under dynamic *operando* conditions to analyze non-equilibrium materials, conditions, and excited-state phenomena.

In addition to single-investigator and small-group research, this subprogram supports Computational Materials Sciences, EFRCs, and the Batteries and Energy Storage Hub. These research modalities support multi-investigator, multidisciplinary research and focus on forefront scientific challenges that relate to the DOE energy mission. The Computational Materials Sciences activity supports integrated, multidisciplinary teams of theorists and experimentalists who focus on development of validated community codes and the associated databases for predictive design of materials that will take advantage of advanced exascale computing platforms. The EFRCs support teams of investigators to perform basic research to accelerate transformative scientific advances for the most challenging topics in materials sciences. Early stage research in the Batteries and Energy Storage Hub focuses on developing the scientific understanding required to advance next generation energy storage for the grid, transportation, and other national priorities.

The Materials Sciences and Engineering subprogram also includes DOE EPSCoR. Previously referred to as the "Experimental Program to Stimulate Competitive Research," this program has been renamed the "Established Program to Stimulate Competitive Research" as directed in the American Innovation and Competitiveness Act, Public Law 114–329, §103(e)(2)(A). The DOE EPSCoR program strengthens investments in early stage energy research for states and US territories that do not historically have large academic research programs.

Scattering and Instrumentation Sciences Research

Advanced characterization tools with very high precision in space and time are essential to understand, predict, and ultimately control matter and energy at the electronic, atomic, and nanoscale levels. Research in Scattering and Instrumentation Science supports innovative technique and instrumentation development for advanced materials science research with scattering, spectroscopy, and imaging using electrons, scanning probes, neutrons, and x-rays, including development of science to understand ultrafast dynamics. These tools provide precise and complementary information on the atomic structure, dynamics, and relationship between structure and properties. The use of DOE's world-leading electron, neutron, and x-ray scattering facilities in major advances in materials sciences provides continuing evidence of the importance of this research field. In addition, the BESAC report on transformative opportunities for discovery science, identified imaging as one of the pillars for transformational advances for the future. The use of multimodal platforms to reveal the most critical features of a material was a major finding of the June 2016 workshop "Basic Research Needs Workshop for Innovation and Discovery of Transformative Experimental Tools: Solving Grand Challenges in the Energy Sciences."

The unique interactions of electrons, neutrons, and x-rays with matter enable a range of complementary tools with different sensitivities and resolution for the characterization of materials at length- and time-scales spanning many orders of magnitude. A distinct aspect of this activity is the development of innovative instrumentation concepts and techniques for scattering, spectroscopy, and imaging needed to correlate the microscopic and macroscopic properties of energy materials. Characterization of multiscale phenomena to extract heretofore unattainable information on multiple length and time scales is a growing aspect of this research, as is the use of combined scattering and imaging techniques.

Understanding how extreme environments (temperature, pressure, stress, photon and radiation flux, electromagnetic fields, and electrochemical potentials) impact materials at the atomic and nanoscale level and cause changes that eventually result in materials failure is required to design transformational new materials for energy-related applications. Advances in characterization tools, emphasizing ultrafast techniques, are needed to measure non-equilibrium and excited-state phenomena at the core of the complex, interrelated physical and chemical processes that underlie materials performance in these conditions. Information from these characterization tools is the foundation for the creation of new materials that have extraordinary tolerance and can function within an extreme environment without property degradation. These tools and techniques are also critical in advancing understanding and discovery of novel quantum materials, including materials for next generation systems to advance QIS.

Condensed Matter and Materials Physics Research

Understanding and controlling the fundamental properties of materials are critical to improving their functionality on every level and are essential to fulfilling DOE's energy mission. The Condensed Matter and Materials Physics activity supports experimental and theoretical research to advance our understanding of phenomena in condensed matter—solids with structures that vary in size from the nanoscale to the mesoscale. These materials make up the infrastructure for energy technologies, including electronic, magnetic, optical, thermal, and structural materials.

A central focus of this research program is to characterize and understand materials whose properties are derived from the interactions of electrons and related entities in their structure, such as unconventional superconductors and magnetic materials. There is a growing emphasis on "quantum materials"—materials whose properties result from strong and coherent interactions of the constituent electrons with each other, the atomic lattice, or light. This activity emphasizes investigation of low-dimensional systems, including nanostructures and two-dimensional layered structures such as graphene, multilayered structures of two-dimensional materials, and studies of the electronic properties of materials at ultra-low temperatures and in high magnetic fields. The research advances the fundamental understanding of the elementary energy conversion steps related to photovoltaics, and the electron spin-phenomena and basic semiconductor physics relevant to next generation electronics and quantum information technologies. Fundamental studies of the quantum mechanical behavior of electrons in materials will lead to an improved understanding of optical, electrical, magnetic, and thermal properties for a wide range of material systems.

This activity also emphasizes research to understand how materials respond to their environments, including the influence of temperature, electromagnetic fields, radiation, and corrosive chemicals. This research includes the defects in materials and their effects on materials' electronic properties, strength, structure, deformation, and failure over a wide range of length and time scales that will enable the design of materials with superior properties and resistance to change under the influence of radiation. There is a growing emphasis on extending knowledge of radiation effects to enable predictive capabilities for the multiple extreme environments envisioned for future nuclear reactors.

There is a critical need to advance the theories that are being used to describe material properties across a broad range of length and time scales, from the atomic scale to properties at the macroscale where the influence of size, shape, and composition is not adequately understood and the time evolution of these properties from femtoseconds to seconds to much longer times. Theoretical research also includes development of advanced computational and data-oriented techniques and predictive theory and modeling for discovery of materials with targeted properties.

Quantum materials research as it relates to QIS is a priority with important connections to national security and energy, including the development of the understanding to enable future generations of sensors, computers, and related technologies. Research priorities are being established through community engagement in roundtable discussions, interactions with other SC program offices, and at the interagency level, to define a unique BES role in this critical field. The research will couple materials expertise in quantum materials, theory for materials discovery, and prototypes of next generation devices.

Materials Discovery, Design, and Synthesis Research

The discovery and development of new materials has long been recognized as the engine that drives science frontiers and technology innovations. Predictive design and discovery of new forms of matter with desired properties continues to be a significant challenge for materials sciences. A strong, vibrant research enterprise in the discovery of new materials is critical to world leadership—scientifically, technologically, and economically. One of the goals of this activity is to grow and maintain U.S. leadership in materials discovery by investing in advanced synthesis capabilities and by coupling these with state-of-the-art user facilities and advanced computational capabilities at DOE national laboratories.

The BESAC report on transformative opportunities for discovery science reinforced the importance of the continued growth of synthesis science, recognizing the transformational opportunity to realize targeted functionality in materials by controlling the synthesis and assembly of hierarchical architectures and beyond equilibrium matter. This program will be enhanced to expand the application of materials discovery and synthesis research to understand the unique properties of rare earth and other critical materials, with the goal of reducing their use through development of substitutes, reducing the quantities required for specific properties, and developing novel synthesis techniques.

In addition to research on chemical and physical synthesis processes, an important element of this portfolio is research to understand how to use bio-mimetic and bio-inspired approaches to design and synthesize novel materials with some of the unique properties found in nature, e.g., self-repair and adaptability to the changing environment. Major research directions include the controlled synthesis and assembly of nanoscale materials into functional materials with desired properties; porous materials with customized porosities and reactivities; mimicking the energy-efficient, low temperature synthesis approaches of biology to produce materials under mild conditions; bio-inspired materials that assemble autonomously and, in response to external stimuli, dynamically assemble and disassemble to form non-equilibrium structures; and adaptive and resilient materials that also possess self-repairing capabilities. The portfolio also supports fundamental research in solid state chemistry to enable discovery of new functional materials and the development of new crystal growth methods and thin film deposition techniques to create complex materials with targeted structure and properties. An important element of this activity is research to understand the progression of structure and properties as a material is formed, in order to understand the underlying physical mechanisms and to gain atomic level control of material synthesis and processing, including the extraordinary challenges for synthesis of quantum materials.

Established Program to Stimulate Competitive Research (EPSCoR)
The DOE EPSCoR program funds early stage research that supports the agency's energy mission in states and territories with historically lower levels of Federal research funding. Eligibility determination for the DOE EPSCoR program follows the National Science Foundation (NSF) eligibility analysis.

The DOE EPSCoR program emphasizes research that will improve the capability of designated states and territories to conduct sustainable and nationally competitive energy-related research; jumpstart research capabilities in designated states and territories through training scientists and engineers in energy-related areas; and build beneficial relationships between scientists and engineers in the designated jurisdictions with world-class laboratories managed by the DOE, leverage DOE national user facilities, and take advantage of opportunities for intellectual collaboration across the DOE system. Through broadened participation, DOE EPSCoR seeks to augment the network of energy-related research performers across the nation.

Energy Frontier Research Centers (EFRCs)
The EFRC program is a unique research modality, bringing together the skills and talents of teams of investigators to perform energy-relevant, basic research with a scope and complexity beyond what is possible in standard single-investigator or small-group awards. These multi-investigator, multi-disciplinary centers foster, encourage, and enable transformative scientific advances for the most challenging topics in materials sciences. The EFRCs supported in this subprogram have historically focused on: the design, discovery, synthesis, characterization, and understanding of novel, solid-state materials that convert energy into electricity; the understanding of materials and processes that are foundational for electrical energy storage, gas separation, and defect evolution in radiation environments; and the exploration of phenomena related to quantum materials that can optimize energy flow and transmission. After eight years of research activity, the program has produced an impressive breadth of scientific accomplishments, including over 9,600 peer-reviewed journal publications.

BES's active management of the EFRCs continues to be an important feature of the program. The program uses a variety of methods to regularly assess the progress of the EFRCs, including annual progress reports, monthly phone calls with the EFRC Directors, periodic Directors' meetings, and on-site visits by program managers. BES also conducts in-person reviews by outside experts. Each EFRC undergoes a review of its management structure and approach in the first year of the award and a midterm assessment of scientific progress compared to its scientific goals. To facilitate communication of results to other EFRCs and DOE, BES holds meetings of the EFRC researchers biennially.

Energy Innovation Hubs—Batteries and Energy Storage
The Joint Center for Energy Storage Research (JCESR) focuses on advancing the understanding of the fundamental electrochemistry and addressing the materials challenges required for advanced electrical energy storage solutions that are critical to the Nation for a reliable electrical grid, improved batteries for vehicles, and other national priorities. JCESR is a multi-institutional research team led by Argonne National Laboratory (ANL) in collaboration with four other national laboratories, ten universities, and five industrial participants. In the initial 5-year award (2013-2018), JCESR research activities focused on the development of an atomic-level understanding of reaction pathways and elucidation of design rules for electrolyte and electrode function for battery systems that go beyond lithium-ion with an emphasis on discovery of new energy storage chemistries. JCESR pioneered the use of technoeconomic modeling to provide a "cost" consideration in prioritizing its fundamental research directions for next generation batteries. JCESR created a library of fundamental scientific knowledge including: demonstration of a new class of membranes for anode protection and flow batteries; elucidation of the characteristics required for multi-valent intercalation electrodes; understanding the chemical and physical processes that must be controlled to protect the inventories of active materials in lithium-sulfur batteries and greatly

improve cycle life; and computational screening of over 16,000 potential electrolyte compounds using the Electrolyte Genome protocols.

The renewal of JCESR will continue the focus on early stage research to tackle forefront, basic scientific challenges for next-generation electrochemical energy storage. The research will be consistent with the priorities established in the recent BES workshop report *Basic Research Needs for Next Generation Electrical Energy Storage,* including discovery science for exploration of new battery chemistries and materials with novel functionality. It is anticipated that advances will elucidate cross-cutting scientific principles for electrochemical stability; ionic and electronic transport at interfaces/interphases, in bulk materials or membranes; solvation structures and dynamics in electrolytes; nucleation and growth of materials, new phases, or defects; coupling of electrochemical and mechanical processes; and kinetic factors that govern reversible and irreversible reactions. Close coupling of theory, simulation, and experimentation is expected to accelerate scientific progress; to unravel the complex, coupled phenomena of electrochemical energy storage; to bridge gaps in knowledge across length and temporal scales; and to enhance the predictive capability of electrochemical models.

Computational Materials Sciences

Major strides in materials synthesis, processing, and characterization, combined with concurrent advances in computational science—enabled by enormous improvements in high-performance computing capabilities—have opened an unprecedented opportunity to design new materials with specific functions and properties. The goal is to leap beyond simple extensions of current theory and models of materials towards a paradigm shift in which specialized computational codes and software enable the design, discovery, and development of new materials, and in turn, create new advanced, innovative technologies. Given the importance of materials to virtually all technologies, computational materials sciences are critical for American competitiveness and global leadership in innovation.

This paradigm shift will accelerate the design of revolutionary materials to meet the Nation's energy security and enhance economic competitiveness. Development of fundamentally new design principles could enable stand-alone research codes and integrated software packages to address multiple length and time scales for prediction of the total functionality of materials over a lifetime of use. Examples include dynamics and strongly correlated matter, conversion of solar energy to electricity, design of new catalysts for a wide range of industrial uses, and electrical and thermal transport in materials for improved electronics. Success will require extensive R&D with the goal of creating experimentally validated, robust community codes that will enable functional materials innovation.

Awards in this program focus on the creation of computational codes and associated experimental/computational databases for the design of functional materials. This research is performed by fully integrated teams, combining the skills of experts in materials theory, modeling, computation, synthesis, characterization, and processing/fabrication. The research includes development of new *ab initio* theory, mining the data from both experimental and theoretical databases, performing advanced *in situ/in operando* characterization to generate the specific parameters needed to validate computational models, and well-controlled synthesis to confirm the predictions of the codes. It uses the unique world leading tools and instruments at DOE's user facilities, from ultrafast free electron lasers to aberration-corrected electron microscopes and neutron and x-ray scattering and includes instrumentation for atomically controlled synthesis. The computational codes will advance the predictive capability for functional materials, use DOE's leadership class computational capabilities, and be positioned to take advantage of today's petascale and tomorrow's exascale leadership class computers. This research will result in publicly accessible databases of experimental/computational data and open source, robust, validated, user friendly software that captures the essential physics and chemistry of relevant materials systems. The ultimate goal is use of these codes/data by the broader research community and by industry to dramatically accelerate the design of new functional materials.

Computational materials science research activities are managed using the approaches developed by BES for similar large team modalities. Management reviews by a peer review panel are held in the first year of the award, followed by a mid-term peer review to assess scientific progress, with regular teleconferences, annual progress reports, and active management by BES throughout the performance period.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Materials Sciences and Engineering $359,641,000	**$361,040,000**	**+$1,399,000**
Scattering and Instrumentation Sciences Research $76,598,000	**$60,925,000**	**-$15,673,000**
Research supported advanced characterization tools and techniques to address forefront scientific challenges to understand materials and related phenomena. Quantitative *in situ* and *in operando* analysis capabilities under perturbing parameters such as temperature, stress, chemical environment, and magnetic and electric fields were investigated. Investments in x-ray science emphasized hypothesis driven research with x-ray free electron laser sources, tailored excitations with pumped laser control, and coherent x-ray imaging. Neutron scattering research emphasized research on thermodynamics of charged polymer systems and emergent quantum phenomena at interfaces and in the bulk. Electron scattering research focused on innovative and multimodal techniques to assess charge-orbital-spin coupling and quantum phenomena, ultrafast techniques, and high energy resolution imaging and spectroscopy.	Research will emphasize the development and use of forefront characterization tools to address challenges in materials science including understanding of quantum phenomena, with an increasing emphasis on ultrafast techniques. In addition to high spatial resolution, the research will emphasize dynamics – understanding how material structures and phenomena evolve with time and in environments that reflect the challenges for energy generation and use. Investments in x-ray science will emphasize hypothesis-driven research with x-ray free electron laser sources, tailored excitations with pumped laser control, and coherent x-ray imaging. Neutron scattering research will emphasize research in emergent quantum phenomena, especially research involving interfaces. Electron scattering research will focus on innovative techniques to assess quantum phenomena, especially with ultrafast techniques.	Research will emphasize development of novel ultrafast techniques, especially using x-ray free electron lasers, and their use to assess materials dynamics including processes related to quantum phenomena. Research that uses long-standing x-ray, neutron scattering, and electron microscopy techniques and research focused on traditional superconductivity and organic electronics will be deemphasized.

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Condensed Matter and Materials Physics Research $101,645,000	**$123,790,000**	**+$22,145,000**
The program continued to support fundamental experimental and theoretical research on the properties of materials. The experimental and theoretical condensed matter physics research emphasized quantum materials, focusing on new and emergent behavior including quantum magnetism, spintronics, topological states, and novel 2D materials. Advancement of theory and computational tools focused on materials discovery, including data-driven and machine learning techniques; novel approaches; and non-equilibrium systems. Physical behavior research emphasized innovative science to understand optical, thermal, and electronic phenomena. For mechanical behavior and radiation effects, there was an increased focus on understanding defect evolution in radiation environments.	Research on fundamental experimental and theoretical research on the properties of materials, emphasizing quantum phenomena, will be continued. Experimental and theoretical condensed matter physics research will emphasize quantum materials, focusing on new and emergent behavior for QIS, including spintronics, topological states and novel 2D materials. Physical behavior research will emphasize innovative science to understand optical and electronic phenomena. Mechanical behavior and radiation effects research will continue to focus on the mechanisms of materials failure due to mechanical strain, corrosion, and radiation environments, including the coupled extremes envisioned for future nuclear reactors.	Research will emphasize forefront research in the topical areas covered by this subprogram. Research will increase focus on quantum materials research, including research relevant for QIS for both experimental and theoretical approaches. Also emphasized is radiation effects research that will illuminate the scientific understanding of materials intended for future nuclear reactors. Topics to be deemphasized include research on traditional superconductivity; theory related to soft matter, glassy systems, granular materials, ionic liquids, surface chemistry, and mechanics; and high-strain-rate deformation behavior.
Materials Discovery, Design, and Synthesis Research $61,931,000	**$62,551,000**	**+$620,000**
Research to develop a scientific understanding for predictive design and synthesis of materials across multiple length scales continued. Emphasis was on innovative approaches, including use of *in situ* and *in operando* diagnostics, to understand the mechanisms of chemical, physical, and biomimetic synthesis of materials to enhance discovery of new and improved materials. Continued emphasis was placed on research that incorporates both experiment and theory with the goal of advancing broad mechanistic insights. Fundamentals of growth kinetics, self-assembly, directed assembly, and the role of interfaces, including organic-inorganic systems, were stressed. In materials chemistry, fundamental research related to polymer chemistry, nanomaterial	Research will continue to focus on understanding the fundamentals of predictive design and synthesis of materials using chemical, physical and bio-inspired techniques. Understanding the dynamics and evolution of materials structure and chemistry during the early stages of materials synthesis will be emphasized, as will research that incorporates both experiment and theory with the goal of advancing broad mechanistic insights. Fundamentals of growth kinetics, self-assembly, directed assembly, and the role of interfaces and defect management will be stressed for complex materials including quantum materials, organic systems, nanomaterials, electrochemical materials, polymers, and high fidelity mesoscale systems.	Research will emphasize forefront science to understand synthesis related to novel functionalities and elucidating the roles of interfaces, especially for quantum and critical materials. Topics to be de-emphasized include research related to optimization of synthetic methods, research focused on specific properties of materials for applications, and research with a primary goal of device fabrication and testing.

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
synthesis, liquids, electrochemistry, and control of porosity continued. For biomolecular materials, research on assembly of materials that incorporate error correction and defect management mechanisms for beyond equilibrium, multicomponent materials was emphasized.		
Established Program to Stimulate Competitive Research (EPSCoR) $14,452,000	**$7,708,000**	**-$6,744,000**
Research supported science crosscutting the DOE mission, with continued emphasis on science that underpins DOE energy technology programs. Implementation grants, state-laboratory partnerships, and investment in early career research staff from EPSCoR states was sustained. Single investigator research through the state-laboratory partnerships component of the program was emphasized.	Efforts will continue to span science in support of the DOE mission, with emphasis on early stage science that underpins DOE energy technology programs. Research will emphasize broadening EPSCoR jurisdiction-laboratory partnerships and investment in early career research faculty from EPSCoR designated jurisdictions.	Research support is reduced compared to the FY 2017 Enacted level, taking into consideration overall funding for core research to institutions in EPSCoR states and emphasis on support for early stage, basic research.
Energy Frontier Research Centers (EFRCs) $55,800,000	**$55,800,000**	**$0**
FY 2017 funds provided the fourth year of funding for awards made in FY 2014, as well as the second year of funding for new awards made in FY 2016.	FY 2019 funds will continue to support four-year EFRC awards that were made in FY 2016 and FY 2018.	As a result of the recompetition of the EFRC program in FY 2018, emphasis is placed on tackling the transformative opportunities related to materials sciences and the research priorities identified in the Basic Research Needs reports on quantum materials, synthesis science, instrumentation science, next-generation electrical energy storage, and future nuclear energy. In order to address these priorities, the following topical areas are deemphasized: phenomena related to more mature areas of solar photovoltaics, thermoelectrics, and solid-state lighting.

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Energy Innovation Hubs—Batteries and Energy Storage $24,088,000	**$24,088,000**	**$0**
FY 2017 funding supported the research for JCESR to complete the five-year award (research continued through mid-FY 2018). Its research activities focused on the development of an atomic-level understanding of reaction pathways and development of universal design rules for electrolyte function for battery systems that go beyond lithium-ion with an emphasis on discovery of new energy storage chemistries.	Research will continue to focus on early stage research to tackle forefront, basic scientific challenges for next-generation electrochemical energy storage. The research will emphasize discovery science, elucidation of cross-cutting scientific principles for electrical energy storage, and integration of theory, experiment, and computational approaches to accelerate progress.	Funding will support renewal of the JCESR award at the same funding level.
Computational Materials Sciences $12,000,000	**$13,000,000**	**+$1,000,000**
Research continued on the computational materials sciences awards focused on basic science necessary to develop research-oriented, open-source, experimentally validated software and the associated databases required to predictively design materials with specific functionality. The software utilizes leadership class computers and incorporates frameworks that are suited for future exascale computer systems. For these four-year awards, management reviews are held in the first year of the award, and full peer reviews are held after two years. Renewal, based on full peer review, is an option to ensure maximum impact.	Research will continue on the computational materials sciences awards, with ongoing focus on basic science necessary to develop research-oriented, open-source, experimentally validated software and the associated databases required to predictively design materials with specific functionality. Software will be developed that utilizes leadership class computers, and made available to the broad research community. In addition, the codes will incorporate frameworks that are suited for future exascale computer systems. Awards that complete their fourth year of research will be considered for renewal in a solicitation that also considers new applications.	The additional funds will support awards related to theory for predictive design of quantum materials for next generation QIS.
SBIR/STTR $13,127,000	**$13,178,000**	**+$51,000**
In FY 2017, SBIR/STTR funding was set at 3.65% of non-capital funding.	In FY 2019, SBIR/STTR funding is set at 3.65% of non-capital funding.	

Description

Transformations of energy among forms, and rearrangements of matter at the atomic, molecular, and nano-scales, are essential in every energy technology. The Chemical Sciences, Geosciences, and Biosciences subprogram supports research to discover fundamental knowledge of chemical reactivity and energy conversion that is the foundation for energy-relevant chemical processes, such as catalysis, synthesis, and light-induced chemical transformation. Research addresses the challenge of understanding how physical and chemical phenomena at the scales of electrons, atoms, and molecules control complex and collective behavior of macro-scale energy conversion systems. At the most fundamental level, understanding of the quantum mechanical behavior of electrons, atoms, and molecules is rapidly evolving into the ability to control and direct such behavior to achieve desired outcomes. This subprogram seeks to extend the new era of control science to include the capability to tailor chemical transformations with atomic and molecular precision. Here, the challenge is to achieve fully predictive understanding of complex chemical, geochemical, and biochemical systems at the same level of detail now known for simple molecular systems.

To address these challenges, the portfolio includes coordinated research activities in three areas:

- **Fundamental Interactions**—Discover the factors controlling chemical reactivity and dynamics in the gas phase, condensed phases and at interfaces, based upon a quantum description of the interactions among photons, electrons, atoms, and molecules.

- **Chemical Transformations**—Understand and control the mechanisms of chemical catalysis, synthesis, separation, stabilization and transport in complex chemical systems, from atomic to geologic scales.

- **Photochemistry and Biochemistry**—Elucidate the molecular mechanisms of the capture of light energy and its conversion into electrical and chemical energy through biological and chemical pathways.

This portfolio encompasses five synergistic, fundamental research themes that are at the intersections of multiple research focus areas. An important component of ultrafast science, *Ultrafast Chemistry,* develops and applies approaches to probe the dynamics of electrons that control chemical bonding and reactivity; to understand energy flow underlying energy conversions in molecular, condensed phase, and interfacial systems; and to elucidate structural dynamics accompanying bond breaking and bond making in chemical transformations. *Chemistry at Complex Interfaces* addresses the challenge of understanding how the complex environment created at interfaces influences chemical phenomena such as reactivity and transport that are important in photochemical, catalytic, separation, biochemical and geochemical systems. These complex interfaces are structurally and functionally disordered, exhibit complex dynamic behavior, and have disparate properties in each phase. *Charge Transport and Reactivity* explores how the dynamics of charges contribute to energy flow and conversion and how charge transport and reactivity are coupled. *Reaction Pathways in Diverse Environments* discovers the influence of nonequilibrium, heterogeneous, nanoscale, and extreme environments on complex reaction mechanisms in chemical conversions. Research in this area increases understanding of the factors controlling chemical processes and provides mechanistic insights into the efficiency, control, and selectivity of reaction pathways. *Chemistry in Aqueous Environments* addresses the unique properties of water, particularly how they manifest in extreme environments such as confinement (e.g., nanoscale pores) and multi-component, multi-phase solutions (e.g., concentrated electrolytes), and the role aqueous systems play in energy and chemical conversions. The advancement of characterization tools and instrumentation with high spatial and temporal resolution and ability to study real-world systems under operating conditions, as well as computational and theoretical tools that provide predictive capabilities for studies of progressively more complex systems, are essential for advancing fundamental science in these areas.

In addition to single-investigator and small-group research, the subprogram supports EFRCs, which are multi-investigator, multidisciplinary research efforts focused on forefront scientific challenges that relate to the DOE energy mission. The EFRCs support teams of investigators to perform basic research to accelerate transformative scientific advances for the most challenging topics in chemical sciences, geosciences, and biosciences.

The FY 2019 Request focuses resources toward the highest priorities in early-stage fundamental research, with targeted reductions of activities that extend to later-stage fundamental research. High priority areas include ultrafast science, particularly through the cross-cutting research theme in *Ultrafast Chemistry* and complemented by research supported in other research themes, QIS to understand the quantum nature of atomic and molecular systems and research to exploit recent advances in quantum computing to address scientific challenges that are beyond the capabilities of classical computers, and chemical processes in extreme environments, in particular the extremes of radiation, temperature, stress, and chemical reactivity, to provide fundamental knowledge needed to understand as well as advance nuclear energy systems.

Fundamental Interactions Research

This activity emphasizes structural and dynamical studies of atoms, molecules, and nanostructures, and the description of their interactions in full quantum detail. The goal is to achieve a complete understanding of reactive chemistry in the gas phase, condensed phase, and at interfaces. Using techniques and tools developed for *Ultrafast Sciences*, novel sources of photons, electrons, and ions are used to probe and control atoms and molecules. Ultrafast optical and x-ray sources are developed and used to study and direct molecular dynamics and chemical reactions to increase basic understanding of *Charge Transport and Reactivity* and *Reaction Pathways in Diverse Environments,* and to understand how the dynamics of molecular environments influence reactivity and transport that is important in *Chemistry at Complex Interfaces* and *Chemistry in Aqueous Environments.* Research encompasses structural and dynamical studies of chemical systems in the gas and liquid phases. New algorithms for computational chemistry are developed for an accurate and efficient description of chemical processes to better understand *Reaction Pathways in Diverse Environments*, *Charge Transport and Reactivity, Chemistry at Complex Interfaces,* and *Ultrafast Chemistry*. These theoretical and computational approaches are applied in close coordination with experiment. The knowledge and techniques produced by Fundamental Interactions research form a science base that underpins numerous aspects of the DOE mission.

The principal research thrusts in this activity are atomic, molecular, and optical sciences (AMOS) and three areas of chemical physics: gas phase chemical physics, condensed phase and interfacial molecular science, and computational and theoretical chemistry. AMOS research emphasizes the fundamental interactions of atoms and molecules with electrons and photons, particularly intense, ultrafast x-ray pulses, to characterize and control their behavior and provide the foundation for understanding the making and breaking of chemical bonds. The goal is to develop accurate quantum mechanical descriptions of ultrafast dynamical processes such as chemical bond breaking and forming, interactions in strong fields, and electron correlation. Novel attosecond sources are used to image the dynamics of electrons and charge transport. Chemical physics research builds from the AMO foundation by examining the reactive chemistry of molecules whose chemistry is profoundly affected by the environment, especially at complex interfaces. The transition from molecular-scale chemistry to collective phenomena is explored at a molecular level in condensed phase systems, such as the effects of solvation or interfaces on chemical structure and reactivity. The goal is to understand reactivity and dynamical processes in liquid systems and at complex interfaces using model systems. Understanding of such collective behavior is critical in a wide range of energy and environmental applications, from solar energy conversion to radiolytic effects in condensed phases and interfacial systems, to catalysis. Gas-phase chemical physics emphasizes experimental and theoretical studies of the ultrafast dynamics and rates of chemical reactions, as well as the chemical and physical properties of key intermediates relevant to catalysis. Computational and theoretical research supports the development and integration of new and existing theoretical and computational approaches for accurate and efficient descriptions of ultrafast processes relevant to catalysis and charge transport and to understand quantum effects, such as coherence in molecular systems, that are the foundation for creating novel QIS systems. Of special interest is foundational research on computational design of molecular- to meso-scale materials, and on next-generation simulation of complex dynamical processes. Research in this area is crucial to utilize planned exascale computing facilities and to optimize use of existing petascale computers, leveraging U.S. leadership in the development of computational chemistry codes. Additional emphasis will be placed on codes that contribute to a fundamental understanding of how molecules might function as components of quantum computers.

Chemical Transformations Research

Fundamentally, Chemical Transformations Research emphasizes advancing the knowledge of chemical reactivity, matter transport, and chemical separation and stabilization processes that will ultimately impact fuel science, separation science, heavy element chemistry and geosciences. The research uses tools from *Ultrafast Chemistry* to identify transient species during reactions and refine theories of reactivity; advances understanding of *Charge Transport and Reactivity* important in electrocatalytic and geochemical redox processes; explores *Chemistry at Complex Interfaces* in catalytic, geochemical and separation systems; and develops understanding of *Chemistry in Aqueous Environments* that play important roles in geochemical transformations and chemical separations, including heavy elements. This research breadth demands a broad coverage of scientific disciplines and analytical tools. Hence, Chemical Transformations comprise four core areas: Catalysis Science, Separation Science, Heavy Element Chemistry and Geosciences.

Reaction Pathways in Diverse Environments represent a major fraction of the research in this activity, particularly focused on achieving predictability and control of catalytic conversions, which are dominated by correlated structural and electronic dynamics under reaction conditions. This chemistry encompasses interfacial dynamics of catalytic particles, transient or reactive interfacial species, multifunctional membranes, nanostructured electrodes, and multiphase electrolytes. This activity supports development and application of theoretical and computational approaches to achieve a deeper understanding of reaction and separation pathways and processes; design new catalysts, membranes or separation media; and predict transport and reaction processes in the Earth's subsurface. This activity contains the largest federally funded program in non-biological Catalysis Science. The fundamental knowledge gained from this research activity provides the foundation for replacing critical elements such as noble metals in catalytic processes.

This activity supports fundamental separation science to resolve complex organic or inorganic mixtures, extract actinides from complex solutions, or recover targeted species from streams. Controlling the interaction of electric fields and matter allows for improved separations and controlled reactions. Controlling charge transport and reactivity is essential to efficiently control electroseparations as well as redox processes in fuel cells, electrocatalysts, reactive membranes or mineral interfaces. The fundamental knowledge gained from this research activity provides the foundations for extracting and purifying critical elements from waste as well as new resources.

Foundational knowledge for future nuclear energy approaches is provided through fundamental studies of the structure and reactivity of actinide-containing molecules in extreme environments such as those in nuclear reactors and nuclear waste containment. Radionuclides and heavy elements under extreme radiation environments exhibit unique dynamic and kinetic behavior. The challenges are further compounded by the evolution of these chemical mixtures over time. The chemistry of aqueous systems plays an important role in understanding the science of separations for these mixtures as well as their evolution.

Geosciences research provides the fundamental scientific basis underlying the subsurface chemistry and physics of natural substances under extreme conditions of pressure in solid or confined environments (e.g., porous media). Understanding chemistry of aqueous solutions at mineral interfaces and in confined environments is a common theme for this research activity, which advances knowledge of subsurface fracture, fluid flow and complex chemistry occurring over multiple scales of time and space.

<u>Photochemistry and Biochemistry Research</u>
This activity supports research on the molecular mechanisms that capture light energy and convert it into electrical and chemical energy in both natural and man-made systems. An important component of this activity is its leadership role in the support of basic research in both solar photochemistry and natural photosynthesis. A breadth of approaches and unique tools, such as those in *Ultrafast Chemistry*, are developed and used to investigate the structural and chemical dynamics of energy absorption, transfer, conversion and storage across multiple spatial and temporal scales as well as to better understand *Charge Transport and Reactivity*. Such efforts target the basic understanding of mechanisms and dynamics of chemical processes such as water oxidation, charge transfer, and redox interconversion of small molecules (e.g. carbon dioxide/methane, nitrogen/ammonia, and protons/hydrogen). Crosscutting research underpins a fundamental understanding of the synthesis, dynamics, and function of natural and artificial membranes and nano- to mesoscale-structures and develops new knowledge of the *Chemistry at Complex Interfaces* as well as *Chemistry in Aqueous Environments*. To develop knowledge of *Reaction Pathways in Diverse Environments*, structural, functional and mechanistic properties of enzymes, enzyme systems, and energy-relevant biological reactions are studied, identifying principles important for catalyst function, selectivity, and stability. These cross-cutting synergistic efforts are illustrated by studies of the mechanism of the water splitting reaction catalyzed by the metallocluster of the oxygen evolving complex in natural photosynthesis. The fundamental chemical and physical concepts resulting from studies of both natural systems (e.g.

photosynthetic and affiliated downstream biological processes) and man-made chemical systems provide crucial foundational knowledge on processes of energy capture, conversion, and storage.

Studies of natural photosynthesis provide an understanding of the dynamic mechanisms of solar energy capture and conversion in biological systems, from the atomic scale through the mesoscale. Research efforts encompass light harvesting, photosynthetic electron and proton transport, photosynthetic uptake and reduction of carbon dioxide, and mechanisms of self-assembly, self-regulation, and self-repair exhibited by the proteins, membranes and cellular compartments that perform natural photosynthesis. Physical science tools, such as those used for *Ultrafast Chemistry*, are used extensively to probe structural, functional, and mechanistic properties of enzymes, enzyme systems, and energy-relevant biological reactions and pathways related to energy capture, conversion, and storage, including complex multielectron redox reactions, electron transfer and bifurcation, and processes beyond primary photosynthesis such as nitrogen reduction and deposition of the reduced carbon into energy-dense carbohydrates and lipids. Complementary research on solar energy conversion in chemical and artificial systems focuses on the elementary steps of light absorption, charge separation, and charge transport within a number of chemical systems. Supported research incorporates organic and inorganic photochemistry, catalysis and photocatalysis, light-driven electron and energy transfer in the condensed phase and across interfaces, photoelectrochemistry, and artificial assemblies for charge separation and transport and provides fundamental insights for electricity generation from sunlight and artificial photosynthetic fuel production.

This activity also supports radiation science, investigating fundamental physical and chemical effects produced by the absorption of energy from ionizing radiation. These fundamental studies provide understanding of the chemical reactions that occur in radiation fields of nuclear reactors, including in their fuel and coolants. A common theme is the exploration of radiolytic processes that occur across solid-liquid and solid-gas interfaces, where surface chemistry can be activated and changed by radiolysis.

Energy Frontier Research Centers (EFRCs)

The EFRC program is a unique research modality, bringing together the skills and talents of teams of investigators to perform energy-relevant, basic research with a scope and complexity beyond what is possible in standard single-investigator or small-group awards. These multi-investigator, multi-disciplinary centers foster, encourage, and accelerate basic research to enable transformative scientific advances for the most challenging topics in chemical sciences, geosciences, and biosciences. The EFRCs supported in this subprogram have historically focused on the following topics: the design, discovery, characterization, and control of the chemical, biochemical, and geological moieties and processes for the advanced conversion of solar energy into chemical fuels and for improved electrochemical storage of energy; the understanding of catalytic chemistry and biochemistry that are foundational for fuels, chemicals, and separations; and advanced interrogation and characterization of the earth's subsurface. After eight years of research activity, the program has produced an impressive breadth of accomplishments, including over 9,600 peer-reviewed journal publications.

BES's active management of the EFRCs continues to be an important feature of the program. A variety of methods are used to regularly assess the progress of the EFRCs, including annual progress reports, monthly phone calls with the EFRC Directors, periodic Directors' meetings, and on-site visits by program managers. BES also conducts in-person reviews by outside experts. Each EFRC undergoes a review of its management structure and approach in the first year of the award and a midterm assessment of scientific progress compared to its scientific goals. To facilitate communication of results to other EFRCs and DOE, BES holds meetings of the EFRC researchers biennially.

Energy Innovation Hubs—Fuels from Sunlight

Established in September 2010, the Fuels from Sunlight Hub, called the Joint Center for Artificial Photosynthesis (JCAP), is a multi-disciplinary, multi-investigator, multi-institutional effort to create the scientific foundation for transformative advances in the development of artificial photosynthetic systems for the conversion of sunlight, water, and carbon dioxide into a range of commercially useful fuels. JCAP was renewed by BES for a final five-year award term starting on September 30, 2015, at an annual funding level of $15M. JCAP is led by the California Institute of Technology (Caltech) in primary partnership with Lawrence Berkeley National Laboratory (LBNL). Other partners include the SLAC National Accelerator Laboratory and University of California institutions.

In the second award, JCAP focused on the fundamental science of carbon dioxide reduction to establish the foundation for production of hydrocarbon fuels using only sunlight, carbon dioxide, and water as inputs. Guided by theoretical results, scientists discovered that nickel-gallium films require less energy to reduce carbon dioxide to ethylene, ethane, and methanol than copper-based materials, which were previously considered to be the best candidate catalysts. The research team combined JCAP's unique computational and experimental high-throughput capabilities to discover new earth-abundant metal vanadates that meet demanding requirements for water-splitting photoanodes. These results nearly doubled the number of materials that could considered for this key component of solar fuel generators and are helping researchers understand how material properties can be tuned for a specific function. Theoretical and experimental photocatalysis efforts also produced nanocrystals that exhibited the first demonstration of plasmon-enhanced photocurrent in carbon dioxide reduction and are being used to understand the interplay between plasmon and single particle excitation, providing insight into the possible use of plasmons in photo-induced chemical reactions.

The FY 2019 Request continues to focus resources toward the highest priorities in early-stage fundamental research on carbon dioxide reduction, with targeted decreases in activities that extend to later-stage fundamental research.

<u>Computational Chemical Sciences</u>

Software solutions and infrastructure provide the enabling tools for an effective scientific strategy to address the nation's energy challenges. BES-supported activities are entering a new era in which chemical reactions can be controlled and matter can be built with atom-by-atom precision. At the foundation of this new era are computational models that can accurately predict the behavior of molecules and materials based on theoretical calculations prior to their experimental synthesis. Open-source and commercial codes have established American dominance in computational chemistry. However, that dominance is being challenged with the transition to predominantly massively-parallel high performance computing (HPC) platforms, because most existing computational chemistry codes are unable to use efficiently more than one percent of the processors available on existing leadership-class supercomputers. While recent breakthroughs in computational chemistry provide a strong foundation for future success, a multidisciplinary team effort is critically needed to modify or replace existing computational chemistry codes with codes that are well-adapted to current petascale and anticipated exascale architectures.

BES launched research awards in FY 2017 to perform computational chemistry research that focus on the creation of computational codes and associated experimental/computational databases for the design of chemical processes and assemblies. These research efforts combine the skills of experts in theoretical chemistry, modeling, computation, and applied mathematics. The research includes development of new *ab initio* theory, mining data from both experimental and theoretical databases, and experimental validation of the codes. The computational codes will advance the predictive capability for chemical processes and assemblies, using DOE's scientific user facilities (including both advanced experimental as well as leadership class computational capabilities). This research will result in publicly accessible databases of experimental/computational data and open source, robust, validated, user friendly software that captures the essential physics and chemistry of relevant chemical systems. The ultimate goal is use of these codes/data by the broader research community and by industry to dramatically accelerate chemical research in the United States.

Computational chemical science research activities are managed using the approaches developed by BES for similar large team modalities. Management reviews by a peer review panel are held in the first year of the award, followed by a mid-term peer review to assess scientific progress, with monthly teleconferences, annual progress reports, and active management by BES throughout the performance period.

<u>General Plant Projects (GPP)</u>

GPP funding provides for minor new construction, for other capital alterations and additions, and for improvements to land, buildings, and utility systems to maintain the productivity and usefulness of Department-owned facilities and to meet requirements for safe and reliable facilities operation.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Chemical Sciences, Geosciences, and Biosciences $329,127,000	**$327,970,000**	**-$1,157,000**
Fundamental Interactions Research $62,606,000	**$69,581,000**	**+$6,975,000**
This activity is a major supporter of ultrafast chemical sciences and chemical physics, underpinning energy conversion and chemical transformation phenomena. This activity supported structural and dynamical studies of atoms and molecules, and the description of their interactions in full quantum detail, with the aim of providing a complete understanding of reactive chemistry in the gas phase, condensed phase, and at interfaces. Novel sources of photons, electrons, and ions were used to probe and control atomic, molecular, and nanoscale matter. Ultrafast optical and x-ray techniques were developed and used to study and direct molecular, dynamics, and chemical reactions.	This activity will continue to develop and apply forefront ultrafast x-ray and optical probes of matter to study and control energy flow and bond rearrangements. Gas phase research will continue to develop and apply approaches to examine the structure and dynamics of reactive intermediates and how they impact reaction pathways in heterogeneous environments. Research will extend efforts to understand and control chemical processes and dynamics, at the molecular level, in increasingly complex aqueous and interfacial systems. Research will expand the use of ultrafast techniques to study gas-phase, condensed phase and interfacial chemical phenomena. The activity will develop advanced theoretical methods for electronic structure calculations that can be scaled to operate on exascale computers. Research will support the development of new computational tools to calculate electronically excited states in molecules and extended mesoscale systems, to guide and interpret ultrafast measurements, and to develop new catalysts. The activity will emphasize efforts to drive advances in the application of quantum computing for molecular calculations.	The Request emphasizes imaging studies of molecular dynamics using as well as developing ultrafast capabilities at BES light sources, research to understand increasingly complex interfacial systems, advances in computational and theoretical chemistry for molecular systems of increasing complexity, advanced computational tools, and exascale computing. This activity will continue leading efforts to discover the factors controlling chemical reactivity and dynamics in the gas phase, condensed phases and at interfaces, based upon fundamental knowledge of the interactions among photons, electrons, atoms, and molecules. This activity will increase research in support of the application of quantum computing to calculations of molecular structure and dynamics. The activity will de-emphasize aspects of nanoscience and combustion research.

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Chemical Transformations Research $81,687,000	**$88,869,000**	**+$7,182,000**
This activity is a major supporter of catalysis and heavy element chemistry that have been the focus of community workshops and National Academy studies. This activity supported fundamental research for the characterization, control, and optimization of chemistry in many forms. Catalysis science supported the design of new catalytic methods for the clean and efficient production of fuels and chemicals through thermally and non-thermally induced reaction pathways. It involved catalysts of various types: inorganic and organic complexes, nanostructured and macromolecular phases, and solids and interfaces in complex environments. Heavy element chemistry explored the unique molecular bonding of the actinide and transactinide elements using experiment and theory to elucidate electronic and molecular structure as well as reaction thermodynamics. Research on chemical separations focused on understanding pathways and developing principles for how to control atomic and molecular interactions with separation media, including solvents, inorganic and organic/hybrid membranes, confined environments, complex mixtures and interfaces. Geosciences research covered molecular to mesoscale processes underlying interfacial geochemistry, flow and transport, and geomechanics.	This activity will continue to support predictive fundamental research on the design and synthesis of novel catalysts to efficiently convert chemical feedstocks to high-value fuels and chemicals. New routes to the efficient synthesis of high-energy chemicals such as hydrogen, ammonia, methanol, and others, will continue to be pursued. Fundamental separation science research will continue on innovative approaches for separating chemical mixtures. Molecular recognition at complex interfaces, predictive theory for transport and separation in confined environments, and multiscale methods for bonding and dynamics will continue to be supported, increasingly with exascale capabilities. Geochemical and geophysical mechanisms of reaction and transport processes in the subsurface environments, such as nucleation, growth and mineralization, solvation in aqueous environments at extreme conditions, and dynamics at mineral-water interfaces will continue to be supported. Heavy element research will continue to expand the knowledge of the chemistry of actinide reactivity, bonding, synthesis, and separation, and also support training in nuclear chemistry. Theoretical methods will continue to be advanced to accurately describe the chemistry of f-element compounds.	This Request emphasizes efforts in ultrafast spectroscopy for detailed studies of pathways, electronic structure calculations for systems of increasing molecular and solid complexity, and multiscale modeling and simulations for complex bonding or reaction and transport processes. Research will continue to lead the development of fundamental knowledge of mechanisms of chemical catalysis, synthesis, separations, stabilization and transport required to control chemical processes in complex systems. This activity will emphasize fundamental studies of the chemical processes that occur in nuclear environments, aimed towards an understanding of the structure, dynamics, and energetics of molten salt coolants and fuels as well as of the chemical and physical properties of interfaces and heavy elements. Also emphasized are the catalytic and separation mechanisms that operate within diverse environments created by complex atomic architectures, solvents, electric or mechanical fields, at various temperatures and pressures. It will provide new knowledge on reaction systems that integrate multiple steps, including chemical conversion, energy conversion and chemical separation steps that are resilient and adaptable to multiple sources of energy and feedstocks. The activity will de-emphasize research on chemical analysis, synthesis of nanomaterials, physics of fluids in rock systems, and biocatalytic reactions that are better aligned under other activities.

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Photochemistry and Biochemistry Research **$89,168,000**	**$74,386,000**	**-$14,782,000**
This activity is a major supporter of solar photochemistry and natural photosynthesis research, and central to understanding chemical processes and dynamics during energy capture and conversion. Research supported the molecular mechanisms involved in the capture of light energy and its conversion into chemical and electrical energy through biological and chemical pathways. Study of natural photosynthetic systems provided insights for artificial and bio-hybrid systems that exhibit the biological traits of self-assembly, regulation, and self-repair. Complementary research encompassed organic and inorganic photochemistry, photo-electrochemistry, electron and energy transfer, photo- and bio-catalysis, and molecular assemblies for artificial photosynthesis.	The activity will continue to support fundamental research on light energy capture and conversion into chemical and electrical energy through non-biological (chemical) and biological (photosynthetic) pathways. Studies of light absorption, energy transfer, and charge transport and separation will continue to be emphasized in both natural and artificial systems. Research of the fundamental mechanisms of photocatalysis and biocatalysis will continue to make use of innovative ultrafast methodologies as well as computation and modeling. Efforts to understand processes and reactions on ultrafast timescales for energy conversion in natural and artificial systems will continue to be supported and will target a fundamental understanding of ultrafast chemistry and of reactivity across complex interfaces, in aqueous environments, and under dynamic conditions. Research will also continue to examine how water drives formation of mesoscale structures for energy capture and conversion in natural systems and the chemistry and structure of water and other molecules within the field of highly ionizing radiation.	The Request emphasizes the use and development of ultrafast techniques and theory and computation to understand excited-state dynamics and charge and energy transfer in photochemical and biochemical processes. Cutting-edge research will continue to develop fundamental knowledge and innovative approaches to understand physical, chemical, and biochemical processes of light energy capture and conversion in non-biological and biological systems. Research in fundamental radiation chemistry will be emphasized to provide a foundation for prediction and control of radiation-chemical transformations in complex and extreme environmental systems. Fundamental research on charge transport, energy transfer, and catalytic mechanisms will provide new knowledge of processes important for energy capture, conversion, and storage as will efforts in the chemistry of ultrafast processes, complex interfaces, and water-driven processes. The activity will de-emphasize efforts in plant cell wall biosynthesis and structure, light signaling in plant development, and polyelectrolytes in solar photoconversion.
Energy Frontier Research Centers (EFRCs) **$54,200,000**	**$54,200,000**	**$0**
FY 2017 funds provided the fourth year of funding for awards made in FY 2014, as well as the second year of funding for new awards made in FY 2016.	The Request will continue to support four-year EFRC awards that were made in FY 2016 and FY 2018.	As a result of the recompetition of the EFRC program in FY 2018, the FY 2019 Request will emphasize tackling the transformative opportunities related to chemical sciences, geosciences, and biosciences and the research priorities identified in the Basic Research Needs reports on catalysis science, synthesis science, instrumentation science, energy-water issues, and future nuclear energy. In order to address these priorities, the following topical areas are

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
		deemphasized: phenomena related to more mature areas of solar photovoltaics; carbon dioxide sequestration; and biologically-mediated breakdown and conversion of lignocellulosic biomass.
Energy Innovation Hubs—Fuels from Sunlight $15,000,000	**$15,000,000**	**$0**
The Fuels from Sunlight Hub continued to perform research on the fundamental science of carbon dioxide reduction needed to enable efficient, sustainable solar-driven production of liquid transportation fuels. JCAP underwent a scientific and merit review in FY 2017 to assess progress toward meeting project milestones and goals.	FY 2019 funds will continue to support JCAP's fundamental research on the science of carbon dioxide reduction.	The Request focuses resources toward the highest priorities in early-stage fundamental research, with targeted reductions of activities that extend to later-stage fundamental research.
Computational Chemical Sciences $13,489,000	**$13,000,000**	**-$489,000**
Computational Chemical Sciences (CCS) projects were initiated to develop open-source modular software tools that can be reused and tailored for fundamental research needs of the chemistry community. This investment builds on current quantum chemistry software, seeking to create new codes that fully leverage massively-parallel high performance computing platforms and target implementation on future exascale computer systems. Funded research areas included: hierarchical and scalable software for spectra, transformation and separation; transition-metal molecules for chemical control and quantum systems; and photocatalytic and field-driven chemistry and transport.	FY 2019 funds will continue to support CCS awards that were made in FY 2017 and any new awards in complementary research areas made in FY 2018.	The Request will support awards that enable the use of leadership class computing and exascale computer systems for research areas complementary to the FY 2017 awards, including to understand quantum mechanical behavior of molecular systems for next generation QIS.
General Plant Projects $1,000,000	**$1,000,000**	**$0**
Funding supports minor facility improvements at Ames Laboratory.	Funding supports minor facility improvements at Ames Laboratory.	No changes.
SBIR/STTR $11,977,000	**$11,934,000**	**-$43,000**
In FY 2017, SBIR/STTR funding was set at 3.65% of non-capital funding.	In FY 2019, SBIR/STTR funding is set at 3.65% of non-capital funding.	

Basic Energy Sciences
Scientific User Facilities

Description

The Scientific User Facilities subprogram supports the operation of a geographically diverse suite of major research facilities that provide thousands of researchers from universities, industry, and government laboratories unique tools to advance a wide range of sciences. These user facilities are operated on an open access, competitive merit review basis, enabling scientists from every state and many disciplines from academia, national laboratories, and industry to utilize the facilities' unique capabilities and sophisticated instrumentation.

Studying matter at the level of atoms and molecules requires instruments that can probe structures that are one thousand times smaller than those detectable by the most advanced light microscopes. Thus, to characterize structures with atomic detail, we must use probes such as x-rays, electrons, and neutrons with wavelengths at least as small as the structures being investigated. The BES user facilities portfolio consists of a complementary set of intense x-ray sources, neutron scattering centers, and research centers for nanoscale science. These facilities allow researchers to probe materials in space, time, and energy with the appropriate resolutions that can interrogate the inner workings of matter to answer some of the most challenging grand science questions. By taking advantage of the intrinsic charge, mass, and magnetic characteristics of x-rays, neutrons, and electrons, these tools offer unique capabilities to help understand the fundamental aspects of the natural world.

Advances in tools and instruments often drive scientific discovery. The continual development and upgrade of the instrumental capabilities include new x-ray and neutron experimental stations, improved core facilities, and new stand-alone instruments. The subprogram also supports research in accelerator and detector development to explore technology options for the next generations of x-ray and neutron sources.

In FY 2017, the BES scientific facilities were used by nearly 16,000 scientists and engineers in many fields of science and technology. These facilities provide unique capabilities to the scientific community and industry and are a critical component of maintaining U.S. leadership in the physical sciences. Collectively, these user facilities and enabling tools contribute to important research results that span the continuum from basic to applied research and embrace the full range of scientific and technological endeavors, including chemistry, physics, geology, materials science, environmental science, biology, and biomedical science. These capabilities enable scientific insights that can lead to the discovery and design of advanced materials and novel chemical processes with broad societal impacts, from energy applications to information technologies and biopharmaceutical discoveries. The advances enabled by these facilities extend from energy-efficient catalysts to spin-based electronics and new drugs for cancer therapy. For approved, peer-reviewed projects, operating time is available at no cost to researchers who intend to publish their results in the open literature.

<u>X-Ray Light Sources</u>

X-rays are an essential tool for studying the structure of matter and have long been used to peer into material through which visible light cannot penetrate. Today's light source facilities produce x-rays that are billions of times brighter than medical x-rays. Scientists use these highly focused, intense beams of x-rays to reveal the identity and arrangement of atoms in a wide range of materials. The tiny wavelength of x-rays allows us to see things that visible light cannot resolve, such as the arrangement of atoms in metals, semiconductors, biological molecules, and other materials. The fundamental tenet of materials research is that structure determines function. The practical corollary that converts materials research from an intellectual exercise into a foundation of our modern technology-driven economy is that structure can be manipulated to construct materials with particular desired behaviors. To this end, x-rays have become a primary tool for probing the atomic and electronic structure of materials internally and on their surfaces.

From its first systematic use as an experimental tool in the 1960s, large scale light source facilities have vastly enhanced the utility of pre-existing and contemporary techniques, such as x-ray diffraction, x-ray spectroscopy, and imaging and have given rise to scores of new ways to do experiments that would not otherwise be feasible with conventional x-ray machines. Moreover, the wavelength can be selected over a broad range (from the infrared to hard x-rays) to match the needs of particular experiments. Together with additional features, such as controllable polarization, coherence, and ultrafast pulsed time structure, these characteristics make x-ray light sources an important tool for a wide range of materials research. The wavelengths of the emitted photons span a range of dimensions from the atom to biological cells, thereby providing incisive probes for advanced research in a wide range of areas, including materials science, physical and chemical sciences, metrology, geosciences, environmental sciences, biosciences, medical sciences, and pharmaceutical sciences. BES operates a suite of five light sources, including a free electron laser, the Linac Coherent Light Source (LCLS) at SLAC, and four storage ring based light sources—the Advanced Light Source (ALS) at LBNL, the Advanced Photon Source (APS) at ANL, the Stanford Synchrotron Radiation Lightsource (SSRL) at SLAC, and the newly constructed National Synchrotron Light Source-II (NSLS-II) at BNL. BES also provides funds to support facility operations, to enable cutting-edge research and technical support, and to administer the user program at these facilities, which are made available to all researchers with access determined via peer review of user proposals.

High Flux Neutron Sources

One of the goals of modern materials science is to understand the factors that determine the properties of matter on the atomic scale and to use this knowledge to optimize those properties or to develop new materials and functionality. This process regularly involves the discovery of fascinating new physics, which itself may lead to previously unexpected applications. Among the different probes used to investigate atomic-scale structure and dynamics, thermal neutrons have unique advantages:

- they have a wavelength similar to the spacing between atoms, allowing atomic resolution studies of structure, and have an energy similar to the elementary excitations of atoms and magnetic spins in materials, thus allowing an investigation of material dynamics;
- they have no charge, allowing deep penetration into a bulk material;
- they are scattered to a similar extent by both light and heavy atoms but differently by different isotopes of the same element, so that different chemical sites can be distinguished via isotope substitution experiments, for example in organic and biological materials;
- they have a magnetic moment, and thus can probe magnetism in condensed matter systems; and
- their scattering cross-section is precisely measurable on an absolute scale, facilitating straightforward comparison with theory and computer modeling.

The High Flux Isotope Reactor (HFIR) at ORNL generates neutrons via fission in a research reactor. HFIR operates at 85 megawatts and provides state-of-the-art facilities for neutron scattering, materials irradiation, and neutron activation analysis. It is the world's leading production source of elements heavier than plutonium for medical, industrial, and research applications. There are 12 instruments in the user program at HFIR and the adjacent cold neutron beam guide hall, which include world-class inelastic scattering spectrometers, small angle scattering, powder and single crystal diffractometers, neutron imaging, and an engineering diffraction machine.

Another approach for generating neutron beams is to use an accelerator to generate protons that strike a heavy-metal target. As a result of the impact, neutrons are produced in a process known as spallation. The Spallation Neutron Source (SNS) at ORNL is the world's brightest pulsed neutron facility and presently includes 19 instruments. These instruments include very high resolution inelastic and quasi-elastic scattering capabilities, powder and single crystal diffraction, polarized and unpolarized beam reflectometry, and spin echo and small angle scattering spectrometers. A full suite of high and low temperature, high magnetic field, and high pressure sample environment equipment is available on each instrument. All the SNS instruments are in high demand by researchers world-wide in a range of disciplines from biology to materials sciences and condensed matter physics.

Nanoscale Science Research Centers (NSRCs)

Nanoscience is the study of materials and their behaviors at the nanometer scale—probing and assembling single atoms, clusters of atoms, and molecular structures. The scientific quest is to design new nanoscale materials and structures not found in nature, and observe and understand how they function and interact with their environment. Developments at the nanoscale and mesoscale have the potential to make major contributions to delivering remarkable scientific discoveries that transform our understanding of energy and matter and advance national, economic, and energy security.

The NSRCs focus on interdisciplinary research at the nanoscale, serving as the basis for a national program that encompasses new science, new tools, and new computing capabilities. They are a different class of facility than the x-ray and neutron sources, as NSRCs are not based on a large accelerator or reactor but are comprised of a suite of smaller unique tools and expert scientific staff. The five NSRCs BES currently supports are the Center for Nanoscale Materials at ANL, the Center for Functional Nanomaterials at BNL, the Molecular Foundry at LBNL, the Center for Nanophase Materials Sciences at ORNL, and the Center for Integrated Nanotechnologies at SNL and LANL. Each center has particular expertise and capabilities, such as nanomaterials synthesis and assembly; theory, modeling and simulation; imaging and spectroscopy including electron microscopy; and nanostructure fabrication and integration. Selected thematic areas include catalysis, electronic materials, nanoscale photonics, and soft and biological materials. The centers are housed in custom-designed laboratory buildings near one or more other major BES facilities for x-ray, neutron, electron scattering, or computation which complement and leverage the capabilities of the NSRCs. These laboratories contain clean rooms, nanofabrication resources, one-of-a-kind signature instruments, and other instruments not generally available except at major user facilities. The NSRC electron microscopy capabilities provide superior atomic-scale spatial resolution and the ability to simultaneously obtain structural, chemical, and other types of information from sub-nanometer regions at short time scales. Operating funds enable cutting-edge research and technical support and to administer the user program at these facilities, which are made available to academic, government, and industry researchers with access determined through external peer review of user proposals.

The emerging field of quantum information science (QIS) exploits intricate quantum mechanical phenomena such as entanglement to create fundamentally new ways of obtaining and processing information. Harnessing these counterintuitive properties of matter promises to yield revolutionary new approaches to computing, sensing, communication, and metrology, as well as far-reaching advances in our understanding of the world around us. A part of the FY 2019 BES funding for the NSRCs will be used to develop QIS related research infrastructure for materials synthesis, fabrication, metrology, modeling and simulation. The goal is to develop a flexible and enabling infrastructure so that U.S. institutions and industry can rapidly develop and commercialize the new discoveries and innovations.

Other Project Costs

The total project cost (TPC) of DOE's construction projects is comprised of two major components—the total estimated cost (TEC) and other project costs (OPC). The TEC includes project costs incurred after Critical Decision-1, such as costs associated with all engineering design and inspection; the acquisition of land and land rights; direct and indirect construction/fabrication; the initial equipment necessary to place the facility or installation in operation; and facility construction costs and other costs specifically related to those construction efforts. OPC represents all other costs related to the projects that are not included in the TEC, such as costs that are incurred during the project's initiation and definition phase for planning, conceptual design, research, and development, and those incurred during the execution phase for R&D, startup, and commissioning. OPC is always funded via operating funds.

Major Items of Equipment

BES supports major item of equipment (MIE) projects to ensure the continual development and upgrade of major scientific instrument capabilities, including fabricating new x-ray and neutron experimental stations, improving core facilities, and providing new stand-alone instruments. In general, each MIE with a total project cost greater than $5,000,000 and all line item construction projects follow the DOE Project Management Order 413.3B, which requires formal reviews to obtain critical decisions that advance the developmental stages of a project. Additional reviews may be required depending on the complexity and needs of the projects in question.

Research

This activity supports targeted basic research in accelerator physics, x-ray and neutron detectors, and developments of advanced x-ray optics. Accelerator research is the cornerstone for the development of new technologies that will improve performance of accelerator-based light sources and neutron scattering facilities. Research areas include ultrashort pulse free electron lasers (FELs), new seeding techniques and other optical manipulation to reduce the cost and complexity and improve performance of next generation FELs, and development of intense laser-based THz sources to study non-equilibrium behavior in complex materials. Detector research is a crucial component to enable the optimal utilization of user facilities, together with the development of innovative optics instrumentation to advance photon-based sciences, and data management techniques. The emphasis of the detector activity is on research leading to new and more efficient photon and neutron detectors. X-ray optics research involves development of systems for time-resolved x-ray science that preserve the spatial, temporal, and spectral properties of x-rays. Research includes studies on creating, manipulating, transporting, and performing diagnostics of ultrahigh brightness beams and developing ultrafast electron diffraction systems that complement the capabilities of x-ray FELs. This activity also includes research in sophisticated data management tools to address the vastly accelerated pace and volume of data generated by faster, higher resolution detectors and brighter light sources. This activity also supports training in the field of particle beams and their associated accelerator technologies.

This activity also includes long term surveillance and maintenance (LTSM) responsibilities and legacy cleanup work at BNL and SLAC. The BES commitment for LTSM ends in FY 2018. No funding is requested in FY 2019.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Scientific User Facilities $992,732,000	**$946,690,000**	**-$46,042,000**
X-Ray Light Sources $489,059,000	**$491,059,000**	**+$2,000,000**
Funding supported near optimal operations of the five BES light sources. The light sources supported over 11,000 users in FY 2017. In addition, $5M was appropriated for R&D in support of the Advanced Light Source Upgrade.	LCLS operations will continue in preparation for completion of the LCLS-II project and in support of the BES priority in ultrafast science. To allow installation activities for the LCLS-II construction project to proceed, LCLS will be shut down for one year, starting around 2Q FY 2019. During the shutdown, LCLS will continue to maintain critical systems, advance linac remediation activities, and develop new instruments and capabilities for experiments. APS, ALS, NSLS-II and SSRL operations will continue at 95% of optimum.	The increase supports LCLS operations in preparation for completion of the LCLS-II project and in support of the BES priority in ultrafast science.
High-Flux Neutron Sources $266,000,000	**$265,000,000**	**-$1,000,000**
Funding supported the operation of HFIR and SNS at near optimal levels. The neutron facilities supported over 1,200 users in FY 2017. Limited funding was provided to the Lujan Neutron Scattering Center for the disposition of unused equipment.	SNS and HFIR operations will continue at 95% of optimum. No funding is requested for the Lujan Neutron Scattering Center for the disposition of unused equipment.	No funding is requested for the disposition of unused equipment at the Lujan Neutron Scattering Center.
Nanoscale Science Research Centers $122,272,000	**$122,272,000**	**$0**
Funding supported operations at the five BES NSRCs at near optimal levels. The NSRCs continued to expand the user base from universities, national laboratories, and industry. In FY 2017, the NSRCs supported over 3,300 users.	All five NSRCs will be supported, with part of the funding designated for tool development for QIS.	No change.

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Other Project Costs $5,000,000	**$10,100,000**	**+$5,100,000**
OPC funds were appropriated by Congress for the Advanced Light Source Upgrade (ALS-U) project.	Funds are requested for Other Project Costs for the LCLS-II project at SLAC National Accelerator Laboratory, ALS-U at Argonne National Laboratory, and LCLS-II-HE at SLAC per the project plans.	Other Project Costs increase according to the project plans.
Major Items of Equipment $42,500,000	**$0**	**-$42,500,000**
The Advanced Photon Source Upgrade (APS-U) project continued with R&D, engineering design, prototyping, fabrication, and long lead and advance procurements of critical systems.	APS-U was proposed to be transitioned from a Major Item of Equipment (MIE) to a separate line item construction project in the FY 2018 Request. No MIE funds are requested in this program in FY 2019.	APS-U is included as a separate line-item construction project in the FY 2019 Request.
Research $34,618,000	**$25,000,000**	**-$9,618,000**
Research funding for the scientific user facilities continued to support selected, high-priority research activities for detectors and optics. Funding continued for long term surveillance and maintenance activities at BNL and SLAC.	The Request will support limited high-priority research activities for detectors and optics instrumentation. The BES commitment for long term surveillance and maintenance at BNL and SLAC ends in FY 2018. No funding is requested for these activities in FY 2019.	No funding is requested for long term surveillance and maintenance.
SBIR/STTR $33,283,000	**$33,259,000**	**-$24,000**
In FY 2017, SBIR/STTR funding was set at 3.65% of non-capital funding.	In FY 2019, SBIR/STTR funding is set at 3.65% of non-capital funding.	

Basic Energy Sciences
Construction

Description
Reactor-based neutron sources, accelerator-based x-ray light sources, and accelerator-based pulsed neutron sources are essential user facilities that enable critical DOE mission-driven science. These user facilities provide the academic, laboratory, and industrial research communities with the tools to fabricate, characterize, and develop new materials and chemical processes to advance basic and applied research, advancing chemistry, physics, earth science, materials science, environmental science, biology, and biomedical science. Regular investments in construction of new user facilities and upgrades to existing user facilities are essential to maintaining U.S. leadership in these research areas.

The **Linac Coherent Light Source-II (LCLS-II)** project will provide a second source of electrons at LCLS by constructing a 4 GeV, high repetition rate, superconducting linear accelerator in addition to adding two new variable gap undulators to generate an unprecedented high-repetition-rate free-electron laser. This new x-ray source will solidify the LCLS complex as the world leader in ultrafast x-ray science for decades to come. The project received approval for CD-2, Approve Performance Baseline, and CD-3, Approve Start of Construction, on March 21, 2016, establishing a Total Project Cost (TPC) of $1,045,000,000 and a CD-4, Project Completion date of June 30, 2022.

The **Advanced Photon Source Upgrade (APS-U)** project will provide scientists with an x-ray source possessing world-leading transverse coherence and extreme brightness. The magnetic lattice of the APS storage ring will be upgraded to a multi-bend achromat configuration to provide 100-1000 times increased brightness and coherent flux. APS-U will ensure that the APS remains a world leader in hard x-ray science.

Critical Decision-3B, Approve Long-Lead Procurements, was approved for APS-U on October 6, 2016, authorizing long lead and advanced procurements for accelerator components and associated systems. The project has a TPC range of $700,000,000 - $1,000,000,000 and TPC point estimate of $770,000,000. The proposed CD-4, Approve Project Completion, is FY 2026.

The **Advanced Light Source Upgrade (ALS-U)** project will upgrade the existing Advanced Light Source facility by replacing the existing electron storage ring with a new electron storage ring based on a multi-bend achromat lattice design which will provide a soft x-ray source that is brighter, up to 1000 times greater brightness, and with a significantly higher coherent flux fraction. ALS-U will leverage two decades of investments in scientific tools at the ALS by making use of the existing beamlines and infrastructure. ALS-U will ensure that the ALS facility remains a world leader in soft x-ray science. Critical Decision-0 (CD-0), Approve Mission Need, was approved for ALS-U on September 27, 2016. The preliminary TPC range, based on early concepts under consideration, is $260,000,000 - $420,000,000.

The **Linac Coherent Light Source-II-HE (LCLS-II-HE)** project will increase the energy of the superconducting linac currently under construction as part of the LCLS-II project from 4 GeV to 8 GeV and thereby expand the high rep rate operation (1 million pulses per second) of this unique FEL into the hard x-ray regime (5-12 keV). LCLS-II-HE will add new and upgraded instrumentation to augment existing capabilities and upgrade the facility infrastructure as needed. The LCLS-II-HE project will upgrade and expand the capabilities of the LCLS-II to maintain U.S. leadership in ultrafast x-ray science. Critical Decision-0 (CD-0), Approve Mission Need, was approved for LCLS-II-HE on December 15, 2016. The preliminary TPC range, based on early concepts under consideration, is $260,000,000 - $450,000,000.

All BES construction projects are conceived and planned with the scientific community, adhere to the highest standards of safety, and are executed on schedule and within cost through best practices in project management. In accordance with DOE Order 413.3B, each project is closely monitored and must perform within 10% of the cost and schedule performance baselines, established at Critical Decision 2, Approve Performance Baseline, which are reproduced in the construction project data sheet.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Construction $190,000,000	**$214,300,000**	**+$24,300,000**
Linac Coherent Light Source-II (LCLS-II) $190,000,000	**$139,300,000**	**-$50,700,000**
FY 2017 funding supported critical procurement of materials and equipment needed to maintain the project schedule and expand the construction efforts. Design, long lead and advance procurements, R&D, prototyping, site preparation activities, fabrication, and installation also continued in FY 2017.	FY 2019 funding will be used for installation of major accelerator and x-ray systems and facilities including the linear accelerator and its cryogenic refrigeration facilities, electron beam transport, undulator x-ray sources, x-ray optics and experimental systems and supporting infrastructure.	Funding for the LCLS-II construction project decreases per the project plan. FY 2019 will be the last year of funding for the project.
Advanced Photon Source Upgrade (APS-U) $0	**$60,000,000**	**+$60,000,000**
APS-U was included as a Major Item of Equipment project in FY 2017.	The FY 2018 Request proposed to transition APS-U from a MIE to a line item construction project. FY 2019 funding will be used for targeted R&D, engineering design, equipment prototyping, testing, fabrication, site preparation, installation, and long lead and advance procurements.	The Request continues funding for the APS-U construction project.
Advanced Light Source Upgrade (ALS-U) $0	**$10,000,000**	**+$10,000,000**
N/A	FY 2019 funding will be used for R&D, engineering design, equipment prototyping, testing and other activities required to advance the ALS-U project.	This is the first request for the ALS-U project.
Linac Coherent Light Source-II High Energy (LCLS-II-HE) $0	**$5,000,000**	**+$5,000,000**
N/A	FY 2019 funding will be used for R&D, engineering design, equipment prototyping, testing and other activities required to advance the LCLS-II-HE project.	This is the first request for the LCLS-II-HE project.

Basic Energy Sciences
Performance Measures

In accordance with the GPRA Modernization Act of 2010, the Department sets targets for, and tracks progress toward, achieving performance goals for each program.

	FY 2017	FY 2018	FY 2019
Performance Goal (Measure)	**BES Construction/MIE Cost & Schedule - Cost-weighted mean percentage variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects**		
Target	< 10 %	< 10 %	< 10 %
Result	Met	TBD	TBD
Endpoint Target	Adhering to the cost and schedule baselines for a complex, large scale, science project is critical to meeting the scientific requirements for the project and for being good stewards of the taxpayers' investment in the project.		
Performance Goal (Measure)	**BES Energy Storage - Deliver two high-performance research energy storage prototypes for transportation and the grid that project at the battery pack level to be five times the energy density at 1/5 the cost of the 2011 commercial baseline.**		
Target	Develop and demonstrate energy storage research prototypes that are scalable for transportation and grid applications using concepts beyond lithium ion (multivalent ions, chemical transformation, and non-aqueous redox flow), as identified through materials discovery and techno-economic modeling.	N/A	N/A
Result	Met	N/A	N/A
Endpoint Target	Three specific outcomes: 1) A library of the fundamental science of the materials and phenomena of energy storage at atomic and molecular levels; 2) two prototypes, one for transportation and one for the electricity grid, that, when scaled up to manufacturing, have the potential to meet the Joint Center for Energy Storage Research's (JCESR) 5-5-5 goals; 3) A new paradigm for battery R&D that integrates discovery science, battery design, research prototyping and manufacturing collaboration in a single highly interactive organization.		
Performance Goal (Measure)	**BES Facility Operations - Average achieved operation time of BES user facilities as a percentage of total scheduled annual operation time**		
Target	≥ 90 %	≥ 90 %	≥ 90 %
Result	Met	TBD	TBD

	FY 2017	FY 2018	FY 2019
Endpoint Target	Many of the research projects that are undertaken at the Office of Science's scientific user facilities take a great deal of time, money, and effort to prepare and regularly have a very short window of opportunity to run. If the facility is not operating as expected the experiment could be ruined or critically setback. In addition, taxpayers have invested millions or even hundreds of millions of dollars in these facilities. The greater the period of reliable operations, the greater the return on the taxpayers' investment.		
Performance Goal (Measure)	**BES Research - Conduct discovery-focused research to increase our understanding of matter, materials and their properties**		
Target	N/A	Expand computational materials and chemical discovery through increased data production and additional online computational resources: add electronic properties data for 7,000 compounds, elastic properties data for 3,000 compounds and reaction energies for 5,000 catalytic reactions to publicly available databases; add new or expanded functionality to on-line, high performance computer software/codes for prediction of materials properties.	Expand computational materials and chemical discovery through increased data production and open source software: add 2000 adsorption energies for chemicals in nanoporous materials to publically available databases; add new or expanded functionality to 10 online, high performance computer software/codes for prediction of materials and chemical properties.
Result	N/A	TBD	TBD
Endpoint Target	Understand, predict, and ultimately control matter and energy at the electronic, atomic, and molecular levels		

Basic Energy Science
Capital Summary ($K)

	Total	Prior Years	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Capital Operating Expenses Summary						
Capital Equipment	n/a	n/a	60,188	—	24,500	-35,688
General Plant Projects (GPP)	n/a	n/a	4,005	—	1,000	-3,005
Accelerator Improvement Projects (AIP)	n/a	n/a	7,000	—	11,000	+4,000
Total, Capital Operating Expenses	**n/a**	**n/a**	**71,193**	—	**36,500**	**-34,693**
Capital Equipment						
Major Items of Equipment						
Advanced Photon Source Upgrade (APS-U), ANL (TPC TBD)[b]	151,000	108,500	42,500	—	0	-42,500
Linac Coherent Light Source-II (LCLS-II), SLAC[c,d]	85,600	85,600	0	—	0	0
NSLS-II Experimental Tools (NEXT), BNL (TPC $90,000)	90,000	90,000	0	—	0	0
Total, Major Items of Equipment	n/a	n/a	42,500	—	0	-42,500
Total, Non-MIE Capital Equipment	n/a	n/a	17,688	—	24,500	+6,812
Total, Capital equipment	**n/a**	**n/a**	**60,188**	—	**24,500**	**-35,688**
General Plant Projects (GPP)						
Other general plant projects under $5 million TEC	n/a	n/a	4,005	—	1,000	-3,005
Accelerator Improvement Projects (AIP)						
Accelerator improvement projects under $5 million TEC	n/a	n/a	7,000	—	11,000	+4,000

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).
[b] APS-U is requested as a line item construction project beginning in FY 2018.
[c] LCLS-II is requested as a line item construction project beginning in FY 2014.
[d] LCLS-II received $85,600,000 in FY 2010–FY 2013 as an MIE.

Construction Projects Summary ($K)

	Total	Prior Years	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
13-SC-10, Linac Coherent Light Source-II (LCLS-II), SLAC						
TEC	993,100	343,000	190,000	188,710	139,300	-50,700
OPC	51,900	28,600	0	7,900	6,100	+6,100
TPC	**1,045,000**	**371,600**[b]	**190,000**	**196,610**	**145,400**	**-44,600**
18-SC-10, Advanced Photon Source Upgrade (APS-U), ANL						
TEC	770,000	0	0	—	60,000	+60,000
OPC	0	0	0	—	0	0
TPC	**770,000**	**0**[c]	0	—	**60,000**	**+60,000**
19-SC-10, Advanced Light Source Upgrade (ALS-U), LBNL						
TEC	282,000	0	0	—	10,000	+10,000
OPC	38,000	5,000	5,000	—	2,000	-3,000
TPC	**320,000**	**5,000**	**5,000**	—	**12,000**	**+7,000**
19-SC-11, Linac Coherent Light Source-II-HE (LCLS-II-HE), SLAC						
TEC	300,000	0	0	—	5,000	+5,000
OPC	20,000	0	0	—	2,000	+2,000
TPC	**320,000**	0	0	—	**7,000**	**+7,000**
Total, Construction						
TEC	n/a	n/a	190,000	188,710	214,300	+24,300
OPC	n/a	n/a	5,000	7,900	10,100	+5,100
TPC	**n/a**	**n/a**	**195,000**	**196,610**	**224,400**	**+29,400**

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

[b] LCLS-II received $85,600,000 in FY 2010-FY 2013 as an MIE.

[c] APS-U received $151,000,000 in FY 2010-FY 2017 as an MIE.

Funding Summary ($K)

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Research	755,669	—	746,269	-9,400
Scientific User Facilities Operations	877,331	—	878,331	+1,000
Projects				
Major Items of Equipment	42,500	—	0	-42,500
Construction Projects (includes OPC)	195,000	—	224,400	+29,400
Total Projects	237,500	—	224,400	-13,100
Other[b]	1,000	—	1,000	0
Total, Basic Energy Sciences	**1,871,500**	**1,858,791**	**1,850,000**	**-21,500**

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

[b] Includes non-Facility related GPP.

Scientific User Facility Operations ($K)

The treatment of user facilities is distinguished between two types: TYPE A facilities that offer users resources dependent on a single, large-scale machine; TYPE B facilities that offer users a suite of resources that is not dependent on a single, large-scale machine.

Definitions:
Achieved Operating Hours – The amount of time (in hours) the facility was available for users.
Planned Operating Hours –

- For Past Fiscal Year (PY), the amount of time (in hours) the facility was planned to be available for users.
- For Current Fiscal Year (CY), the amount of time (in hours) the facility is planned to be available for users.
- For the Budget Fiscal Year (BY), based on the proposed budget request the amount of time (in hours) the facility is anticipated to be available for users.

Optimal Hours – The amount of time (in hours) a facility would be available to satisfy the needs of the user community if unconstrained by funding levels.

Percent of Optimal Hours – An indication of utilization effectiveness in the context of available funding; it is not a direct indication of scientific or facility productivity.

- For BY and CY, Planned Operating Hours divided by Optimal Hours expressed as a percentage.
- For PY, Achieved Operating Hours divided by Optimal Hours.

Unscheduled Downtime Hours - The amount of time (in hours) the facility was unavailable to users due to unscheduled events. NOTE: For type “A” facilities, zero Unscheduled Downtime Hours indicates Achieved Operating Hours equals Planned Operating Hours.

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
TYPE A FACILITIES				
Advanced Light Source	**$64,950**	—	**$64,950**	**$0**
Number of Users	2,129	—	2,000	-129
Achieved operating hours	4,587	—	N/A	N/A
Planned operating hours	4,900	—	4,850	-50
Optimal hours	5,300	—	5,300	0
Percent optimal hours	86.5%	—	91.5%	N/A
Unscheduled downtime hours	<10%	—	<10%	N/A

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Advanced Photon Source	**$133,995**	—	**$133,995**	**$0**
Number of Users	5,742	—	5,400	-342
Achieved operating hours	4,936	—	N/A	N/A
Planned operating hours	5,000	—	4,900	-100
Optimal hours	5,000	—	5,000	0
Percent optimal hours	98.7%	—	98.0%	N/A
Unscheduled downtime hours	<10%	—	<10%	N/A
National Synchrotron Light Source-II, BNL	**$111,834**	—	**$111,834**	**$0**
Number of Users	1,037	—	1,100	+63
Achieved operating hours	4,402	—	N/A	N/A
Planned operating hours	4,500	—	4,750	+250
Optimal hours	4,700	—	5,000	+300
Percent optimal hours	93.7%	—	95.0%	N/A
Unscheduled downtime hours	<10%	—	<10%	N/A
Stanford Synchrotron Radiation Lightsource	**$41,986**	—	**$41,986**	**$0**
Number of Users	1,729	—	1,500	-229
Achieved operating hours	5,169	—	N/A	N/A
Planned operating hours	5,100	—	5,000	-100
Optimal hours	5,400	—	5,400	0
Percent optimal hours	95.7%	—	92.6%	N/A
Unscheduled downtime hours	<10%	—	<10%	N/A

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Linac Coherent Light Source	**$136,294**	—	**$138,294**	**+$2,000**
Number of Users	766	—	250	-516
Achieved operating hours	3,212	—	N/A	N/A
Planned operating hours	3,000	—	1,350	-1,650
Optimal hours	3,100	—	1,400[b]	-1,700
Percent optimal hours	103.6%	—	96.4%	N/A
Unscheduled downtime hours	<10%	—	<10%	N/A
High Flux Isotope Reactor	**$65,000**	—	**$65,000**	**$0**
Number of Users	511	—	460	-51
Achieved operating hours	4,165	—	N/A	N/A
Planned operating hours	3,900	—	3,750	-150
Optimal hours	4,000	—	4,000	0
Percent optimal hours	104.1%	—	93.8%	N/A
Unscheduled downtime hours	<10%	—	<10%	N/A
Lujan Neutron Scattering Center	**$1,000**	—	**$0**	**-$1,000**
Achieved operating hours	N/A	—	N/A	N/A
Planned operating hours	0	—	0	N/A
Optimal hours	0	—	0	0
Percent optimal hours	N/A	—	N/A	N/A
Unscheduled downtime hours	N/A	—	N/A	N/A
Spallation Neutron Source	**$200,000**	—	**$200,000**	**$0**
Number of Users	764	—	780	+16
Achieved operating hours	4,807	—	N/A	N/A
Planned operating hours	4,800	—	4,750	-50
Optimal hours	5,000	—	5,000	0
Percent optimal hours	96.1%	—	95.0%	N/A
Unscheduled downtime hours	<10%	—	<10%	N/A

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).
[b] LCLS Optimal hours reduced in preparation for LCLS-II.

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
TYPE B FACILITIES				
Center for Nanoscale Materials	**$25,205**	—	**$25,205**	**$0**
Number of users	598	—	500	-98
Center for Functional Nanomaterials	**$21,418**	—	**$21,418**	**$0**
Number of users	571	—	500	-71
Molecular Foundry	**$28,406**	—	**$28,406**	**$0**
Number of users	866	—	600	-266
Center for Nanophase Materials Sciences	**$24,638**	—	**$24,638**	**$0**
Number of users	666	—	500	-166
Center for Integrated Nanotechnologies	**$22,605**	—	**$22,605**	**$0**
Number of users	614	—	500	-114
Total, All Facilities	**$877,331**	—	**$878,331**	**+$1,000**
Number of Users	15,993	—	14,090	-1,903
Achieved operating hours	31,278	—	N/A	N/A
Planned operating hours	31,200	—	29,350	-1,850
Optimal hours	32,500	—	31,100	-1,400
Percent of optimal hours	97.4%	—	95.3%	N/A
Unscheduled downtime hours	<10%	—	<10%	N/A

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

Scientific Employment

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Number of permanent Ph.D.'s (FTEs)	4,460	—	4,410	-50
Number of postdoctoral associates (FTEs)	1,180	—	1,200	20
Number of graduate students (FTEs)	1,810	—	1,870	60
Other[b]	2,900	—	2,810	-90

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

[b] Includes technicians, support staff, and similar positions.

13-SC-10, Linac Coherent Light Source-II
SLAC National Accelerator Laboratory, Menlo Park, California
Project is for Design and Construction

1. Significant Changes and Summary

Significant Changes

This Construction Project Data Sheet (CPDS) is an update of the FY 2018 CPDS and does not include a new start for the budget year. There are no significant changes to the project.

Summary

The FY 2019 Request for the Linac Coherent Light Source-II (LCLS-II) is $145,400,000, including $139,300,000 in Total Estimated Cost (TEC) funds and $6,100,000 in Other Project Costs (OPC) funds, consistent with the approved baseline funding profile. FY 2019 will be the last year of construction funding for the project. The most recent DOE Order 413.3B approved Critical Decisions (CD) are CD-2/3, (Approve Performance Baseline and Approve Start of Construction), which were approved on March 21, 2016.

A Federal Project Director, certified to level IV, has been assigned to this project and has approved this CPDS.

The LCLS-II project will construct a new high repetition rate electron injector and replace the first kilometer of the existing linac with a 4 GeV superconducting linac to create the electron beam required for x-ray production in the 0.2–5 keV range with a repetition rate near 1 MHz. The new electron beam will be transported to the existing undulator hall and will be capable of feeding either of the two new variable gap undulators. At the completion of the LCLS-II project, the facility will operate two independent electron linacs and two independent x-ray sources, supporting up to six experiment stations. A liquid helium refrigeration plant is required to cool the linac to superconducting temperatures and a building will be constructed to house the refrigeration plant equipment. Modifications to the existing experimental halls, beam transport and switchyard areas, and to the experimental equipment will be made as necessary to maximize the use of the new x-ray source.

FY 2017 funding supported critical procurement of materials and equipment needed to maintain the project schedule and expand the construction efforts. Design, long lead and advance procurements (LLP/APs), R&D, prototyping, site preparation activities, fabrication, and installation also continued in FY 2017. FY 2018 funding will support the completion of the major cryomodule and undulator production lines and the start of critical installation activities requiring the shutdown of the LCLS facility. Commissioning activities for some technical systems will begin in FY 2018. In addition, the design, LLP/APs, R&D, prototyping, site preparation activities, fabrication, installation, and testing activities will carry forward into FY 2019 and beyond until they have been completed. FY 2019 funding will be used to complete installation of all major accelerator and x-ray systems and facilities including the linear accelerator and its cryogenic refrigeration facilities, electron beam transport, undulator x-ray sources, x-ray optics, and experimental systems and supporting infrastructure.

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2013	4/22/2010		10/14/2011	1Q FY 2013	4Q FY 2016	3Q FY 2013	N/A	4Q FY 2019
FY 2014	4/22/2010		10/14/2011	4Q FY 2013	4Q FY 2016	4Q FY 2013	N/A	4Q FY 2019
FY 2015	4/22/2010		10/14/2011	4Q FY 2015	4Q FY 2017	4Q FY 2016	N/A	4Q FY 2021
FY 2016	4/22/2010	1/21/2014	8/22/2014	2Q FY 2016	4Q FY 2017	2Q FY 2016	N/A	4Q FY 2021
FY 2017	4/22/2010	1/21/2014	8/22/2014	2Q FY 2016	4Q FY 2017	2Q FY 2016	N/A	3Q FY 2022
FY 2018	4/22/2010	1/21/2014	8/22/2014	3/21/2016	4Q FY 2017	3/21/2016	N/A	6/30/2022
FY 2019	4/22/2010	1/21/2014	8/22/2014	3/21/2016	4Q FY 2018	3/21/2016	N/A	6/30/2022

CD-0 – Approve Mission Need for a construction project with a conceptual scope and cost range
Conceptual Design Complete – Actual date the conceptual design was completed (if applicable)
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
Final Design Complete – Estimated/Actual date the project design will be/was complete (d)
CD-3 – Approve Start of Construction
D&D Complete – Completion of D&D work
CD-4 – Approve Start of Operations or Project Closeout

	Performance Baseline Validation	CD-3A[a]	CD-3B
FY 2013	1Q FY 2013	3/14/2012	
FY 2014	4Q FY 2013	3/14/2012	
FY 2015	4Q FY 2015	3/14/2012	
FY 2016	2Q FY 2016	3/14/2012	3Q FY 2015
FY 2017	2Q FY 2016	3/14/2012	5/28/2015
FY 2018	3/21/2016	3/14/2012	5/28/2015
FY 2019	3/21/2016	3/14/2012	5/28/2015

CD-3A – Approve Long-Lead Procurements, Original Scope
CD-3B – Approve Long-Lead Procurements, Revised Scope

3. Project Cost History

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D	OPC, D&D	OPC, Total	TPC
FY 2013	18,000	367,000	385,000	20,000	N/A	20,000	405,000
FY 2014	18,000	367,000	385,000	20,000	N/A	20,000	405,000
FY 2015	47,000	799,400	846,400	48,600	N/A	48,600	895,000
FY 2016	47,000	869,400	916,400	48,600	N/A	48,600	965,000
FY 2017	47,000	946,100	993,100	51,900	N/A	51,900	1,045,000
FY 2018	47,000	946,100	993,100	51,900	N/A	51,900	1,045,000
FY 2019[b]	47,000	946,100	993,100	51,900	N/A	51,900	1,045,000

4. Project Scope and Justification

Scope
SLAC's advances in the creation, compression, transport, and monitoring of bright electron beams have spawned a new generation of x-ray radiation sources based on linear accelerators rather than on storage rings. The Linac Coherent Light Source (LCLS) produces a high-brightness x-ray beam with properties vastly exceeding those of current x-ray sources in three key areas: peak brightness, coherence, and ultrashort pulses. The peak brightness of the LCLS is 10 billion times greater than current synchrotrons, providing up to 10^{12} x-ray photons in a pulse with duration in the range of 3–500 femtoseconds. These characteristics of the LCLS have opened new realms of research in the chemical, material, and biological sciences. LCLS-II will build on the success of LCLS by expanding the spectral range of hard x-rays produced at the facility by adding a new high

[a] CD-3A was approved as part of the original project scope prior to the July 2013 BESAC recommendation. All original project scope long lead procurement work was suspended.
[b] Includes MIE funding of $7,000,000 for the design phase and $60,000,000 for the construction phase, which results in $67,000,000 of TEC funding, as well as $18,600,000 of OPC funding, for a total of $85,600,000 of MIE funding in the TPC.

repetition rate, spectrally tunable x-ray source. The repetition rate for x-ray production in the 0.2–5 keV range will be increased by at least a factor of 1,000 to yield unprecedented high average brightness x-rays that will be unique worldwide.

LCLS is based on the existing SLAC linear accelerator (linac), which is not a superconducting linac. The linac was originally designed to accelerate electrons and positrons to 50 GeV for colliding beam experiments and for nuclear and high energy physics experiments on fixed targets. It was later adapted for use as a free electron laser (FEL, the LCLS facility) and for advanced accelerator research. At present, the last third of the three kilometer linac is being used to operate the LCLS facility, and the first two kilometers are used for advanced accelerator research.

The revised scope of the LCLS-II project is based on the July 2013 Basic Energy Sciences Advisory Committee (BESAC) report and will construct a new high repetition rate electron injector and replace the first kilometer of the linac with a 4 GeV superconducting linac to create the electron beam required for x-ray production in the 0.2–5 keV range with a repetition rate near 1 MHz. The new electron beam will be transported to the existing undulator hall and will be capable of feeding either of the two new variable gap undulators. The revised project will require cryogenic cooling to operate the linac at superconducting temperatures. The increased cryogenic capacity will require increasing the cryogenic equipment building size to approximately 20,000 square feet.

The third kilometer of the linac will continue to produce 14 GeV electron bunches for hard x-ray production at a 120 Hz repetition rate. The electron bunches will be sent to both of the new undulators to produce two simultaneous x-ray beams. The x-ray beams will span a tunable photon energy range of 1 to 25 keV, beyond the range of the existing LCLS facility, and they will incorporate “self-seeding sections” to greatly enhance the longitudinal coherence of the x-ray beams. The middle kilometer of the existing linac will not be used as part of LCLS-II but will continue to be used for advanced accelerator research. It would be available for future expansion of the LCLS-II capabilities.

At the completion of the LCLS-II project, the facility will operate two independent electron linacs and two independent x-ray sources, supporting up to six experiment stations. Both the capability and capacity of the facility will be significantly enhanced. The combined characteristics (spectral content, peak power, average brightness, pulse duration, and coherence) of the new x-ray sources will surpass the present capabilities of the LCLS beam in spectral tuning range and brightness. The high repetition rate will accommodate more experiments. Furthermore, the two new undulators will be independently controlled to enable more experiments to be conducted simultaneously.

Experience with LCLS has, for the first time, provided data on performance of the x-ray instrumentation and optics required for scientific experiments with the LCLS. The LCLS-II project will take advantage of this knowledge base to design LCLS-II x-ray transport, optics, and diagnostics matched to the characteristics of these sources. The LCLS-II project scope is able to leverage the existing suite of LCLS instrumentation for characterization of the x-ray sources with moderate upgrades primarily to address the higher repetition rate operation.

The existing LCLS Beam Transport and Undulator Hall will be modified as necessary to house the new undulators, electron beam dumps, and x-ray optics. The existing experimental stations will be updated as necessary for the exploitation of the new x-ray sources. In contrast to the initial version of the project, construction of a new undulator tunnel and a new instrument suite will not be required.

The LCLS-II project developed strategic partnerships with other SC laboratories for the design, fabrication, installation, and commissioning of the new superconducting linear accelerator, the high repetition rate electron injector and the new variable gap undulators.

Prior to implementing the revised LCLS-II project, the original LCLS-II scope included construction of the Sector 10 Annex with a total cost of $8.2M. The construction costs are included in the Total Project Cost of $1,045M.

Justification
The LCLS-II project’s purpose is to expand the x-ray spectral operating range and the user capacity of the existing LCLS facility. The expanded spectral range will enable researchers to tackle new research frontiers. The capacity increase is

critically needed as the demand for LCLS capabilities far exceeds the available time allocation to users. In FY 2015, only about 20% of the experiment proposals received beam time. The addition of a second x-ray source will allow two or more experiments to be run simultaneously. The revised LCLS-II presented here is informed by the 2013 BESAC recommendations to provide "high repetition rate, ultra-bright, transform limited, femtosecond x-ray pulses over a broad photon energy (about 0.2–5 keV) with full spatial and temporal coherence" and the "linac should feed multiple independently tunable undulators each of which could have multiple endstations." Collectively, the project will enable groundbreaking research in a wide range of scientific disciplines in chemical, material and biological sciences.

Based on the factors described above, the most effective and timely approach for DOE to meet the Mission Need and realize the full potential of the LCLS is upgrading the existing x-ray free electron laser at SLAC with a new superconducting accelerator and x-ray sources.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, Program and Project Management for the Acquisition of Capital Assets.

Key Performance Parameters (KPPs)

The Threshold KPPs, represent the minimum acceptable performance that the project must achieve. Achievement of the Threshold KPPs will be a prerequisite for approval of CD-4, Project Completion. The Objective KPPs represent the desired project performance. If project performance is sustained and funds are available, the project will strive to attain the Objective KPPs.

Preliminary LCLS-II Key Performance Parameters

Performance Measure	Threshold	Objective
Variable gap undulators	2 (soft and hard x-ray)	2 (soft and hard x-ray)
Superconducting linac-based FEL system		
Superconducting linac electron beam energy	3.5 GeV	≥ 4 GeV
Superconducting linac repetition rate	93 kHz	929 kHz
Superconducting linac charge per bunch	0.02 nC	0.1 nC
Photon beam energy range	250–3,800 eV	200–5,000 eV
High repetition rate capable end stations	≥ 1	≥ 2
FEL photon quantity (10^{-3} BW[a])	$5x10^8$ (10x spontaneous @ 2,500 eV)	> 10^{11} @ 3,800 eV
Normal conducting linac-based system		
Normal conducting linac electron beam energy	13.6 GeV	15 GeV
Normal conducting linac repetition rate	120 Hz	120 Hz
Normal conducting linac charge per bunch	0.1 nC	0.25 nC
Photon beam energy range	1,000–15,000 eV	1,000–25,000 eV
Low repetition rate capable end stations	≥ 2	≥ 3
FEL photon quantity (10^{-3} BW[a])	10^{10} (lasing @ 15,000 eV)	> 10^{12} @ 15,000 eV

[a] Fractional bandwidth. The specified KPPs are the number of photons with an energy within 0.1% of the specified central value.

5. Preliminary Financial Schedule

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Total Estimated Cost (TEC)			
Design phase			
MIE funding			
FY 2012	2,000	2,000	2,000
FY 2013[b]	5,000	5,000	5,000
Total, MIE funding	7,000	7,000	7,000
Line item construction funding			
FY 2014	4,000	4,000	2,040
FY 2015	21,000	21,000	9,089
FY 2016	15,000	15,000	20,500
FY 2017	0	0	6,040
FY 2018	0	0	2,331
Total, Line item construction funding	40,000	40,000	40,000
Total, Design phase	47,000	47,000	47,000
Construction phase			
MIE funding			
FY 2012	42,500[c]	20,000	13,862
FY 2013[b]	17,500	40,000	33,423
FY 2014	0	0	12,256
FY 2015	0	0	455
FY 2016	0	0	0
FY 2017	0	0	4
Total, MIE funding	60,000	60,000	60,000
Line item construction funding			
FY 2014	71,700	71,700	16,673
FY 2015	117,700	117,700	65,442
FY 2016	185,300	185,300	125,476
FY 2017	190,000	190,000	226,933
FY 2018	182,100	182,100	270,000
FY 2019	139,300	139,300	180,000
FY 2020	0	0	1,576
Total, Line item construction funding	886,100	886,100	886,100
Total, Construction phase	946,100	946,100	946,100
TEC			
MIE funding			
FY 2012	44,500[c]	22,000	15,862
FY 2013[b]	22,500	45,000	38,423
FY 2014	0	0	12,256
FY 2015	0	0	455
FY 2016	0	0	0
FY 2017	0	0	4
Total, MIE funding	67,000	67,000	67,000

[a] Costs through FY 2017 reflect actual costs; costs for FY 2018 and the outyears are estimates.
[b] FY 2013 funding was requested as a line item, but due to a Continuing Resolution, FY 2013 funds were executed as an MIE.
[c] FY 2012 funding shown includes $22,500,000 of prior year balances from FY 2012 that was reallocated to the LCLC-II project during FY 2013.

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Line item construction funding			
FY 2014	75,700	75,700	18,713
FY 2015	138,700	138,700	74,531
FY 2016	200,300	200,300	145,976
FY 2017	190,000	190,000	232,973
FY 2018	182,100	182,100	272,331
FY 2019	139,300	139,300	180,000
FY 2020	0	0	1,576
Total, Line item construction funding	926,100	926,100	926,100
Total, TEC[b]	993,100	993,100	993,100
Other Project Cost (OPC)			
OPC except D&D			
MIE funding			
FY 2010	1,126	1,126	938
FY 2011	9,474	9,474	8,033
FY 2012	8,000	8,000	8,893
FY 2013[c]	0	0	116
FY 2014	0	0	439
FY 2015	0	0	10
FY 2016	0	0	0
FY 2017	0	0	0
FY 2018	0	0	171
Total, MIE funding	18,600	18,600	18,600
Line item construction funding			
FY 2014	10,000	10,000	8,142
FY 2015	9,300	9,300	2,650
FY 2016	0	0	34
FY 2017	0	0	758
FY 2018	7,900	7,900	12,000
FY 2019	6,100	6,100	9,000
FY 2020	0	0	716
Total, Line item construction funding	33,300	33,300	33,300
Total, OPC	51,900	51,900	51,900
Total Project Cost (TPC)			
MIE funding			
FY 2010	1,126	1,126	938
FY 2011	9,474	9,474	8,033
FY 2012	52,500	30,000	24,755
FY 2013[c]	22,500	45,000	38,539
FY 2014	0	0	12,695
FY 2015	0	0	465
FY 2016	0	0	0
FY 2017	0	0	4
FY 2018	0	0	171
Total, MIE funding	85,600	85,600	85,600

[a] Costs through FY 2017 reflect actual costs; costs for FY 2018 and the outyears are estimates.
[b] Amounts shown include MIE funding of $67,000,000 in the TEC, $18,600,000 in the OPC, and $85,600,000 in the TPC.
[c] FY 2013 funding was requested as a line item, but due to a Continuing Resolution, FY 2013 funds were executed as an MIE.

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Line item construction funding			
FY 2014	85,700	85,700	26,855
FY 2015	148,000	148,000	77,181
FY 2016	200,300	200,300	146,010
FY 2017	190,000	190,000	233,731
FY 2018	190,000	190,000	284,331
FY 2019	145,400	145,400	189,000
FY 2020	0	0	2,292
Total, Line item construction funding	959,400	959,400	959,400
Total, TPC[b]	1,045,000	1,045,000	1,045,000

6. Details of Project Cost Estimate

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	43,200	42,400	42,125
Contingency	3,800	4,600	4,875
Total, Design	47,000	47,000	47,000
Construction			
Site Preparation	24,700	24,700	24,700
Equipment	776,112	692,742	678,205
Other Construction	58,500	58,500	58,500
Contingency	86,788	170,158	184,695
Total, Construction	946,100	946,100	946,100
Total, TEC[b]	993,100	993,100	993,100
Contingency, TEC	90,588	174,758	189,570
Other Project Cost (OPC)			
OPC except D&D			
Conceptual Planning	1,980	1,980	1,980
Conceptual Design	23,408	23,408	23,408
Research and Development	1,972	1,972	1,972
Start-Up	15,790	15,790	15,790
Contingency	8,750	8,750	8,750
Total, OPC	51,900	51,900	51,900
Contingency, OPC	8,750	8,750	8,750
Total, TPC[b]	1,045,000	1,045,000	1,045,000
Total, Contingency	99,338	183,508	198,320

[a] Costs through FY 2017 reflect actual costs; costs for FY 2018 and the outyears are estimates.
[b] Amounts shown include MIE funding of $67,000,000 in the TEC, $18,600,000 in the OPC, and $85,600,000 in the TPC.

7. **Schedule of Appropriations Requests**

(dollars in thousands)

Request		Prior Years	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	Outyears	Total
FY 2012	TEC	22,000	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
(MIE)	OPC	18,600	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
	TPC	40,600	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
FY 2013[a]	TEC	165,800	94,000	105,300	19,900	0	0	0	0	385,000
(MIE)	OPC	19,300	0	700	0	0	0	0	0	20,000
	TPC	185,100	94,000	106,000	19,900	0	0	0	0	405,000
FY 2014	TEC	162,000	122,500	100,500	0	0	0	0	0	385,000
	OPC	19,300	0	700	0	0	0	0	0	20,000
	TPC	181,300	122,500	101,200	0	0	0	0	0	405,000
FY 2015	TEC	142,700	138,700	204,000	185,100	156,000	19,900	0	0	846,400
	OPC	28,600	9,300	0	0	5,900	4,800	0	0	48,600
	TPC	171,300	148,000	204,000	185,100	161,900	24,700	0	0	895,000
FY 2016	TEC	142,700	138,700	200,300	189,100	176,000	69,600	0	0	916,400
	OPC	28,600	9,300	0	0	5,900	4,800	0	0	48,600
	TPC	171,300	148,000	200,300	189,100	181,900	74,400	0	0	965,000
FY 2017	TEC	142,700	138,700	200,300	190,000	192,100	129,300	0	0	993,100
	OPC	28,600	9,300	0	0	7,900	6,100	0	0	51,900
	TPC	171,300	148,000	200,300	190,000	200,000	135,400	0	0	1,045,000
FY 2018	TEC	142,700	138,700	200,300	199,919	182,100	129,381	0	0	993,100
	OPC	28,600	9,300	0	0	7,900	6,100	0	0	51,900
	TPC	171,300	148,000	200,300	199,919	190,000	135,481	0	0	1,045,000
FY 2019	TEC	142,700	138,700	200,300	190,000	182,100	139,300	0	0	993,100
	OPC	28,600	9,300	0	0	7,900	6,100	0	0	51,900
	TPC	171,300	148,000	200,300	190,000	190,000	145,400	0	0	1,045,000

8. **Related Operations and Maintenance Funding Requirements**

Start of Operation or Beneficial Occupancy (fiscal quarter or date)	4Q FY 2021
Expected Useful Life (number of years)	25
Expected Future Start of D&D of this capital asset (fiscal quarter)	4Q FY 2046

(Related Funding Requirements)

	Annual Costs		Life Cycle Costs	
	Current Total Estimate	Previous Total Estimate	Current Total Estimate	Previous Total Estimate
Operations and Maintenance	$38.6M	$38.6M	$1,317.0M	$1,317.0M

The numbers presented are the incremental lifecycle operations and maintenance costs above the existing LCLS. The estimate will be updated as the project is executed.

[a] FY 2013 funding was requested as a line item, but due to a Continuing Resolution, FY 2013 funds were executed as an MIE.

9. D&D Information

The new area being constructed in this project is not replacing existing facilities.

	Square Feet
New area being constructed by this project at SLAC	~20,000
Area of D&D in this project at SLAC	0
Area at SLAC to be transferred, sold, and/or D&D outside the project including area previously "banked"	~20,000
Area of D&D in this project at other sites...	0
Area at other sites to be transferred, sold, and/or D&D outside the project including area previously "banked"	0
Total area eliminated	~20,000

Prior to implementing the revised LCLS-II project, the original LCLS-II scope included construction of the Sector 10 Annex. This facility is 2,275 ft^2 and was offset by demolition of a 1,630 ft^2 building with the balance offset using banked space. The information above reflects only the new construction associated with the revised project.

10. Acquisition Approach

DOE determined that the LCLS-II project was to be acquired by the SLAC National Accelerator Laboratory under the existing DOE M&O contract.

A Conceptual Design Report for the LCLS-II project was completed and was revised based on the new technical parameters. Key design activities, requirements, and high-risk subsystem components were identified to reduce cost and schedule risk to the project and expedite the startup. The necessary project management systems are fully up-to-date, operating, and are maintained as a SLAC-wide resource.

SLAC is partnering with other SC laboratories for design and procurement of key technical subsystem components. Technical system designs will require research and development activities. Preliminary cost estimates for these systems are based on actual costs from LCLS and other similar facilities, to the extent practicable. Recent cost data has been exploited fully in planning and budgeting for the project. Design of the technical systems will be completed by SLAC or partner laboratory staff. Technical equipment will either be fabricated in-house or subcontracted to vendors with the necessary capabilities.

All subcontracts will be competitively bid and awarded based on best value to the government. Project performance metrics for SLAC are included in the M&O contractor's annual performance evaluation and measurement plan.

Lessons learned from the LCLS Project and other similar facilities will be exploited fully in planning and executing LCLS-II.

18-SC-10, Advanced Photon Source-Upgrade
Argonne National Laboratory, Argonne, Illinois
Project is for Design and Construction

1. Significant Changes and Summary

Significant Changes
This Construction Project Data Sheet (CPDS) is an update of the FY 2018 CPDS and does not include a new start for the budget year. The FY 2018 CPDS included removal and installation of storage ring components in preparation for commissioning as part of Other Project Costs (OPC) in FY 2021-2023. These activities are properly classified as construction costs and included in Total Estimated Cost (TEC). The FY 2019 CPDS has been updated for this change. The preliminary estimate for Total Project Cost (TPC) of $770,000,000 is unchanged.

Summary
The FY 2019 Request for the Advanced Photon Source-Upgrade (APS-U) project is $60,000,000. The most recent DOE Order 413.3B approved Critical Decision, CD-3B (Approve Long-Lead Procurements), was approved on October 6, 2016. The project has a preliminary Total Project Cost (TPC) range of $700,000,000-$1,000,000,000 and TPC point estimate of $770,000,000. The proposed CD-4, Approve Project Completion, is FY 2026.

A Federal Project Director, certified to level IV, has been assigned to this project and has approved this CPDS.

The APS-U project will deliver a next-generation high-energy x-ray storage ring optimized for providing hard x-rays (>20 keV) to experiments. The APS-U project includes advanced beamlines, optics and detectors, and will result in narrow nano-focused x-ray beams ideal for imaging. This project includes the design and construction of the APS-U accelerator incorporating a multi-bend achromat (MBA) magnet lattice, insertion devices, front ends, beamlines/experimental stations, and any required modifications to the linac, booster, and radio frequency (RF) systems. APS-U will exceed the current APS performance by 2 to 3 orders of magnitude in brightness and coherent flux. The upgrade will provide brighter and more intense beams at all beamline locations and improved performance capabilities.

In FY 2017, APS-U continued with R&D, engineering design, pre-production prototyping, fabrication, and initiated long lead and advanced procurements (LLP/APs) of critical systems. In FY 2018 funding will support targeted R&D, engineering design, equipment prototyping, testing, fabrication, site preparation, installation, and additional LLP/APs. Planned activities for FY 2019 include targeted R&D, engineering design, equipment prototyping, testing, fabrication, site preparation, installation, and LLP/APs.

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2018	04/22/2010	09/18/2015	02/04/2016	1Q FY 2019	2Q FY 2020	4Q FY 2019	N/A	1Q FY 2026
FY 2019[a]	04/22/2010	09/18/2015	02/04/2016	2Q FY 2019	4Q FY 2021	1Q FY 2020	N/A	2Q FY 2026

CD-0 – Approve Mission Need for a construction project with a conceptual scope and cost range
Conceptual Design Complete – Actual date the conceptual design was completed (if applicable)
CD-1 – Approve Design Scope and Project Cost and Schedule Ranges
CD-2 – Approve Project Performance Baseline
Final Design Complete – Estimated/Actual date the project design will be/was complete(d)

[a] This project is pre-CD-2; the estimated cost and schedule are preliminary. Construction will not be executed without appropriate CD approvals.

CD-3 – Approve Start of Construction
D&D Complete – Completion of D&D work
CD-4 – Approve Project Completion

	Performance Baseline Validation	CD-3A	CD-3B
FY 2018	1Q FY 2019	8/30/2012	10/6/2016
FY 2019	2Q FY 2019	8/30/2012	10/6/2016

CD-3A – Approve Long-Lead Procurements for the Resonant Inelastic X-ray Scattering (RIXS) beamline.
CD-3B – Approve Long-Lead Procurements for accelerator components and associated systems.

3. Project Cost History

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D	OPC, D&D	OPC, Total	TPC
FY 2018	157,015	561,985	719,000	51,000	N/A	51,000	770,000
FY 2019[a]	167,000	590,100	757,100	12,900	N/A	12,900	770,000

4. Project Scope and Justification

Scope

There is a growing need to study materials under real conditions in real time through the use of groundbreaking scientific techniques. These techniques must provide the capability to observe, understand, and ultimately control the functions of materials down to the nanoscale and beyond with atomic resolution. To sustain U.S. leadership in this technology frontier, the U.S. Department of Energy's (DOE's) Office of Basic Energy Sciences (BES) will upgrade an existing hard x-ray synchrotron radiation facility to provide world-leading coherence and brightness at levels that are orders of magnitude higher than currently available. High-energy penetrating x-rays are critical for probing materials under real working environments, such as in a battery or fuel cell under load conditions.

By building capability on the existing APS facility, for significantly less than the replacement cost of the APS, the APS-U will provide a world-leading hard x-ray synchrotron radiation facility, which will be a unique asset in the U.S. portfolio of scientific user facilities. The APS-U is a critical and cost effective next step in the photon science strategy that will keep the U.S. at the forefront of scientific research, combining with other facilities to give the U.S. a complementary set of storage ring and free-electron laser x-ray light sources.

The APS-U project will upgrade the existing APS to provide scientists with an x-ray source possessing world-leading transverse coherence and extreme brightness. The APS-U project supports activities to develop, design, build, install, and test the equipment necessary to upgrade the APS, an existing third-generation synchrotron light source facility.

The APS-U project includes a new storage ring incorporating a MBA lattice utilizing the existing tunnel, new insertion devices optimized for brightness and flux, superconducting undulators for selected beamlines, new or upgraded front-ends, and any required modifications to the linac, booster, and RF systems. The MBA lattice will provide 100-1000 times increased brightness and coherent flux. The project will construct new beamlines and incorporate substantial refurbishment of existing beamlines, along with new optics and detectors that will enable the beamlines to take advantage of the improved accelerator performance. Two best-in-class beamlines require conventional civil construction to extend the beamlines beyond the existing APS Experimental Hall to achieve the desired nano-focused beam spot size.

[a] This project is pre-CD-2; the estimated cost and schedule are preliminary. Construction will not be executed without appropriate CD approvals.

With the ever increasing demand for higher penetration power for probing real world materials and applications, the high energy hard x-rays (20 keV and above) produced at APS provide unique capabilities in the suite of U.S. x-ray light sources that are a pre-requisite for tackling the grand science and energy challenges of the 21st Century. The APS-U will ensure that the APS remains a world leader in hard x-ray science.

Justification

The BES mission is to "support fundamental research to understand, predict, and ultimately control matter and energy at the electronic, atomic, and molecular levels in order to provide the foundations for new energy technologies and to support DOE missions in energy, environment, and national security." APS-U is in direct support of the DOE Strategic Plan, 2014-2018, Strategic Objective 3 which includes a strategy to "provide the nation's researchers with world-class scientific user facilities that enable mission-focused research and advance scientific discovery."

Worldwide investments in accelerator-based x-ray light source user facilities threaten U.S. leadership in light source technology within the next 6-10 years. The European Synchrotron Radiation Facility (ESRF) in France, PETRA-III in Germany, and SPring-8 in Japan are well into campaigns of major upgrades of beamlines and are also incorporating technological advancements in accelerator science to enhance performance. In 2015, China announced its intention to construct a next generation 6 GeV hard x-ray synchrotron light source.

The APS-U will upgrade the APS, by replacing the existing 20 year old storage ring with a MBA-based machine, and will provide a beam with a natural emittance that is orders of magnitude lower than what is currently available with third-generation light sources. With this investment and the current APS infrastructure, the APS-U will position the APS as the leading storage ring-based hard x-ray source in the U.S. for decades to come.

The high-energy penetrating x-rays will provide a unique scientific capability directly relevant to problems in energy, the environment, new and improved materials, and biological studies. The upgraded APS will complement the capabilities of x-ray free electron lasers (e.g., the Linac Coherent Light Source and Linac Coherent Light Source-II), which occupy different spectral, flux, and temporal range of technical specifications.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, Program and Project Management for the Acquisition of Capital Assets.

Key Performance Parameters (KPPs)

The threshold KPPs, which will define the official performance baseline at CD-2, Approve Project Performance Baseline, represent the minimum acceptable performance that the project must achieve. Achievement of the threshold KPPs will be a prerequisite for CD-4, Approve Project Completion. The objective KPPs represent the desired project performance. The KPPs presented here are preliminary and may change as the project continues towards CD-2. The final key parameters will be established as part of CD-2, Approve Project Performance Baseline.

Preliminary APS-U Key Performance Parameters

Performance Measure	Threshold	Objective
Storage Ring Energy	> 5.7 GeV, with systems installed for 6 GeV operation	6 GeV
Beam Current	> 25 mA in top-up with systems installed for 200 mA operation	200 mA in top-up
Horizontal Emittance	< 150 pm-rad	75 pm-rad
Brightness @ 20 keV[1]	> 2 x 10^{20}	2.5 x 10^{21}
Brightness @ 65 keV[2]	> 2 x 10^{19}	6 x 10^{20}
New MBA Beamlines	5	≥6

[1]Units = photons/sec/0.1% BW/mm^2/mrad^2; determined from a 2.75 cm period, 2.4 m long permanent magnet undulator

[2]Units = photons/sec/0.1% BW/mm^2/mrad^2; determined from a 1.6 cm period, 1.5 m long superconducting undulator

5. Preliminary Financial Schedule

	(dollars in thousands)		
	Appropriations	Obligations	Costs
Total Estimated Cost (TEC)			
Design phase			
MIE funding			
FY 2012	19,200	19,200	8,679
FY 2013	15,000	15,000	17,825
FY 2014	17,015	17,015	13,122
FY 2015	20,000	20,000	19,678
FY 2016	20,000	20,000	22,529
FY 2017	30,000	30,000	16,441
FY 2018	0	0	14,000
FY 2019	0	0	8,941
Total, MIE funding	121,215	121,215	121,215
Line item construction funding			
FY 2018	9,300	9,300	8,500
FY 2019	27,985	27,985	26,000
FY 2020	8,500	8,500	8,000
FY 2021	0	0	2,885
FY 2022	0	0	400
Total, Line item construction funding	45,785	45,785	45,785
Total, Design phase	167,000	167,000	167,000
Construction phase			
MIE funding			
FY 2012	800	800	416
FY 2013	5,000	5,000	3,391
FY 2014	2,985	2,985	4,301
FY 2015	0	0	677
FY 2016	0	0	0
FY 2017	12,500	12,500	7,046
FY 2018	0	0	5,454
Total, MIE funding	21,285	21,285	21,285
Line item construction funding			
FY 2018	10,700	10,700	9,500
FY 2019	32,015	32,015	31,515
FY 2020	141,500	141,500	130,600
FY 2021	159,780	159,780	150,000
FY 2022	133,100	133,100	125,500
FY 2023	91,720	91,720	82,000
FY 2024	0	0	26,000
FY 2025	0	0	13,700
Total, Line item construction funding	568,815	568,815	568,815
Total, Construction phase	590,100	590,100	590,100

	(dollars in thousands)		
	Appropriations	Obligations	Costs
TEC			
MIE funding			
FY 2012	20,000	20,000	9,095
FY 2013	20,000	20,000	21,216
FY 2014	20,000	20,000	17,423
FY 2015	20,000	20,000	20,355
FY 2016	20,000	20,000	22,529
FY 2017	42,500	42,500	23,487
FY 2018	0	0	19,454
FY 2019	0	0	8,941
Total, MIE funding	142,500	142,500	142,500
Line item construction funding			
FY 2018	20,000	20,000	18,000
FY 2019	60,000	60,000	57,515
FY 2020	150,000	150,000	138,600
FY 2021	159,780	159,780	152,885
FY 2022	133,100	133,100	125,900
FY 2023	91,720	91,720	82,000
FY 2024	0	0	26,000
FY 2025	0	0	13,700
Total, Line item construction funding	614,600	614,600	614,600
Total, TEC	757,100	757,100	757,100
Other Project Cost (OPC)			
OPC except D&D			
MIE funding			
FY 2010	1,000	1,000	587
FY 2011	7,500	7,500	3,696
FY 2012	0	0	4,217
Total MIE funding	8,500	8,500	8,500
Line item construction funding			
FY 2022	2,200	2,200	2,000
FY 2023	2,200	2,200	2,000
FY 2024	0	0	400
Total, Line item construction funding	4,400	4,400	4,400
Total, OPC	12,900	12,900	12,900

	(dollars in thousands)		
	Appropriations	Obligations	Costs
Total Project Cost (TPC)			
MIE funding			
FY 2010	1,000	1,000	587
FY 2011	7,500	7,500	3,696
FY 2012	20,000	20,000	13,312
FY 2013	20,000	20,000	21,216
FY 2014	20,000	20,000	17,423
FY 2015	20,000	20,000	20,355
FY 2016	20,000	20,000	22,529
FY 2017	42,500	42,500	23,487
FY 2018	0	0	19,454
FY 2019	0	0	8,941
Total, MIE funding	151,000	151,000	151,000
Line item construction funding			
FY 2018	20,000	20,000	18,000
FY 2019	60,000	60,000	57,515
FY 2020	150,000	150,000	138,600
FY 2021	159,780	159,780	152,885
FY 2022	135,300	135,300	127,900
FY 2023	93,920	93,920	84,000
FY 2024	0	0	26,400
FY 2025	0	0	13,700
Total, Line item construction funding	619,000	619,000	619,000
Total, TPC	770,000	770,000	770,000

6. Details of Project Cost Estimate

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	157,150	151,375	N/A
Contingency	9,850	5,640	N/A
Total, Design	167,000	157,015	N/A
Construction			
Equipment	426,420	395,625	N/A
Other Construction	14,680	12,700	N/A
Contingency	149,000	153,660	N/A
Total, Construction	590,100	561,985	N/A
Total, TEC	757,100	719,000	N/A
Contingency, TEC	158,850	159,300	N/A

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Other Project Cost (OPC)			
OPC except D&D			
Conceptual Planning	1,000	1,000	N/A
Conceptual Design	7,500	7,500	N/A
Start-Up	3,250	31,800	N/A
Contingency	1,150	10,700	N/A
Total, OPC	12,900	51,000	N/A
Contingency, OPC	1,150	10,700	N/A
Total, TPC	770,000	770,000	N/A
Total, Contingency	160,000	170,000	N/A

7. Schedule of Appropriations Requests

(dollars in thousands)

Request		Prior Years	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	Outyears	Total
FY 2018	TEC	80,000	20,000	42,500	20,000	81,772	152,419	160,000	162,309	719,000
	OPC	8,500	0	0	0	0	0	5,000	37,500	51,000
	TPC	88,500	20,000	42,500	20,000	81,772	152,419	165,000	199,809	770,000
FY 2019[a]	TEC	80,000	20,000	42,500	20,000	60,000	150,000	159,780	224,820	757,100
	OPC	8,500	0	0	0	0	0	0	4,400	12,900
	TPC	88,500	20,000	42,500	20,000	60,000	150,000	159,780	229,220	770,000

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy (fiscal quarter or date)	2Q FY 2026
Expected Useful Life (number of years)	25
Expected Future Start of D&D of this capital asset (fiscal quarter)	2Q FY 2051

(Related Funding Requirements)

	Annual Costs		Life Cycle Costs	
	Current Total Estimate	Previous Total Estimate	Current Total Estimate	Previous Total Estimate
Operations and Maintenance	$12M	N/A	$300M	N/A

The numbers presented are the incremental lifecycle operations and maintenance costs above the existing APS. The estimate will be updated and additional details will be provided after CD-2, Approve Project Performance Baseline.

[a] This project has not yet received CD-2 approval; funding and cost estimates are preliminary.

9. D&D Information

	Square Feet
New area being constructed by this project at ANL	7,000-10,000
Area of D&D in this project at ANL	0
Area at ANL to be transferred, sold, and/or D&D outside the project including area previously "banked"	7,000-10,000
Area of D&D in this project at other sites...	0
Area at other sites to be transferred, sold, and/or D&D outside the project including area previously "banked"	0
Total area eliminated	0

Approximately 7,000-10,000 square feet of new construction is needed for the 2 beamlines extending beyond the current APS experimental facility.

10. Acquisition Approach

The APS-U project will be acquired by the Argonne National Laboratory (ANL) under the existing DOE M&O contract between DOE and UChicago Argonne, LLC, which operates ANL. The acquisition of equipment and systems for large research facilities is within the scope of the DOE contract for the management and operations of ANL and consistent with the general expectation of the responsibilities of DOE M&O contractors.

ANL will have prime responsibility for oversight of all contracts required to execute this project which will include managing the design and construction of the APS-U accelerator incorporating a MBA magnet lattice, insertion devices, front ends, beamlines/experimental stations, and any required modifications to the linac, booster, and RF systems. ANL has established an APS-U project organization with project management, procurement management, and ES&H management with staff qualified to specify, select and oversee procurement and installation of the accelerator and beamline components and other technical equipment. These items will be procured from a variety of sources, depending on the item. Procurements will be competitively bid on a 'best value' basis following all applicable ANL procurement requirements. The APS-U project will most likely be accomplished using the design-bid-fabricate method. This proven approach provides the project with direct control over the accelerator components and beamline design, equipment specification and selection, and all contractors.

19-SC-10, Advanced Light Source Upgrade
Lawrence Berkeley National Laboratory, Berkeley, California
Project is for Design and Construction

1. Significant Changes and Summary

Significant Changes

This Construction Project Data Sheet (CPDS) is new and includes a new start for the budget year.

Summary

The FY 2019 Request for the Advanced Light Source Upgrade (ALS-U) project is $12,000,000, including $10,000,000 in Total Estimated Cost (TEC) funds and $2,000,000 in Other Project Costs (OPC) funds. The most recent DOE Order 413.3B approved Critical Decisions (CD) is CD-0 (Approve Mission Need), approved September 27, 2016. The preliminary total project cost (TPC) range, based on early concepts under consideration, is $260,000,000 - $420,000,000.

A Federal Project Director, certified to level III, has been assigned to this project and has approved this CPDS.

The ALS-U project will upgrade the existing ALS facility by replacing the existing electron storage ring with a new electron storage ring based on a multi-bend achromat lattice design to provide a soft x-ray source that is orders of magnitudes brighter—a 10-1000 times increase in brightness over the current ALS—and to provide a significantly higher fraction of coherent light in the soft x-ray region (~50-2,000 eV) than is currently available at ALS. With an aggressive accelerator design, ALS-U will provide the highest coherent flux of any existing or planned storage ring facility worldwide, up to a photon energy of about 3.5 keV. This range covers the entire soft x-ray regime. To make use of the new source, the project may also include construction activities to build new beamlines or reconfigure existing beamlines. The ALS-U project is the most cost effective way to meet the soft x-ray capability gap stated in the mission need statement at this stage of project development.

FY 2019 funding will be used for planning, engineering design, R&D and prototyping activities.

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2019[a]	9/27/2016	4Q FY 2019	4Q FY 2019	4Q FY 2020	4Q FY 2022	4Q FY 2021	N/A	4Q FY 2026

CD-0 – Approve Mission Need for a construction project with a conceptual scope and cost range
Conceptual Design Complete – Actual date the conceptual design was completed (if applicable)
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
Final Design Complete – Estimated/Actual date the project design will be/was completed
CD-3 – Approve Start of Construction
D&D Complete – Completion of D&D work
CD-4 – Approve Start of Operations or Project Closeout

[a] The project is pre-CD-2; the estimated cost and schedule shown are preliminary. Construction will not be executed without appropriate CD approvals.

	Performance Baseline Validation	CD-3A
FY 2019[a]	4Q FY 2020	4Q FY 2020

CD-3A – Approve Long-Lead Procurements: As the project planning and design matures, long lead procurement may be requested in FY 2020 to mitigate cost and schedule risk to the project.

3. Project Cost History

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D	OPC, D&D	OPC, Total	TPC
FY 2019[a]	39,000	243,000	282,000	38,000	N/A	38,000	320,000

4. Project Scope and Justification

Scope

The ALS-U project will upgrade the existing ALS facility by replacing the existing electron storage ring with a new electron storage ring based on a multi-bend achromat (MBA) lattice design to provide a soft x-ray source that is orders of magnitudes brighter—a 10-1000 times increase in brightness over the current ALS—and to provide a significantly higher fraction of coherent light in the soft x-ray region (~50-2,000 eV) than is currently available at ALS. The project will replace the existing triple-bend achromat storage ring with a new, high-performance storage ring based on a nine-bend achromat design. In addition, the project will add a low-emittance, full-energy accumulator ring to the existing tunnel to enable on-axis, swap-out injection using fast kicker magnets. The new source will require upgrading x-ray optics on existing beamlines with some beamlines being realigned or relocated. The project adds three new undulator beamlines that are optimized for the novel science made possible by the beam's new high coherent flux. If possible, the project intends to reuse the existing building, utilities, electron gun, linac, and booster synchrotron equipment currently at ALS. Related scope may be added as necessary to optimize the final design and provide the maximum performance achievable to support the science needs and goals contained in the Mission Need Statement. With an aggressive accelerator design, ALS-U will provide the highest coherent flux of any existing or planned storage ring facility worldwide, up to a photon energy of about 3.5 keV. This range covers the entire soft x-ray regime.

Justification

At this time, our ability to observe and understand materials and material phenomena in real-time and as they emerge and evolve is limited. Soft x-rays (~50 to 2,000 eV) are ideally suited for revealing the chemical, electronic, and magnetic properties of materials, as well as the chemical reactions that underpin these properties. This knowledge is crucial for the design and control of new advanced materials that address the challenges of new energy technologies.

Existing storage ring light sources lack a key attribute that would revolutionize x-ray science: stable, nearly continuous soft x-rays with high brightness and high coherent flux—that is, smooth, well organized soft x-ray wave fronts. Such a stable, high brightness, high coherent flux source would enable 3D imaging with nanometer resolution and the measurement of spontaneous nanoscale motion with nanosecond resolution—all with electronic structure sensitivity.

Currently the Office of Basic Energy Sciences (BES) operates advanced ring-based light sources that produce soft x-rays. The National Synchrotron Light Source-II (NSLS-II), commissioned in 2015, is the brightest soft x-ray source in the U.S. The ALS, completed in 1993, is competitive with NSLS-II for x-rays below 200 eV but not above that. NSLS-II is somewhat lower in brightness than the new Swedish light source, MAX-IV, which is currently under commissioning and represents the first use of a MBA lattice design in a light source facility. Neither NSLS-II nor ALS make use of the newer MBA lattice design.

[a] The project is pre-CD-2 and is not baselined. The cost and schedule shown are preliminary and may change as the project matures towards CD-2. Construction will not be executed without appropriate CD approvals.

Switzerland's SLS-2 (an MBA-based design in the planning stage) will be a brighter soft x-ray light source than both NSLS-II and MAX-IV when it is built and brought into operation. These international light sources, and those that follow, will present a significant challenge to U.S. light source community to provide competitive x-ray sources to domestic users. Neither NSLS-II nor ALS soft x-ray light sources possess sufficient brightness or coherent flux to provide the capability to meet the mission need in their current configurations.

BES is currently supporting two major light source upgrade projects, the Advanced Photon Source-Upgrade (APS-U) and the Linac Coherent Light Source-II (LCLS-II). These two projects will upgrade existing x-ray facilities in the U.S. and will provide significant increases in brightness and coherent flux. These upgrades will not address the specific research needs that demand stable, nearly continuous soft x-rays with high brightness and high coherence.

APS-U (in planning and design) will deploy the MBA lattice design optimized for its higher 6 GeV electron energy and to produce higher energy (hard) x-rays in the range of 10-100 keV. Because the ring will be optimized for high energy, the soft x-ray light it produces will not be sufficiently bright to meet the research needs described above.

LCLS-II (under construction) is a high repetition rate (up to 1 MHz) free electron laser (FEL) designed to produce high brightness, coherent x-rays, but in extremely short bursts rather than as a nearly continuous beam. Storage rings offer higher stability than FELs. In addition, there is a need for a facility that can support a larger number of concurrent experiments than LCLS-II can in its current configuration. This is critical for serving the large and expanding soft x-ray research community. LCLS-II will not meet this mission need.

The ALS is a 1.9 GeV storage ring operating at 500 mA of beam current. It is optimized to produce intense beams of soft x-rays, which offer spectroscopic contrast, nanometer-scale resolution, and broad temporal sensitivity. The ALS facility includes an accelerator complex and photon delivery system that are capable of providing the foundations for an upgrade that will achieve world-leading soft x-ray coherent flux. The existing ALS provides a ready-made foundation, including conventional facilities, a $500M scientific infrastructure investment and a vibrant user community of over 2,500 users per year already attuned to the potential scientific opportunities an upgrade offers. The facility also includes extensive (up to 40) simultaneously operating beamlines and instrumentation, an experimental hall, computing resources, ancillary laboratories, offices, and related infrastructure that will be heavily utilized in an upgrade scenario. Furthermore, the upgrade leverages the ALS staff, who are experts in the scientific and technical aspects of the proposed upgrade.
In summary, the capabilities at our existing x-ray light source facilities are insufficient to develop the next generation of tools that combine high resolution spatial imaging together with precise energy resolving spectroscopic techniques in the soft x-ray range. To enable these cutting edge experimental techniques, it is necessary to possess an ultra-bright source of soft x-ray light that generates the high coherent x-ray flux required to resolve nanometer-scale features and interactions, and to allow the real-time observation and understanding of materials and phenomena as they emerge and evolve. Developing such a light source will ensure the U.S. has the tools to maintain its leadership in soft x-ray science and will significantly accelerate the advancement of the fundamental sciences that underlie a broad range of emerging and future energy applications.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, Program and Project Management for the Acquisition of Capital Assets.

<u>Key Performance Parameters (KPPs)</u>
The threshold KPPs, which will define the official performance baseline at CD-2, Approve Project Performance Baseline, represent the minimum acceptable performance that the project must achieve. Achievement of the threshold KPPs will be a prerequisite for CD-4, Approve Project Completion. The objective KPPs represent the desired project performance. The KPPs presented here are preliminary and may change as the project continues towards CD-2. The final key parameters will be established as part of CD-2, Approve Project Performance Baseline.

Preliminary Key Performance Parameters

Performance Measure	Threshold	Objective
Storage Ring Energy	≥ 1.9 GeV	2.0 GeV
Beam Current	> 25 mA	500 mA
Horizontal Emittance	< 150 pm-rad	<75 pm-rad
Brightness @ 1 keV[1]	> 2 x 10^{19}	2 x 10^{21}
New MBA Beamlines	2	3

5. Preliminary Financial Schedule

	(dollars in thousands)		
	Appropriations	Obligations	Costs
Total Estimated Cost (TEC)			
Design			
FY 2019	6,000	6,000	2,000
FY 2020	15,000	15,000	13,000
FY 2021	12,000	12,000	12,000
FY 2022	6,000	6,000	9,000
FY 2023	0	0	3,000
Total, Design	39,000	39,000	39,000
Construction			
FY 2019	4,000	4,000	4,000
FY 2020	11,540	11,540	11,000
FY 2021	20,640	20,640	20,000
FY 2022	45,560	45,560	45,000
FY 2023	63,530	63,530	65,000
FY 2024	63,350	63,350	60,000
FY 2025	34,380	34,380	30,000
FY 2026	0	0	8,000
Total, Construction	243,000	243,000	243,000
TEC			
FY 2019	10,000	10,000	6,000
FY 2020	26,540	26,540	24,000
FY 2021	32,640	32,640	32,000
FY 2022	51,560	51,560	54,000
FY 2023	63,530	63,530	68,000
FY 2024	63,350	63,350	60,000
FY 2025	34,380	34,380	30,000
FY 2026	0	0	8,000
Total, TEC	282,000	282,000	282,000

	(dollars in thousands)		
	Appropriations	Obligations	Costs
Other Project Cost (OPC)			
OPC except D&D			
FY 2016	5,000	5,000	1,500
FY 2017	5,000	5,000	5,500
FY 2018	0	0	3,000
FY 2019	2,000	2,000	2,000
FY 2020	5,000	5,000	5,000
FY 2021	0	0	0
FY 2022	0	0	0
FY 2023	5,000	5,000	3,000
FY 2024	6,000	6,000	6,000
FY 2025	10,000	10,000	8,000
FY 2026	0	0	4,000
Total, OPC	38,000	38,000	38,000
Total Project Cost (TPC)			
FY 2016	5,000	5,000	1,500
FY 2017	5,000	5,000	5,500
FY 2018	0	0	3,000
FY 2019	12,000	12,000	8,000
FY 2020	31,540	31,540	29,000
FY 2021	32,640	32,640	32,000
FY 2022	51,560	51,560	54,000
FY 2023	68,530	68,530	71,000
FY 2024	69,350	69,350	66,000
FY 2025	44,380	44,380	38,000
FY 2026	0	0	12,000
Total, TPC[a]	320,000	320,000	320,000

6. Details of Preliminary Project Cost Estimate

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	30,000	N/A	N/A
Contingency	9,000	N/A	N/A
Total, Design	39,000	N/A	N/A
Construction		N/A	N/A
Site Preparation	5,000	N/A	N/A
Equipment	170,000	N/A	N/A
Other Construction	0	N/A	N/A
Contingency	68,000	N/A	N/A
Total, Construction	243,000	N/A	N/A
Total, TEC	282,000	N/A	N/A
Contingency, TEC	77,000	N/A	N/A

[a] The project is pre-CD-2 and is not baselined. The cost and schedule shown are preliminary and may change as the project matures towards CD-2. Construction will not be executed without appropriate CD approvals.

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Other Project Cost (OPC)		N/A	N/A
OPC except D&D		N/A	N/A
Conceptual Planning	2,000	N/A	N/A
Conceptual Design	12,000	N/A	N/A
Research and Development	10,000	N/A	N/A
Start-Up	6,000	N/A	N/A
Contingency	8,000	N/A	N/A
Total, OPC	38,000	N/A	N/A
Contingency, OPC	8,000	N/A	N/A
Total, TPC[a]	320,000	N/A	N/A
Total, Contingency	85,000	N/A	N/A

7. Schedule of Appropriations Requests

(dollars in thousands)

Request		Prior Years	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	Outyears	Total
FY 2019	TEC	0	10,000	26,540	32,640	51,560	63,530	63,350	34,380	282,000
	OPC	10,000	2,000	5,000	0	0	5,000	6,000	10,000	38,000
	TPC	10,000	12,000	31,540	32,640	51,560	68,530	69,350	44,380	320,000

8. Related Operations and Maintenance Funding Requirements

Operations and maintenance funding requirements will be provided when the project receives CD-2 approval.

9. D&D Information

At this stage of project planning and development, it is anticipated that there will be no new area being constructed in the construction project.

10. Preliminary Acquisition Approach

DOE has determined that the ALS-U project will be acquired by the Lawrence Berkeley National Laboratory under the existing DOE M&O contract.

A Conceptual Design Report for the ALS-U project will be prepared. Key design activities, requirements, and high-risk subsystem components will be identified to reduce cost and schedule risk to the project and expedite the startup. The necessary project management systems will be fully up-to-date, operating, and are maintained as a LBNL-wide resource.

LBNL may partner with other laboratories for design and procurement of key technical subsystem components. Technical system designs will require research and development activities. Preliminary cost estimates for these systems are based on ALS actual costs and other similar facilities, to the extent practicable. Recent cost data from similar projects will be exploited fully in planning and budgeting for the project. Design of the technical systems will be completed by LBNL or partner laboratory staff. Technical equipment will either be fabricated in-house or subcontracted to vendors with the necessary capabilities. All subcontracts will be competitively bid and awarded based on best value to the government.

Lessons learned from other Office of Science projects and other similar facilities will be exploited fully in planning and executing ALS-U.

[a] The project is pre-CD-2 and is not baselined. The cost and schedule shown are preliminary and may change as the project matures towards CD-2. Construction will not be executed without appropriate CD approvals.

19-SC-11, Linac Coherent Light Source-II High Energy
SLAC National Accelerator Laboratory, Menlo Park, California
Project is for Design and Construction

1. Significant Changes and Summary

Significant Changes

This Construction Project Data Sheet (CPDS) is new and includes a new start for the FY 2019 budget year.

Summary

The FY 2019 Request for the Linac Coherent Light Source-II High Energy (LCLS-II-HE) project is $7,000,000, including $5,000,000 in Total Estimated Cost (TEC) funds and $2,000,000 in Other Project Costs (OPC) funds. The most recent DOE Order 413.3B approved Critical Decisions (CD) is CD-0 (Approve Mission Need), approved on December 15, 2016. The preliminary total project cost (TPC) range, based on early concepts under consideration, is $260,000,000 - $450,000,000.

A Federal Project Director, certified to level IV, has been assigned to this project and has approved this CPDS.

The Linac Coherent Light Source-II High Energy (LCLS-II-HE) project will increase the energy of the superconducting linac currently under construction as part of the LCLS-II project from 4 GeV to 8 GeV. To make use of the new source, the project may also include construction activities to build new beamlines or reconfigure existing beamlines. The project will upgrade the facility infrastructure as needed. The LCLS-II-HE project is the most cost effective way to meet the hard x-ray capability gap described in the mission need statement.

FY 2019 funding will be used for planning, engineering, design, R&D, prototyping activities, and long lead procurements.

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2019[a]	12/15/2016	3Q FY 2019	3Q FY 2019	1Q FY 2021	1Q FY 2023	2Q FY 2022	N/A	2Q FY 2026

CD-0 – Approve Mission Need for a construction project with a conceptual scope and cost range
Conceptual Design Complete – Actual date the conceptual design was completed (if applicable)
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
Final Design Complete – Estimated/Actual date the project design will be/was completed
CD-3 – Approve Start of Construction
D&D Complete – Completion of D&D work
CD-4 – Approve Start of Operations or Project Closeout

	Performance Baseline Validation	CD-3A
FY 2019[a]	1Q FY 2021	4Q FY 2019

CD-3A – Approve Long-Lead Procurements: As the project planning and design matures, long lead procurement may be requested in FY 2019 to mitigate cost and schedule risk to the project.

[a] The project is pre-CD-2; the estimated cost and schedule shown are preliminary. Construction will not be executed without appropriate CD approvals.

3. Project Cost History

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D	OPC, D&D	OPC, Total	TPC
FY 2019[a]	34,000	266,000	300,000	20,000	N/A	20,000	320,000

4. Project Scope and Justification

Scope

There is a limited ability to observe and understand the structural dynamics of complex matter at the atomic scale with hard x-rays, at ultrafast time scales, and in operational environments. Overcoming this capability gap is crucial for the design, control and understanding of new advanced materials necessary to develop new energy technologies. To achieve this objective, the Department needs a hard x-ray source capable of producing high energy ultrafast bursts, with full spatial and temporal coherence, at high repetition rates. Possession of a hard x-ray source with a photon energy range from 5 keV to 12 keV and beyond would enable spectroscopic analysis of additional key elements in the periodic table, deeper penetration into materials, and enhanced resolution. This capability cannot be provided by any existing or planned light source.

The Linac Coherent Light Source-II (LCLS-II) project at SLAC National Accelerator Laboratory (SLAC), which is currently under construction and will begin operations in 2020-2021, only partially addresses this capability gap. LCLS-II will be the premier x-ray free electron laser (XFEL) facility in the world at energies ranging from 200 eV up to approximately 5 keV. The cryomodule technology that underpins LCLS-II is a major advance from prior designs that will allow continuous operation up to 1 MHz.

When completed, LCLS-II will be powered by SLAC's 4 GeV superconducting electron linear accelerator (linac). Over the past years, the cryomodule design for LCLS-II has performed beyond expectations, providing the technical basis to double the electron beam energy. It is therefore conceivable to add additional acceleration capacity at SLAC to double the electron beam energy from 4 GeV to 8 GeV. Calculations indicate that an 8 GeV linac will deliver a hard x-ray photon beam with peak energy of 12.8 keV, which will meet the mission need.

The LCLS-II High Energy (LCLS-II-HE) project will upgrade the LCLS-II to maintain U.S. leadership in XFEL science. The upgrade will provide world leading experimental capabilities for the U.S. research community by extending the x-ray energy of LCLS-II from 5 keV to 12 keV and beyond. The flexibility and detailed pulse structure associated with the proposed LCLS-II-HE facility will not be matched by other facilities under development worldwide.

The LCLS-II-HE project will increase the superconducting linac energy from 4 GeV to 8 GeV by installing additional cryomodules in the first kilometer of the existing linac tunnel. The electron beam will be transported to the existing undulator hall to extend the x-ray energy to 12 keV and beyond. The project will also modify or upgrade existing infrastructure and x-ray transport, optics and diagnostics system, and provide new or upgraded instrumentation to augment existing and planned capabilities.

Justification

The leadership position of LCLS-II will be challenged by the European XFEL at DESY in Hamburg, Germany, which began operations in 2017. The European XFEL has a higher electron energy, which allows production of shorter (i.e., harder) x-ray wavelength pulses compared to LCLS-II. More recent plans emerging from DESY have revealed how the European XFEL could be extended from a pulsed operation mode to continuous operation, which would create a profound capability gap compared to LCLS-II. The continuous operation improves the stability of the electron beam and provides uniformly spaced

[a] The project is pre-CD-2; the estimated cost and schedule shown are preliminary. Construction will not be executed without appropriate CD approvals.

pulses of x-rays or, if desired, the ability to customize the sequence of x-ray pulses provided to experiments to optimize the measurements being made.

In the face of this challenge to U.S. scientific leadership, extending the energy reach of x-rays beyond the upper limit of LCLS-II (5 keV) is a high priority. 12 keV x-rays correspond to an x-ray wavelength of approximately 1 Ångstrom, which is particularly important for high resolution structural determination experiments since this is the characteristic distance between bound atoms in matter. Expanding the photon energy range beyond 5 keV will allow U.S. researchers to probe earth-abundant elements that will be needed for large-scale deployment of photo-catalysts for electricity and fuel production; it allows the study of strong spin-orbit coupling that underpins many aspects of quantum materials; and it reaches the biologically important selenium k-edge, used for protein crystallography.

Based on the factors described above, the most effective and timely approach for DOE to meet the Mission Need and realize the full potential of the facility is by upgrading the LCLS-II, currently under construction at SLAC, by increasing the energy of the superconducting accelerator and upgrading the existing infrastructure and instrumentation.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, Program and Project Management for the Acquisition of Capital Assets.

Key Performance Parameters (KPPs)

The threshold KPPs, which will define the official performance baseline at CD-2, Approve Project Performance Baseline, represent the minimum acceptable performance that the project must achieve. Achievement of the threshold KPPs will be a prerequisite for CD-4, Approve Project Completion. The objective KPPs represent the desired project performance. The KPPs presented here are preliminary and may change as the project continues towards CD-2. The final key parameters will be established as part of CD-2, Approve Project Performance Baseline.

Preliminary Key Performance Parameters

Performance Parameters	**Threshold**	**Objective**
Superconducting linac electron beam energy	≥ 7 GeV	≥ 8 GeV
Electron bunch repetition rate	93 kHz	929 kHz
Superconducting linac charge per bunch	0.02 nC	0.1 nC
Photon beam energy range	200 to ≥ 8,000 eV	200 to ≥ 12,000 eV
High repetition rate capable, hard X-ray end stations	≥ 3	≥ 5
FEL photon quantity (10^{-3} BW)	$5x10^{8}$ (10x spontaneous @8 keV)	> 10^{11} @ 12 keV

5. Preliminary Financial Schedule

	(dollars in thousands)		
	Appropriations	Obligations	Costs
Total Estimated Cost (TEC)			
Design			
FY 2019	2,000	2,000	2,000
FY 2020	8,000	8,000	8,000
FY 2021	10,000	10,000	10,000
FY 2022	10,000	10,000	10,000
FY 2023	4,000	4,000	4,000
Total, Design	34,000	34,000	34,000

	(dollars in thousands)		
	Appropriations	Obligations	Costs
Construction			
FY 2019	3,000	3,000	3,000
FY 2020	12,060	12,060	12,000
FY 2021	15,000	15,000	15,000
FY 2022	40,000	40,000	40,000
FY 2023	57,375	57,375	55,000
FY 2024	78,000	78,000	78,000
FY 2025	60,565	60,565	55,000
FY 2026	0	0	8,000
Total, Construction	266,000	266,000	266,000
TEC			
FY 2019	5,000	5,000	5,000
FY 2020	20,060	20,060	20,000
FY 2021	25,000	25,000	25,000
FY 2022	50,000	50,000	50,000
FY 2023	61,375	61,375	59,000
FY 2024	78,000	78,000	78,000
FY 2025	60,565	60,565	55,000
FY 2026	0	0	8,000
Total, TEC	300,000	300,000	300,000
Other Project Cost (OPC)			
OPC except D&D			
FY 2019	2,000	2,000	2,000
FY 2020	4,000	4,000	3,000
FY 2021	0	0	1,000
FY 2022	0	0	0
FY 2023	0	0	0
FY 2024	4,000	4,000	4,000
FY 2025	10,000	10,000	9,000
FY 2026	0	0	1,000
Total, OPC	20,000	20,000	20,000
Total Project Cost (TPC)			
FY 2019	7,000	7,000	7,000
FY 2020	24,060	24,060	23,000
FY 2021	25,000	25,000	26,000
FY 2022	50,000	50,000	50,000
FY 2023	61,375	61,375	59,000
FY 2024	82,000	82,000	82,000
FY 2025	70,565	70,565	64,000
FY 2026	0	0	9,000
Total, TPC[a]	320,000	320,000	320,000

[a] The project is pre-CD-2 and is not baselined. The cost and schedule shown are preliminary and may change as the project matures towards CD-2. Construction will not be executed without appropriate CD approvals.

6. Details of Preliminary Project Cost Estimate

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	30,500	N/A	N/A
Contingency	3,500	N/A	N/A
Total, Design	34,000	N/A	N/A
Construction			
Site Preparation	3,000	N/A	N/A
Equipment	182,000	N/A	N/A
Other Construction	9,000	N/A	N/A
Contingency	72,000	N/A	N/A
Total, Construction	266,000	N/A	N/A
Total, TEC	300,000	N/A	N/A
Contingency, TEC	75,500	N/A	N/A
Other Project Cost (OPC)			
OPC except D&D			
Conceptual Planning	1,500	N/A	N/A
Conceptual Design	4,000	N/A	N/A
Research and Development	4,000	N/A	N/A
Start-Up	8,000	N/A	N/A
Contingency	2,500	N/A	N/A
Total, OPC	20,000	N/A	N/A
Contingency, OPC	2,500	N/A	N/A
Total, TPC[a]	320,000	N/A	N/A
Total, Contingency	78,000	N/A	N/A

7. Schedule of Appropriations Requests

(dollars in thousands)

Request		Prior Years	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	Outyears	Total
FY 2019	TEC	0	5,000	20,060	25,000	50,000	61,375	78,000	60,565	300,000
	OPC	0	2,000	4,000	0	0	0	4,000	10,000	20,000
	TPC	0	7,000	24,060	25,000	50,000	61,375	82,000	70,565	320,000

8. Related Operations and Maintenance Funding Requirements

Operations and maintenance funding requirements will be provided when the project receives CD-2 approval.

9. D&D Information

At this stage of project planning and development, it is anticipated that there will be no new area being constructed in the construction project.

[a] The project is pre-CD-2 and is not baselined. The cost and schedule shown are preliminary and may change as the project matures towards CD-2. Construction will not be executed without appropriate CD approvals.

10. Preliminary Acquisition Approach

DOE has determined that the LCLS-II-HE project will be acquired by the SLAC National Accelerator Laboratory under the existing DOE M&O contract.

A Conceptual Design Report for the LCLS-II-HE project will be prepared. Key design activities, requirements, and high-risk subsystem components will be identified to reduce cost and schedule risk to the project and expedite the startup. The necessary project management systems will be fully up-to-date, operating, and are maintained as a SLAC-wide resource.

SLAC may partner with other laboratories for design and procurement of key technical subsystem components. Technical system designs will require research and development activities. Preliminary cost estimates for these systems are based on actual costs from LCLS-II and other similar facilities, to the extent practicable. Recent cost data has been exploited fully in planning and budgeting for the project. Design of the technical systems will be completed by SLAC or partner laboratory staff. Technical equipment will either be fabricated in-house or subcontracted to vendors with the necessary capabilities.

All subcontracts will be competitively bid and awarded based on best value to the government.

Lessons learned from the LCLS-II project and other similar facilities will be exploited fully in planning and executing LCLS-II-HE.

Biological and Environmental Research

Overview
The mission of the Biological and Environmental Research (BER) program is to support transformative science and scientific user facilities to achieve a predictive understanding of complex biological, earth, and environmental systems for energy and infrastructure security, independence, and prosperity.

The program seeks to understand the biological, biogeochemical, and physical principles needed to understand fundamentally and be able to predict the processes occurring at scales ranging from the molecular and genomics-controlled smallest scales to environmental and ecological processes at the scale of planet Earth. Starting with the genetic information encoded in organisms' genomes, BER research seeks to discover the principles that guide the translation of the genetic code into the functional proteins and the metabolic and regulatory networks underlying the systems biology of plants and microbes as they respond to and modify their environments. This predictive understanding will enable design and reengineering of microbes and plants underpinning energy independence and a broad clean energy portfolio, including improved biofuels and bioproducts, improved carbon storage capabilities, and controlled biological transformation of materials such as nutrients and contaminants in the environment. An equally important focus is ensuring that emerging technologies in gene editing and genomics are developed using approaches that enhance the stability, resilience, and controlled performance of biological systems in the environment. BER research also advances the fundamental understanding of dynamic, physical, and biogeochemical processes required to systematically develop Earth System models that integrate across the atmosphere, land masses, oceans, sea ice, and subsurface. These predictive tools and approaches are needed to inform policies and plans for ensuring the security and resilience of the Nation's critical infrastructure.

Over the last two decades, BER's scientific impact has been transformative. Mapping the human genome through the U.S.-supported international Human Genome Project that DOE initiated in 1990 ushered in a new era of modern biotechnology and genomics-based systems biology. Today, researchers in the BER Genomic Sciences activity and the Joint Genome Institute (JGI), as well as in the four DOE Bioenergy Research Centers (BRCs), are using the powerful tools of plant and microbial systems biology to pursue the innovative early-stage research that will lead to the development of future transformative bio-based products, clean energy, and next generation technologies.

Since the 1950s, BER and its predecessor organizations have been critical contributors to fundamental scientific understanding of the atmospheric, land, ocean, and environmental systems in which life exists. The earliest work included atmospheric and ocean circulation studies initiated to understand the effects of fallout from nuclear explosions in the early period of the Cold War. These efforts were the forerunners of the modern Earth System models that are in use today. Presently, BER research contributes to model development and analysis and intercomparison; in the last decade, DOE research has made considerable advances in increasing the reliability and predictive capabilities of these models using applied mathematics and systematic comparisons with observational data to reduce uncertainties. BER-supported research also has produced the software and algorithms that enable the productive application of these models on DOE supercomputers, which are among the most capable in the world. These leading U.S. models are used to further fundamental understanding of two of the most critical areas of uncertainty in contemporary Earth system sciences—the impacts of clouds and aerosols—with data provided by the Atmospheric Radiation Measurement Research Facility (ARM), a DOE user facility serving hundreds of scientists worldwide. Also, BER research has pioneered ecological and environmental studies in terrestrial ecosystems, seeking to describe the continuum of biological, biogeochemical, and physical processes across the multiple scales that control the flux of environmentally-relevant compounds between the terrestrial surface and the atmosphere. BER's Environmental Molecular Sciences Laboratory (EMSL) provides the scientific community with a powerful suite of tools to characterize biological organisms and molecules as well as atmospheric aerosol particulates.

Highlights of the FY 2019 Budget Request
The FY 2019 BER Request continues the Administration decisions in FY 2018 to prioritize early-stage, innovative research and technologies that show promise in harnessing American energy resources safely and efficiently. This program supports research that advances the core missions of the DOE while maintaining American leadership in the area of scientific inquiry and discovery. BER's support of basic research today will contribute to a future of stable, reliable, and secure sources of American energy based on transformative science for economic prosperity. BER activities continue to support core research in genomics and high-resolution Earth System models, leveraging investments and scientific user facilities in key areas of bioenergy and secure biosystems design, Earth systems modeling and observations, and environmental sciences.

The federally chartered BER Advisory Committee (BERAC) advises BER on its future development of effective research strategies for sustained leadership in biological and environmental research. BERAC holds targeted workshops, periodic reviews, and forward looking overviews of BER relevant science, and the outcomes of these activities inform BER's ongoing and future research in reports such as the "Grand Challenges for Biological and Environmental Research: Progress and Future Vision"[a].

Biological Systems Science

Investments in the Biological Systems Science subprogram provide the fundamental understanding to underpin transformative science in sustainable bioenergy production and to gain a predictive understanding of plant and microbial physiology, microbiomes, and biological systems in support of DOE's energy and environmental missions. The Genomic Sciences activity will prioritize support for the second year of four next phase DOE Bioenergy Research Centers (BRCs), performing new fundamental research underpinning the production of fuels and chemicals from sustainable biomass resources and the building blocks of new technological advances for translation of basic research results to industry. Within the Genomics Sciences activity, Genomics Analysis and Validation and Metabolic Synthesis and Conversion will be combined and retitled Environmental Genomics. New secure biosystems design activities will be initiated to identify the fundamental engineering principles that control biological systems, with a specific goal of enhancing the stability, resilience, and controlled performance of engineered biological systems. These fundamental genomic science activities will consolidate and coordinate ongoing environmental genomics efforts on sustainability and microbiomes research in mission-relevant ecosystems. Computational Biosciences efforts will continue to combine molecular and genomic scale information within the DOE Systems Biology Knowledgebase and to develop integrated networks and computational models of system dynamics and behavior.

Mesoscale to Molecules and Structural Biology Infrastructure will be combined and retitled Biomolecular Characterization and Imaging Science. Research will continue to support structural, spatial, and temporal understanding of functional biomolecules and processes occurring within living cells. New efforts in advanced bioimaging and characterization of quantum information science (QIS) and advanced sensors will contribute to a systems-level predictive understanding of biological processes.

The DOE Joint Genome Institute (JGI) will continue to be an essential component for DOE systems biology efforts, providing high quality genome sequence data and analysis techniques for a wide variety of plants and microbial communities. The JGI will continue to implement its strategic plan to incorporate new capabilities to sequence DNA and also to interpret, manipulate, and synthesize DNA in support of sustainable, renewable bioenergy and bioproducts research, and environmental research. The JGI will initiate a slow ramp down of activities in preparation for a FY 2020 move into the Integrative Genomics Building on the Lawrence Berkeley National Laboratory campus.

Earth and Environmental Systems Sciences

Earth and Environmental Systems Sciences research activities will focus on scientific analysis of how physical and biogeochemical processes impact the sensitivity and uncertainty of Earth system predictions. The Subsurface Biogeochemistry Research activity will focus on modeling of the flows of subsurface nutrients and materials. Investments will continue to support the E3SM (Energy Exascale Earth System Model) capability, tailored to DOE requirements for a variety of scenarios applied to spatial scales as small as 10 km. The model system will have improved resolution that will include advanced software for running on numerous processors, flexibility toward future DOE computer architectures, and enhanced usability, testing, adaptability, multi-scale treatments, and provenance. The modeling efforts will be validated against new atmospheric and terrestrial observations.

ARM will continue to provide new observations selected to represent the diversity of environmental conditions necessary to advance Earth System models. ARM continues long-term measurements at fixed sites in Alaska and Oklahoma. ARM will limit operations of the Arctic mobile facility at Oliktok and maintain operations at the Azores fixed site. The mobile facility will be deployed to the Cloud, Aerosol, and Complex Terrain Interactions (CACTI) field campaign in the Andes to improve understanding of cloud life cycle and organization in relation to environmental conditions so that cumulus, microphysics,

[a] https://science.energy.gov/~/media/ber/berac/pdf/Reports/BERAC-2017-Grand-Challenges-Report.pdf

and aerosol parameterizations in multiscale models can be improved. The ARM facility will acquire and replace the aerial capability.

EMSL will focus on a research agenda aligned with priority BER biology and environmental program research areas enabling characterization and quantification of the biological and chemical constituents as well as dynamics of complex natural systems in the environment, with a focus on microbial communities, and soil and rhizosphere ecosystems.

The Data Management effort will focus on field observations and data from environmental field experiments.

Biological and Environmental Research
Funding ($K)

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Biological Systems Science				
Genomic Science				
Foundational Genomics Research	89,571	–	80,000	-9,571
Environmental Genomics[b]	25,510	–	16,000	-9,510
Computational Biosciences	16,395	–	16,000	-395
Bioenergy Research Centers	75,000	–	100,000	+25,000
Total, Genomic Science	**206,476**	–	**212,000**	**+5,524**
Biomolecular Characterization and Imaging Science[c]	**19,623**	–	**24,908**	**+5,285**
Biological Systems Facilities and Infrastructure				
Joint Genome Institute	69,463	–	70,000	+537
Total, Biological Systems Facilities and Infrastructure	**69,463**	–	**70,000**	**+537**
SBIR/STTR	11,159	–	11,589	+430
Total, Biological Systems Science	**306,721**	–	**318,497**	**+11,776**
Earth and Environmental Systems Sciences				
Atmospheric System Research	**25,836**	–	**12,000**	**-13,836**
Environmental System Science				
Terrestrial Ecosystem Science	40,035	–	14,000	-26,035
Subsurface Biogeochemical Research	22,143	–	5,000	-17,143
Total, Environmental System Science	**62,178**	–	**19,000**	**-43,178**
Earth and Environmental Systems Modeling[d]	**90,564**	–	**33,626**	**-56,938**
Earth and Environmental Systems Sciences Facilities and Infrastructure				
Atmospheric Radiation Measurement Research Facility	65,429	–	66,000	+571
Environmental Molecular Sciences Laboratory	43,191	–	42,000	-1,191
Data Management	7,066	–	3,000	-4,066
Total, Earth and Environmental Systems Sciences Facilities and Infrastructure	**115,686**	–	**111,000**	**-4,686**

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

[b] Environmental Genomics contains previous subprograms of Genomics Analysis and Validation, and Metabolic Synthesis and Conversion.

[c] Biomolecular Characterization and Imaging Science contains previous Mesoscale to Molecules, and Structural Biology Infrastructure.

[d] Earth and Environmental Systems Modeling reflects all previous Modeling activities (Regional and Global Model Analysis, Earth System Modeling, and Integrated Assessment).

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
SBIR/STTR	11,015	–	5,877	-5,138
Total, Earth and Environmental Systems Sciences	**305,279**	–	**181,503**	**-123,776**
Total, Biological and Environmental Research	**612,000**	**607,844**	**500,000**	**-112,000**

SBIR/STTR Funding:

- FY 2017 Enacted: SBIR $19,440,000; and STTR $2,734,000
- FY 2019 Request: SBIR $15,313,000; and STTR $2,153,000

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

Biological and Environmental Research
Explanation of Major Changes ($K)

	FY 2019 Request vs FY 2017 Enacted
Biological Systems Science: Within Genomic Sciences, the Request prioritizes research activities to continue early-stage core research to understand the complex mechanisms controlling the interplay of microbes and plants within broader organized biological systems. Foundational Genomics research supports secure biosystems design research to understand the fundamental genome structure and functional relationships that result in specific new and beneficial plant and microbial traits. Environmental Genomics (formerly Genomics Analysis and Validation, and Metabolic Synthesis and Conversion) supports research on understanding environmentally relevant microbiomes and the interdependencies between plants and microbes in a sustainable and resilient ecosystem. The four DOE Bioenergy Research Centers will be fully supported in their second year of bioenergy research to underpin efforts to produce innovative biofuels and bioproducts from renewable biomass resources. Development of new bioimaging, measurement and characterization approaches through the Biomolecular Characterization and Imaging Science activity (formerly Mesoscale to Molecules and Structural Biology Infrastructure) will include new integrative imaging and analysis platforms, including using QIS materials, to understand the expression, structure, and function of genome information encoded within cells.	**+11,776**
Earth and Environmental Systems Sciences: The Request continues to support the development of high-resolution Earth system modeling, analysis, and intercomparison capabilities focused on DOE mission needs for energy and infrastructure resilience and security. Environmental System Science will continue a focus on Arctic field studies and the fate and transport of nutrients. ARM will acquire and replace its aerial capability. Using observations from the ARM facility, Atmospheric System Research will continue to advance knowledge and improve model representations of atmospheric gases, aerosols, and clouds on the Earth's energy balance. The ARM mobile facility will be deployed to the Andes; operations of the Arctic mobile facility at Oliktok will be seasonally limited. EMSL will focus on biological and environmental molecular science.	**-123,776**
Total, Biological and Environmental Research	**-112,000**

Basic and Applied R&D Coordination

BER research underpins the needs of DOE's energy and environmental missions, and is coordinated through the National Science and Technology Council (NSTC). This includes all biological, Earth and environmental systems modeling, renewable energy, and field experiments involving atmospheric, ecological, and hydro-biogeochemical sciences research. Basic research on microbes and plants provides fundamental knowledge that can be used to develop new bioenergy crops and improved biofuel and bioproduct production processes that enable a more sustainable bioeconomy, coordinated with other federal agencies on priority bioeconomy science needs occurs through the Biomass Research and Development Board, a Congressionally-mandated interagency group created by the Biomass Research and Development Act of 2000, as amended by the Energy Policy Act of 2005 and the Agricultural Act of 2014.

In general, BER coordinates with DOE's applied technology programs through regular joint program manager meetings, by participating in their internal program reviews and in joint principal investigator meetings, as well as conducting joint technical workshops.

Program Accomplishments

Fundamental Bioenergy Research. Efforts at the DOE BRCs continue to lead the world in basic research to underpin the development of biofuels and bioproducts from sustainable biomass resources.

Bioenergy Research Centers: Ten years of research from the original three BRCs has led to significant advances in bioenergy research. The prospect of developing dedicated bioenergy crops with specific engineered traits capable of thriving in the environment was recently demonstrated by researchers at the BioEnergy Science Center (BESC). Switchgrass engineered to express an altered lignin structure thrived in field trials over a 3-year period relative to controls. The crops retained the reduced recalcitrance phenotype and yielded 25-32% more sugar release upon deconstruction demonstrating the viability of a specifically designed bioenergy crop. Progress in biomass deconstruction has led Great Lakes Bioenergy Research Center (GLBRC) researchers towards development of new solvents that can break down biomass into defined component streams. Research with gamma-valerolactone dissolves and separates up to 80% of biomass into cellulose, hemicellulose and lignin. These components can be further converted to useful biofuels, specialty chemicals and lignin-based carbon foam, all commercially valuable products, as a basis for an integrated biorefinery process producing fuels and chemicals from renewable biomass. Research at the Joint BioEnergy Institute (JBEI) built on previous metabolic engineering advances to produce advanced jet fuel compounds from cellulosic sugars. A constructed mevalonate pathway was designed to produce linalool and eucalyptol, jet fuel components from cellulosic glucose. The research is a culmination of a series of metabolic engineering advances at JBEI laying a foundation for a broader biotechnology industry producing fuels and chemicals from renewable biomass.

Genomic Science: Basic research efforts continue to gain insights into the functioning of biological systems relevant to DOE missions.

- Researchers at Massachusetts Institute of Technology have designed a yeast strain that accumulates 25% more lipids than control strains, useful for renewable biodiesel fuel production. The research uses an innovative combination of computational hypothesis generation and experimental testing to guide metabolic engineering techniques, an important approach for systematizing biosystems design techniques.
- Oak Ridge National Laboratory researchers using multi-omics approaches identified 417 specific genes in *Populus* that may serve as signaling molecules between plants and microbial communities. These molecules secreted by the plant were shown to be present in fungal nuclei and may serve as regulatory proteins for symbiotic interactions, a key finding for understanding controls on plant-microbe interactions.
- Lawrence Berkeley National Laboratory (LBNL)-led researchers are developing new tools to experimentally identify genes of unknown function in bacterial genomes, a major limitation in systems biology research. The new high through-put technique tracks the impact of random mutations in bacteria during growth under a broad range of conditions to identify genes of unknown function. Using this system, the team identified ~8,500 genes whose functions were not previously known from a set of 25 tested bacteria.
- Researchers from the University of Washington examining methane oxidation in lake sediments have developed a new approach to understand microbial community dynamics. Using a combination of constructed microbial communities and multi-omics techniques, the researchers could track gene expression within the community and observed nutritional dependencies within the population to explain changes in observed methane oxidation

patterns from the environment. The work demonstrates an approach to use advanced "-omics" techniques of microbial communities to explain larger biogeochemical processes in the environment.

***Joint Genome Institute*:** The JGI continues to be the primary source for genomic information on plants, microorganisms and microbial communities for BER programs and a leader in developing new genomics techniques for BER research. Deep sequencing of environmental samples continues to reveal the breadth of microbial species and the diversity of genes detected in the environment. JGI, in a collaboration led by the University of Washington are using metagenomics to identify protein encoding genes from environmental samples. Using the Rosetta software, researchers were able to generate 614 model structures of protein families with no known structure. Many of these structures contained unique protein folds not currently represented in the Protein Data Bank. The work highlights a unique attempt to marry structural biology with environmental metagenomics to uncover the diversity of protein structures detectable in nature, with broad implications for bioenergy, environmental and health research.

Modeling the Earth System. Advanced modeling concepts, high performance computing, and new observations allow emerging Earth System models to more confidently capture extreme weather events and to better understand how these events interact with the atmospheric, oceanic, and terrestrial components of the Earth system. A new DOE high-resolution Earth System model will be released in April 2018 as the world's highest resolution capability to study interdependencies involving the atmosphere, oceans, and terrestrial processes. With the power of DOE's fastest supercomputers, this Energy Exascale Earth System Model (E3SM) will be able to conduct complex uncertainty analyses on spatial resolutions that span from 10 km down to 500 m. These analyses resulted in identification and reduction of significant errors and biases in Earth System models that have previously been limiting confidence in model analyses and predictions. In addition, super parameterization of clouds in the high resolution atmospheric component of E3SM can more accurately capture extreme precipitation patterns and rainfall events. Results also indicate that the amount of precipitation can vary over the course of successive El Niño Southern Oscillation (ENSO) events of different strengths, thereby producing even more confident projections of extreme precipitation in the future.

Observations from the Atmospheric Radiation Measurement Research Facility (ARM), a SC scientific user facility, were used to develop and evaluate new formulations of low cloud processes for global models. Low clouds, which are highly reflective of incoming sunlight, are a source of significant uncertainty in Earth System models. An analysis of cloud condensation nuclei from ARM observations collected at five different sites around the world led to improved model representation of the variability of cloud water content in different geographic regions.

Biological and Environmental Research
Biological Systems Science

Description
Biological Systems Science integrates discovery- and hypothesis-driven science with technology development on plant and microbial systems relevant to national priorities energy security and resilience and innovation in life sciences and biology. Systems biology is the multidisciplinary study of complex interactions specifying the function of entire biological systems—from single cells to multicellular organisms—rather than the study of individual isolated components. The Biological Systems Science subprogram employs systems biology approaches to define the functional principles that drive living systems, from microbes and microbial communities to plants and other whole organisms.

Key questions that drive these studies include:
- What information is encoded in the genome sequence?
- How is information exchanged between different subcellular constituents?
- What molecular interactions regulate the response of living systems and how can those interactions be understood dynamically and predictively?

The subprogram builds upon a successful track record in defining and tackling bold, complex scientific problems in genomics—problems that require the development of large tools and infrastructure; strong collaboration with the computational sciences community; and the mobilization of multidisciplinary teams focused on plant and microbial bioenergy research. The subprogram employs approaches such as genome sequencing, proteomics, metabolomics, structural biology, high-resolution imaging and characterization, and integration of information into computational models that can be iteratively tested and validated to advance a predictive understanding of biological systems from molecules to mesoscale.

The subprogram supports the operation of the DOE Bioenergy Research Centers (BRCs) and the DOE Joint Genome Institute (JGI) scientific user facility.

<u>Genomic Science</u>
The Genomic Science activity supports research seeking to reveal the fundamental principles that drive biological systems relevant to DOE missions in energy security and resilience. These principles guide the interpretation of the genetic code into functional proteins, biomolecular complexes, metabolic pathways, and the metabolic/regulatory networks underlying the systems biology of plants, microbes, and communities. Advancing fundamental knowledge of these systems will enable new solutions to clean energy production, breakthroughs in genome-based biotechnology, understanding the role of biological systems in the environment, and adapting biological design paradigms to physical and material systems.

The major objectives of the Genomic Science activity are to determine the molecular mechanisms, regulatory elements, and integrated networks needed to understand genome-scale functional properties of microbes, plants, and communities; to develop "-omics" experimental capabilities and enabling technologies needed to achieve a dynamic, system-level understanding of organism and community functions; and to develop the knowledgebase, computational infrastructure, and modeling capabilities to advance predictive understanding, manipulation and design of biological systems.

Foundational Genomics supports fundamental research on discovery and manipulation of genome structural and regulatory elements and epigenetic controls to scale from genotype to phenotype in microbes and plants. Efforts in biosystems design research build on and complement existing genomics-based research, through development of new secure gene-editing and multi-gene stacking techniques for microbes and plants. The results will yield an increased range of microorganisms and plants as model research organisms to expand and complement available biological systems for bioenergy and biotechnology research.

Environmental Genomics combines previous Genomics Analysis and Validation, and Metabolic Synthesis and Conversion activities, and supports research focused on understanding plants and soil microbial communities and how they impact the cycling and fate of carbon, nutrients, and contaminants in the environment. The activity includes the study of a range of natural and model microbiomes in targeted field environments relevant to BER's research efforts. With a long history in plant and microbial genomics research coupled with substantial biotechnological and computational capabilities available within the DOE user facilities, BER is well positioned to make transformative contributions in biotechnology and understanding microbiome and phytobiome function.

Computational Biosciences supports all Genomic Science systems biology activities through the ongoing development of bioinformatics and computational biology capabilities within the DOE Systems Biology Knowledgebase (KBase). The integrative KBase project seeks to develop the necessary hypothesis-generating analysis techniques and simulation capabilities on high performance computing platforms to accelerate collaborative and reproducible systems biology research within the Genomic Sciences.

The major DOE BRCs effort within the Genomic Science portfolio seeks to provide a fundamental understanding of the biology of plants and microbes as a basis for developing innovative processes for bioenergy and bioproducts production from inedible cellulosic biomass. The four BRCs develop a range of advanced biofuels and bioproducts from sustainable biomass resources and provide high-payoff technology and early-stage research results that can be adapted for industry adoption and development of transformative commercial products and services.

Biomolecular Characterization and Imaging Science (formerly known as Mesoscale to Molecules, and Structural Biology Infrastructure) supports approaches to systems biology that focus on translating information encoded in an organism's genome to those traits expressed by the organism. These genotype to phenotype translations are key to gaining a predictive understanding of cellular function under a variety of environmental and bioenergy-relevant conditions. The Biomolecular Characterization and Imaging Science activity will enable development of new bioimaging, measurement, and characterization technologies to visualize the structural, spatial, and temporal relationships of key metabolic processes and critical biomaterials governing phenotypic expression in plants and microbes. The activity will include new efforts to characterize quantum information science materials in new environmental sensors. This information is crucial for developing an understanding of the impact of various environmental and/or biosystems designs on whole cell or community function.

Biological Systems Science Facilities and Infrastructure

The DOE JGI is the only federally funded major genome sequencing center focused on genome discovery and analysis in plants and microbes for energy and environmental applications, and is widely used by researchers in academia, the national laboratories, and industry. High-throughput DNA sequencing underpins modern systems biology research, providing fundamental biological data on organisms and groups of organisms. By understanding shared features of multiple genomes, scientists can identify key genes that may link to biological function. These functions include microbial metabolic pathways and enzymes that are used to generate fuel molecules, affect plant biomass formation, degrade contaminants, or capture CO_2, leading to the optimization of these organisms for cost effective biofuels and bioproducts production and other DOE missions.

The DOE JGI is developing aggressive new strategies for interpreting complex genomes through new high-throughput functional assays, DNA synthesis and manipulation techniques, and genome analysis tools in association with the DOE KBase. These advanced capabilities are part of the DOE JGI's latest strategic plan to provide users with additional, highly efficient, capabilities supporting biosystems design efforts for biofuels and environmental process research. The DOE JGI also performs metagenome (genomes from multiple organisms) sequencing and analysis from environmental samples and single cell sequencing techniques for hard-to-culture microorganisms from understudied environments relevant to the DOE missions.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
Biological Systems Science $306,721,000	**$318,497,000**	**+$11,776,000**
Genomic Science $206,476,000	**$212,000,000**	**+$5,524,000**
The funding for Foundational Genomics enabled BER to lead the anticipated growth in synthetic biology and biosystems design efforts for biofuels and bioproducts. This included establishing selected sets of well-defined model microbes, plants and fungi as platforms for synthetic biology, with a robust set of tools tailored to industrially-relevant conditions and a range of environmental variables. Microbiome research focused on improved bioinformatic tools for microbiome gene annotation, high-throughput approaches to cultivate organisms of interest, characterized their physiological properties, and developed genetic tool kits for their experimental manipulation across a range of different plant hosts and soil types. Computational Biosciences continued and integrated new datasets for protein structure, genome-based biomaterials and biosystems design toolkits and software. BER selected four new BRCs from a recompetition in FY 2017, and provided first year funding in FY 2018 at reduced funding levels.	Foundational Genomics research will support biosystems design research to develop the understanding needed to engineer beneficial traits into microbes, plants, and fungi for a variety of bioenergy, bioproduct and biotechnological purposes. Environmental Genomics will focus on environmental microbiome research and develop new multi-omics techniques with computational modeling and experimentation to infer interactions among and between microbial species and/or plants and fungi and the impacts on the cycling of materials in the environment. Computational Bioscience will focus on integration of high priority multi-omic datasets for microbiome and bioenergy-related research within the DOE Systems Biology Knowledgebase in collaboration with bioinformatics capabilities within the JGI. The four BRCs will begin their second year of support. Research will focus on development of dedicated bioenergy crops informed by economic/agronomic modeling, feedstock agnostic deconstruction processes, development of a broader range of microbial conversion pathways to produce fuels and chemicals from cellulose and lignin, and new ways to sustainably cultivate bioenergy crops on marginal lands.	Foundational Genomics will focus on development of a number of high priority platform organisms for secure biosystems design research. Environmental Genomics will emphasize microbiome research efforts to understand interactions among plants and microbes in soils. Computational Bioscience will emphasize multiomics capabilities supporting microbiome and bioenergy research needs within the DOE Systems Biology Knowledgebase, in collaboration with the JGI. The BRCs are fully supported in FY 2019. The BRCs will prioritize research on bioenergy crops with the greatest projected economic/agronomic benefit, cost efficient deconstruction processes, microbial conversion pathways to valorize lignin and new methods to sustainably cultivate bioenergy crops.

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
Biomolecular Characterization and Imaging Science[1] $19,623,000	**$24,908,000**	**+$5,285,000**
Biomolecular Characterization and Imaging Science funding continued to augment advanced imaging capabilities for biological systems through strategic investments in end stations and beamlines for the BES-supported light sources and neutron sources. BER continues to need new capabilities beyond x-ray crystallography, such as electron cryomicroscopy and other bioimaging techniques, including the use of quantum materials, to support BER's systems-level approach to understanding biological processes. Advanced multi-functional imaging techniques provided spatial and temporal understanding of functional genomics within living cells; this information can be integrated to gain a systems-level predictive understanding of biological processes.	Funding will support molecular science capabilities to characterize, measure and image basic metabolic processes and critical biomaterials occurring in plant and microbial cells relevant to BER's bioenergy and environmental research efforts. Development of multi-functional techniques will continue and include quantum techniques providing atomic-level imaging and characterization capabilities. These characterization and imaging capabilities offer the ability to validate current understanding and models of biological processes through direct visualization and/or measurement.	Multifunctional imaging development will prioritize on those methods most relevant to bioenergy and environmental research including quantum imaging, molecular characterization techniques and characterization of critical biomaterials to provide unprecedented observations of biological processes with which to validate current understanding and models.
Biological Systems Science Facilities and Infrastructure $69,463,000	**$70,000,000**	**+$537,000**
JGI continued to focus on sequencing very large and complex plant genomes and metagenomics samples, especially from complex field environments. It continued to advance its capabilities to interpret genomes and provide the research community with a broad variety of new and cutting functional genomics techniques that increase efficiency. Funding also allowed for incorporation of JGI bioinformatics techniques.	JGI will continue to serve as a primary source of genomic sequences of plants, microorganisms and microbial communities for BER programs and the broader research community. It will continue to develop its capabilities to support large complex plant, metagenomics and environmental microbiome sequencing efforts, including support for the four new Bioenergy Research Centers. It will continue to collaborate with the DOE Systems Biology Knowledgebase and prepare for a move to the LBNL campus.	JGI will prioritize on supporting bioenergy research and integrating its bioinformatics capabilities with the DOE Systems Biology Knowledgebase. Support will continue for the Community Science Program to support plant, microbial, fungal and metagenomic sequencing needs of the larger scientific community and preparing for the move to the LBNL campus.
Access to the Structural Biology Infrastructure at the DOE Synchrotron light and Neutron sources continued for high-resolution structural characterization of biomolecules. Efforts began to link data resources (i.e., PDB) with the DOE KBase.	Structural Biology Infrastructure is moved and combined within the Biomolecular Characterization and Imaging Science activity, as noted above.	

[1] Formerly known as Mesoscale to Molecules and Structural Biology Infrastructure

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
SBIR/STTR $11,159,000	**$11,589,000**	**+$430,000**
In FY 2017, SBIR/STTR funding was set at 3.65% of non-capital funding.	In FY 2019, SBIR/STTR funding is set at 3.65% of non-capital funding.	

Biological and Environmental Research
Earth and Environmental Systems Sciences

Description

The Earth and Environmental Systems Sciences subprogram supports fundamental science and research capabilities that enable major scientific developments in Earth system-relevant atmospheric and ecosystem process and modeling research in support of DOE's mission goals for transformative science for energy and national security. This includes research on components such as clouds, aerosols, and terrestrial ecology; modeling of component interdependencies under a variety of forcing conditions; interdependence of atmospheric, hydrological, ecosystem, and cryospheric variabilities; vulnerability and resilience of the full suite of energy and related infrastructures to extreme events; and uncertainty quantification. It also supports subsurface biogeochemical research that advances fundamental understanding of coupled physical, chemical, hydrological, and biological processes controlling energy byproducts in the environment. This integrated portfolio of research from molecular-level to field-scales emphasizes the coupling of multidisciplinary experimentation and advanced computer models, with a goal to develop and enhance a predictive, systems-level understanding of the fundamental science that addresses environmental and energy-related challenges associated with e.g. extreme phenomena. The Department will continue to advance the science necessary to further develop an understanding of Earth System models of variable sophistication, targeting resolution at the regional spatial scale and from seasonal to multi-decadal time scales, and to focus on areas of critical uncertainty. In addition, environmental research activities will continue to advance basic science to optimize and accelerate environmental cleanup and reductions in life cycle costs.

The subprogram supports three primary research activities, two SC scientific user facilities, and a data activity. The two SC scientific user facilities are the Atmospheric Radiation Measurement Research Facility (ARM) and the Environmental Molecular Sciences Laboratory (EMSL). ARM provides unique, multi-instrumented capabilities for continuous, long-term observations and model–simulated high resolution information that researchers need to improve understanding and develop and test hypotheses involving the role of clouds and aerosols on the atmosphere's spectrally-resolved radiative balance over a variety of spatial scales, extending from local to global. EMSL provides integrated experimental and computational resources that researchers utilize in order to extend understanding of the physical, biogeochemical, chemical, and biological processes that underlie DOE's energy and environmental mission. The data activity encompasses both observed and model-generated data that are collected by the ARM facility and during dedicated field experiments; this activity also archives information generated by Earth System models of variable complexity and sophistication.

Atmospheric System Research

Atmospheric System Research (ASR) is the primary U.S. research activity addressing two major areas of uncertainty in earth system models: the interdependence of clouds, atmospheric aerosols, and precipitation that in turn influences the radiation balance. ASR coordinates with ARM, using the facility's continuous long-term datasets that in turn provide three-dimensional measurements of radiation, aerosols, clouds, precipitation, dynamics, and thermodynamics over a range of environmental conditions at diverse geographic locations. The long-term observational datasets are supplemented with laboratory studies and shorter-duration, ground-based and airborne field campaigns to target specific atmospheric processes under diverse locations and atmospheric conditions. Earth System models incorporate ASR research results to both understand the processes that govern atmospheric components and to advance Earth System model capabilities with greater certainty. ASR seeks to develop integrated, scalable test-beds that incorporate process-level understanding of the life cycles of aerosols, clouds, and precipitation, that can be incorporated into dynamic models.

Environmental System Science

Environmental System Science supports research to provide a robust and scale-aware predictive understanding of terrestrial surface and subsurface ecosystems, including the role of hydro-biogeochemistry from the subsurface to the top of the vegetative canopy that considers effects of seasonal to interannual variability and change on spatial scales that span from molecular to global.

Using decadal-scale investments such as the Next Generation Ecosystem Experiment (NGEE) to study the variety of time scales and processes associated with ecological change, Environmental System Science research focuses on understanding, observing, and modeling the processes controlling exchange flows between the atmosphere and the terrestrial biosphere, and improving and validating the representation of terrestrial ecosystems in coupled Earth System models. Subsurface biogeochemical research supports integrated modeling research, ranging from molecular to field scales, to understand and predict the role that hydrological and biogeochemical processes play in controlling the cycling and mobility of energy-relevant materials in the subsurface and across key surface-subsurface interfaces in the environment, including environmental contamination from past nuclear weapons production.

Earth and Environmental Systems Modeling

Earth and Environmental Systems Modeling develops physical, chemical, and biological model components, as well as fully coupled Earth System models, in coordination with other Federal efforts. The research specifically focuses on quantifying and reducing the uncertainties in Earth System models based on more advanced process representations, sophisticated software, robust couplers, diagnostics, and performance metrics. Priority model components include the ocean, sea-ice, land-ice, atmosphere, and terrestrial ecosystems, where each are treated as interdependent and is able to exploit dynamic grid technologies. Support of diagnostic and intercomparison activities, combined with scientific analysis, allows BER funded researchers to exploit the best available science and practice within each of the world's leading Earth system research programs. In addition, DOE will continue to support the Energy Exascale Earth System Model (E3SM) as a computationally efficient model adaptable to DOE's emerging Leadership Computing Facility supercomputer architectures and with greater sophistication and fidelity for high resolution simulation of extreme phenomena and complex processes. Earth system modeling, simulation, and analysis tools are essential for informing energy infrastructure investment decisions that have the future potential for large-scale deployment that in turn benefit our national security.

Earth and Environmental Systems Sciences Facilities and Infrastructure

The Earth and Environmental Systems Sciences Facilities and Infrastructure activity supports data management and two scientific user facilities for the earth and environmental systems sciences communities. The scientific user facilities, ARM and EMSL, provide the broad scientific community with technical capabilities, scientific expertise, and unique information to facilitate science in areas integral to BER's mission.

ARM is a multi-laboratory, multi-platform, multi-site, national scientific user facility, providing the world's most comprehensive continuous and precise observations of clouds, aerosols, and related meteorological information. ARM currently consists of three fixed, long-term measurement facility sites (in Oklahoma, Alaska, and the Azores), three mobile observatories, and an airborne research capability that operates at sites selected by the scientific community. In FY 2019, ARM will continue operations at the fixed sites, prioritizing measurements in Alaska and Oklahoma. In FY 2019, one mobile facility will be deployed for targeted observations and measurements in the southern Andes. Each of the ARM fixed and mobile observatories includes scanning radars, lidar systems, and *in situ* meteorological observing capabilities; the sites are also used to demonstrate technologies as they are developed by the community. ARM investigators study the impact of evolving clouds, aerosols, and precipitation on the Earth's radiative balance and rate of Earth system change, addressing the most significant scientific uncertainties in predictability research. ARM will continue to incorporate very high resolution Large Eddy Simulations at the permanent Oklahoma site during specific campaigns requested by the scientific community. BER is also maintaining the exponentially increasing data archive to support enhanced analyses and model development. The data extracted from the archive are used to improve atmospheric process representations at higher resolution, greater sophistication and robustness of ultra-high resolution models. Besides supporting BER atmospheric sciences and Earth system modeling research, the ARM facility freely provides key information to other agencies that are engaged in, e.g., calibration and validation of space-borne sensors.

The G-1 aircraft used by ARM was built in 1961, is one of only 10 G-1's that remain in service worldwide and is nearing the end of its service life. BER plans to retire and replace the aircraft in 2019. BER-supported scientists require high-quality and well-characterized in situ aircraft observations of aerosol and cloud microphysical properties and coincident dynamical and thermodynamic properties in order to continue to improve fundamental understanding of the physical and chemical processes that control the formation, life cycle, and radiative impacts of cloud and aerosol particles. To meet these needs, the ARM user facility requires a replacement aircraft with the capacity to carry multi-sensor instrument packages; a flight duration of at least 5 hours with full payload; the ability to fly safely at low altitudes at speeds suitable for gathering in situ observations of aerosol and cloud microphysical properties; and multiple engines for safe operations within clouds, and over the ocean or sea-ice.

EMSL provides integrated experimental and computational resources for discovery and technological innovation in the environmental molecular sciences. EMSL enables users to undertake molecular-scale experimental and theoretical research on biological systems, biogeochemistry, and interfacial and surface (including aerosol) science relevant to energy and environmental challenges facing DOE and the nation. This includes science supporting improved catalysts and materials for industrial applications and developing improved representations of biological and subsurface biogeochemical processes. EMSL will address a more focused set of scientific topics that continue to exploit High Resolution and Mass Accuracy Capability, live cell imaging, and more extensive utilization of other EMSL instrumentation into process and systems models and simulations to address challenging problems in the biological and environmental system sciences.

Data sets generated by ARM, other DOE and Federal Earth observing activities, and Earth system modeling activities, are enormous. The information in Earth observations and model-generated data can be used to achieve broad benefits ranging from planning and development of energy infrastructure to natural disaster impact mitigation to commercial supply chain management to natural resource management. Accessibility and usage of these data sets are fundamental to supporting decision-making, scientific discovery, technological innovation, and National security.

The BER Data Management activity will focus efforts to store data from the Earth System Grid Federation, ARM, and NGEE field experiments.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
Earth and Environmental Systems Sciences $305,279,000	**$181,503,000**	**-$123,776,000**
Atmospheric System Research (ASR) $25,836,000	**$12,000,000**	**-$13,836,000**
ASR conducted research on cloud, aerosol, and thermodynamic processes using data collected during observational campaigns involving in-situ sensors and Unmanned Aerial Systems, and the full suite of data from campaigns conducted in Alaska, Oklahoma, Antarctica, the Southern Ocean, and Azores, has been utilized in the research.	ASR will continue research on cloud, aerosol, and thermodynamic processes, with a focus on data from the fixed sites, and using data from prior and ongoing field campaigns in the Southern Andes, Antarctica, the Eastern Atlantic, and the Southern Ocean. ASR research will increasingly make use of data generated by Large Eddy Simulation at the ARM fixed site in Oklahoma.	ASR will focus its investment on cloud and aerosol science in regions that exhibit the greatest uncertainties in earth system prediction, i.e., the Arctic and convection in midlatitudes.
Environmental System Science (ESS) $62,178,000	**$19,000,000**	**-$43,178,000**
Within Environmental System Science, NGEE projects continued to provide new observations for model development and validation. The Subsurface Biogeochemistry Research subprogram focused on fate and transport of subsurface elements and hydrological cycling, uptake, and acquisition by plants and microbes, which allows for improved integration with the Terrestrial Ecosystem Science subprogram and facilitate multi-scale, very high resolution process modeling from the bedrock to the canopy.	ESS will continue to support research on permafrost ecology, and will maintain its investments in modeling studies involving boreal ecology and hydro-biogeochemistry of river catchments. Support to the management of the Ameriflux network will continue at a reduced level. ESS will initiate a pilot project on ecology of Terrestrial-Aquatic Interfaces (TAIs).	ESS will prioritize scientific challenges that demand integrative observations of sensitive ecological system in mountainous watersheds of the western U.S. and permafrost regions of the Alaska Arctic. A small pilot project on TAI will be initiated.

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
Earth and Environmental Systems Modeling **$90,564,000**	**$33,626,000**	**-$56,938,000**
Earth and Environmental Systems Modeling — Earth System Modeling continued investment in the high-resolution E3SM project, with research to introduce a non-hydrostatic dynamical core, dynamic coupling of ocean and ice, and basin and sub-basin treatments for the land models. Activities aligned with anticipated exascale developments in high-performance computing platforms and algorithms. The E3SM version 1 will be released during FY 2018, with both existing and new users conducting basic research using results derived from the newest DOE computer architectures.	Earth and Environmental Systems Modeling will focus its investment in further development of a non-hydrostatic dynamical cores for the atmospheric component of the E3SM model that targets higher resolution over scales that span from seasonal to multi-decadal. Activities will continue to assimilate the best available software for E3SM to exploit DOE's high-performance computing architectures in order to analyze and characterize extreme events within the earth system.	The E3SM model development timetable will be less ambitious, with efforts prioritized on modeling the atmospheric and cryospheric components.
Core research in model intercomparison and diagnostics were continued. Research continued to explore how modes of variability affect spatial and temporal patterns of weather and extreme events, including the roles of atmospheric rivers and droughts. The incorporation of uncertainty and performance benchmarks will increasingly become part of research efforts.	Core research in model intercomparison and diagnostics will continue. Research will focus on the water cycle, in order to understand how uncertainties involving the spatial and temporal patterns of drought can be characterized.	Research will prioritize the science of water cycle in system models; and investments in tropical-extratropical-midlatitude interactions will be eliminated.
Earth and Environmental Systems Sciences Facilities and Infrastructure $115,686,000	**$111,000,000**	**-$4,686,000**
ARM continued to provide new observations, through long-term measurements at fixed sites in Alaska, Oklahoma, and the Eastern North Atlantic; ; observations continued to be collected from the three mobile facilities, based on limit term deployments to Alaska, Southern Oceans, and south Atlantic. ARM will also maintain an aerial capability and explore the science driven need for equipment refresh for archive upgrades, aerial capabilities, and the mobile and fixed observatories. All ARM activities have been prioritized for critical observations necessary to advance earth system models.	ARM will continue to provide new observations, through long-term measurements at fixed sites in Alaska, Oklahoma, and the Eastern North Atlantic. ARM will utilize one of its mobile units for field campaigns, and it will hold one mobile unit in reserve. The mobile unit at Oliktok will operate seasonally. All ARM activities will be prioritized for critical observations necessary to advance the E3SM model. ARM will deploy a mobile facility to the Southern Andes. ARM will acquire a manned aircraft, to replace the existing G1 aircraft that will be retired in FY 2019. The completed analysis of alternatives indicates that purchase of a used aircraft and subsequent	ARM will prioritize investments in its two fixed sites in Alaska and Oklahoma, and the mobile unit will be deployed to the Southern Andes for seven months of field data collection. ARM will acquire a manned aircraft to replace the current ARM G-1 aircraft that will be retired at the end of FY 2019.

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
	retrofitting to achieve functionality for scientific instrumentation is the most cost-effective option.	
EMSL focused on scientific topics that exploit recently installed capabilities involving HRMAC, live cell imaging, and more extensive use of integrating data from other EMSL instrumentation into process and systems models and simulations that addressed challenging problems in the biological and environmental sciences.	EMSL will continue to focus on science that exploits its unique capabilities, including the HRMAC, live cell imaging, Quiet Wing, and high performance computing, in order to advance biological and environmental sciences. EMSL will initiate building a next generation Dynamic Transmission Electron Microscope, to support future BER science.	EMSL will prioritize its investments on the science of biological and biogeochemical systems, and surface chemistry, using best-in-class sensors that combine with high performance computing.
The Earth and Environmental Systems Sciences Data Management activity emphasized the first phase of metadata compatibility and consolidation via common protocols and standards, involving environmental observations and the Earth System Grid Federation. Essential data archiving and storing protocols, capacity, and provenance were achieved, as part of an effort to simplify scientific community access to observed and model generated data produced by DOE.	The Earth and Environmental Systems Sciences Data Management activity will provide support to maintain existing software and data archives in support of ongoing experimental and modeling research. Essential data archiving and storing protocols, capacity, and provenance will be maintained.	Data Management research efforts will prioritize maintenance of existing software and capabilities in support of ongoing DOE research. Research on improved metadata compatibility and enhanced consolidation via common protocols and standards will be completed.
SBIR/STTR $11,015,000	**$5,877,000**	**-$5,138,000**
In FY 2017, SBIR/STTR funding was set at 3.65% of non-capital funding.	In FY 2019, SBIR/STTR funding is set at 3.65% of non-capital funding.	

Biological and Environmental Research
Performance Measures

In accordance with the GPRA Modernization Act of 2010, the Department sets targets for, and tracks progress toward, achieving performance goals for each program.

	FY 2017	FY 2018	FY 2019
Performance Goal (Measure)	**BER Earth System Model - Develop a coupled earth system model with fully interactive water, carbon and sulfur cycles, as well as dynamic vegetation to enable simulations of earth system responses to change.**		
Target	Extend the capabilities of the DOE's high-resolution Earth System Model to simulate and evaluate human-natural interdependencies for the carbon and water cycles.	Demonstrate improved ocean model simulations with the new high-resolution Model for Prediction Across Scales - Ocean (MPAS-Ocean).	Demonstrate in the coupled DOE-E3SM model, the importance of environmental factors in affecting ecosystem productivity and surface energy exchanges.
Result	Met	TBD	TBD
Endpoint Target	BER supports the leading U.S. high-resolution earth system model, and addresses two of the most critical areas of uncertainty in contemporary earth system science—the impacts of clouds and aerosols that combine with biogeochemical and cryospheric processes. Delivery of improved scientific data and models (with quantified uncertainties) about the earth's atmospheric, oceanic, cryospheric, and terrestrial system to more accurately predict the earth system responses to change. The information is essential to plan for future national security, energy and infrastructure needs, water resources, and land use. DOE will continue to advance the science necessary to further develop predictive earth system models at the regional spatial scale and multiple time scales, involving close coordination with the U.S. and international science community.		
Performance Goal (Measure)	**BER Predictive Understanding - Advance an iterative systems biology approach to the understanding and manipulation of plant and microbial genomes as a basis for biofuels development and predictive knowledge of carbon and nutrient cycling in the environment.**		
Target	Develop improved open access platforms for computational analysis of large genomic datasets.	Using genomics-based techniques, develop an approach to explore the functioning of plant-microbe interactions.	Develop metagenomics approaches to assess the functioning of microbial communities in the environment.
Result	Met	TBD	TBD
Endpoint Target	BER will advance understanding of the operating principles and functional properties of plants, microbes, and complex biological communities relevant to DOE missions in energy and the environment. Deciphering the genomic blueprint of organisms and determining how this information is translated to integrated biological systems permits predictive modeling of bioprocesses and enables targeted redesign of plants and microbes. BER research will address fundamental knowledge gaps and provide foundational systems biology information necessary to advance development of biotechnology and predict impacts of changing environmental conditions on carbon cycling and other biogeochemical processes.		

Capital Summary ($K)

	Total	Prior Years	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Capital Operating Expenses Summary						
Total Non-MIE Capital equipment (projects under $5 million TEC)	n/a	n/a	4,500	–	4,000	-500
Major Items of Equipment (TEC over $5 million)						
Atmospheric Radiation Measurement Research Facility (ARM) – ARM Aircraft project (TPC $17,700)	17,700	200[b]	–	–	17,500	+17,500
Total, Capital Summary	n/a	n/a	4,500	–	21,500	+17,000

Atmospheric Radiation Measurement Research Facility - BER-supported scientists require high-quality and well-characterized *in situ* aircraft observations of aerosol and cloud microphysical properties and coincident dynamical and thermodynamic properties to continue to improve fundamental understanding of the physical and chemical processes that control the formation, life cycle, and radiative impacts of cloud and aerosol particles. To meet these needs, the Atmospheric Radiation Measurement (ARM) user facility has been using a dedicated large twin-turboprop Gulfstream-1 (G-1) aircraft to conduct weeks- to months-long intensive observational campaigns over a range of meteorological conditions and locations around the world. The G-1 aircraft used by ARM was built in 1961, is one of only 10 G-1's that remain in service worldwide, and is rapidly nearing the end of its service life. BER will retire and replace the aircraft in 2019.

To replace the capability of the G-1 aircraft, ARM requires: an airborne platform with the payload capacity (floor space, weight, electricity) to carry multi-sensor packages; the appropriate physical structure to install instruments including atmospheric inlets, free airstream sensors, and radiometers; a flight duration capability of at least 5 hours with full payload; the ability to fly safely at low altitudes (200 ft) at speeds (100 m/s) suitable for gathering *in situ* observations of aerosol and cloud microphysical properties; multiple engines for safe operations within clouds, and over the ocean or sea-ice; and the ability to operate in conditions ranging from the Arctic to the Tropics with a full payload.

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

[b] Reporting $200K in prior year ($100K in FY 2017 and $100K in FY 2018). $100K in FY 2017 not previously reported since below the DOE capitalization threshold of $500,000.

Funding Summary ($K)

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Research	426,951	–	319,000	-107,951
Scientific user facilities operations and research	185,049	–	163,500	-21,549
Projects (Major Item of Equipment)	–	–	**17,500**	**+17,500**
Total, Biological and Environmental Research	**612,000**	**607,844**	**500,000**	**-112,000**

Scientific User Facility Operations ($K)

The treatment of user facilities is distinguished between two types: TYPE A facilities that offer users resources dependent on a single, large-scale machine; TYPE B facilities that offer users a suite of resources that is not dependent on a single, large-scale machine.

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
TYPE B FACILITIES				
Atmospheric Radiation Measurement Research Facility (ARM)	**$65,429**	–	**$66,000**	**+571**
Number of users	1,109	–	1,100	-9
Joint Genome Institute	**$69,463**	–	**$70,000**	**+537**
Number of users	1,598	–	1,600	+2
Environmental Molecular Sciences Laboratory	**$43,191**	–	**$42,000**	**-1,191**
Number of users	616	–	600	-16
Total Facilities	**$178,083**	–	**$178,000**	**-83**
Number of users	3,323	–	3,300	-23

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

Scientific Employment

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Estimate	FY 2019 Request vs FY 2017 Enacted
Number of permanent Ph.D.'s	1,350	–	1,195	-155
Number of postdoctoral associates	330	–	280	-50
Number of graduate students	450	–	405	-45
Other[b]	330	–	280	-50

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

[b] Includes technicians, engineers, computer professionals and other support staff.

Fusion Energy Sciences

Overview

The mission of the Fusion Energy Sciences (FES) program is to expand the fundamental understanding of matter at very high temperatures and densities and to build the scientific foundation needed to develop a fusion energy source. This is accomplished through the study of plasma, the fourth state of matter, and how it interacts with its surroundings.

Plasma science is wide-ranging, since 99% of the visible universe is composed of plasmas of various types. High-temperature fusion plasmas at hundreds of millions of degrees occur in national security applications, albeit for very short times. The same fusion plasmas could be exploited in the laboratory in a controlled fashion to become the basis for a future clean nuclear power source, which will provide domestic energy independence and security. This is a large driver for the FES subprograms focused on the scientific study of "burning plasma." In the burning plasma state of matter, the nuclear fusion process itself provides the dominant heat source for sustaining the plasma temperature. Such a self-heated plasma can continue to undergo fusion reactions that produce energy, without requiring the input of heating power from the outside, and thus resulting in large net energy yield.

In the FES program, foundational science for burning plasmas is obtained by investigating the behavior of laboratory fusion plasmas confined with strong magnetic fields. The DIII-D National Fusion Facility and the National Spherical Torus Experiment-Upgrade (NSTX-U) are world-leading Office of Science (SC) user facilities for experimental research available to and used by scientists from national laboratories, universities, and industry research groups. Complementing these experimental activities is a significant effort in fusion theory and simulation to predict and interpret the complex behavior of plasmas as self-organized systems. As part of this effort, FES supports several Scientific Discovery through Advanced Computing (SciDAC) centers in partnership with the Advanced Scientific Computing Research (ASCR) program office.

FES also investigates the behavior of plasmas that are confined near steady state. U.S. scientists take advantage of international partnerships to conduct research on superconducting tokamaks and stellarators with long-duration capabilities. In addition, the development of novel materials, a research area of high interest to many scientific fields, is especially important for fusion energy sciences since fusion plasmas create an environment of high-energy neutrons and huge heat fluxes that impinge on and damage the material structures containing the plasmas.

The frontier scientific area of the actual creation of strongly self-heated fusion burning plasmas will allow the discovery and study of new scientific phenomena relevant to fusion as a future energy source.

The FES program also supports discovery plasma science in research areas such as plasma astrophysics, high energy density laboratory plasmas (HEDLP), and low temperature plasmas. Some of this research is carried out through partnerships with the National Science Foundation (NSF) and the National Nuclear Security Administration (NNSA). Also, U.S. scientists are world leaders in the invention and development of new high-resolution plasma measurement techniques. A recent report[a] from the Fusion Energy Sciences Advisory Committee (FESAC) describes how plasma science advances have led to many spinoff applications and enabling technologies with considerable economic and societal impact for the American quality of life.

The FES program addresses several of the Administration's research and development budget priorities. Research in fusion has the potential to contribute to American energy dominance by making available to the American people a robust base-load electricity clean energy technology that relies on widely available and virtually inexhaustible fuel sources. Research in plasma science, within and beyond fusion, will contribute to American prosperity through the tremendous potential for spinoff applications as well as targeted investments in early-stage low temperature plasma research that can lead to the development of transformative technologies. Investments in our major fusion facilities and smaller-scale experiments will help maintain and modernize our research infrastructure for continuing to conduct world-leading research. Established partnerships within and outside DOE maximize leverage and increase the cost effectiveness of FES research activities. Finally, the unique scientific challenges and rigor of fusion and plasma physics research lead to the development of a well-

[a] https://science.energy.gov/~/media/fes/fesac/pdf/2015/2101507/FINAL_FES_NonFusionAppReport_090215.pdf

trained STEM-focused workforce, which will contribute to maintaining and advancing U.S. competitiveness and world-leadership in key areas of future technological and economic importance, as well as national security.

Highlights of the FY 2019 Request

Strategic choices in this Request are informed by the priorities described in "The Office of Science's Fusion Energy Sciences Program: A Ten-Year Perspective" (submitted to Congress in 2015), the research opportunities identified in a series of community engagement workshops held in 2015[a], and the FY 2017 FESAC investigation on the potential for transformative developments in fusion science and technology. Priorities include keeping SC fusion user facilities world-leading, investing in high performance computing and preparing for Exascale, supporting high-impact research in fusion materials, strengthening partnerships for access to international facilities with unique capabilities, learning how to predict and control transient events in fusion plasmas, and continuing stewardship of discovery plasma science (e.g., via intermediate-scale basic facilities). Furthermore, research priorities for burning plasma science in FY 2019 are to be informed by the FY 2018 report of the National Academy of Sciences (NAS) burning plasma study commissioned by FES.

Key points in the FY 2019 Request include:

<u>Modernizing and Managing Research Infrastructure</u>

- *DIII-D facility enhancements*—DIII-D will focus on completion of facility modifications and enhancements that began in FY 2018, which will maintain the world-leading status of the DIII-D tokamak. The time required for the facility enhancements will allow 12 weeks of research operation.
- *Continued support for NSTX-U program research and recovery activities*—The NSTX-U facility is down for recovery and repair, which will continue in FY 2019. The FY 2019 NSTX-U Operations budget will support high-priority activities to implement repairs and corrective actions required to obtain robust, reliable research operations. The Request for NSTX-U Research will fund the continued analysis of high-impact data, a focused effort on physics topics that directly support the recovery of robust NSTX-U plasma operations, and enhanced collaborative research at other facilities to support NSTX-U research program priorities.
- *Major Item of Equipment (MIE) project for world-leading fusion materials research*—Following the approval of the Linear Divertor Simulator Mission Need (CD-0) and down-selection of alternatives in FY 2018, FES will pursue the Materials Plasma Exposure eXperiment (MPEX) as an MIE project. MPEX will be able to address critical fusion materials science questions on the path toward proving the scientific viability of fusion power. It will provide a world-leading, highly cost-effective experimental device with superior capability, high throughput, and versatility.
- *Fusion nuclear science*—FES will initiate a study to evaluate options for a neutron source that will test materials in fusion-relevant environments.
- *High energy density laboratory plasmas*—FES will initiate a study to evaluate options for an upgrade to the Matter in Extreme Conditions (MEC) instrument on the Linac Coherent Light Source (LCLS) facility at SLAC National Accelerator Laboratory.
- *Continued U.S. hardware development and delivery to ITER*—The U.S. Contributions to ITER (U.S. ITER) First Plasma subproject will continue in the design, fabrication, and delivery of U.S. hardware contributions in support of the multi-billion-dollar international ITER project. The primary focus will be on the continued design and fabrication of the highest priority, in-kind contributions

<u>Innovative Research Partnership Models</u>

- *Scientific Discovery through Advanced Computing*—SciDAC will address high-priority research on tokamak disruptions and large-scale fusion data analysis challenges, and continue development of an integrated whole-device modeling capability in partnership with the ASCR program.
- *Long-pulse tokamak and stellarator research*—Long-pulse tokamak research will provide research opportunities for U.S. scientists on superconducting tokamaks with world-leading capabilities. In addition, there will be research opportunities for U.S. collaborations in the deuterium–tritium (DT) experimental campaign on the Joint European

[a] https://science.energy.gov/fes/community-resources/workshop-reports/

Torus (JET). Long-pulse stellarator research will enable U.S. teams to take full advantage of U.S. hardware investments on Wendelstein 7-X (W7-X) and enhance the scientific output on this device.

- *Discovery plasma science*—Basic plasma research is partially carried out in partnership with NSF and NNSA. Research and operations will be focused on the intermediate-scale plasma science facilities selected in FY 2017 and on HEDLP research on the MEC instrument, an end station at LCLS, stewarded by the SC Basic Energy Sciences (BES) program.

<u>American Prosperity</u>

- *Discovery plasma science*—Activities will continue in low temperature plasma research and HEDLP research, with connections and spinoffs to U.S. industry.

Fusion Energy Sciences
Funding ($K)

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Fusion Energy Sciences				
Burning Plasma Science: Foundations				
Advanced Tokamak	90,238	—	90,350	+112
Spherical Tokamak	76,789	—	63,000	-13,789
Theory & Simulation	40,000	—	36,000	-4,000
GPE/GPP/Infrastructure	5,000	—	1,000	-4,000
Total, Burning Plasma Science: Foundations	**212,027**	**—**	**190,350**	**-21,677**
Burning Plasma Science: Long Pulse				
Long Pulse: Tokamak	10,000	—	9,000	-1,000
Long Pulse: Stellarators	7,569	—	7,000	-569
Materials & Fusion Nuclear Science	24,000	—	22,500	-1,500
Total, Burning Plasma Science: Long Pulse	**41,569**	**—**	**38,500**	**-3,069**
Discovery Plasma Science				
Plasma Science Frontiers	52,409	—	24,500	-27,909
Measurement Innovation	10,255	—	0	-10,255
SBIR/STTR & Other	13,740	—	11,650	-2,090
Total, Discovery Plasma Science	**76,404**	**—**	**36,150**	**-40,254**
Subtotal, Fusion Energy Sciences	**330,000**	**327,759**	**265,000**	**-65,000**
Construction				
14-SC-60 U.S. Contributions to ITER	50,000	49,660	75,000	+25,000
Total, Fusion Energy Sciences	**380,000**	**377,419**	**340,000**	**-40,000**

SBIR/STTR:

- FY 2017 Enacted: SBIR $8,814,000; and STTR: $1,239,000
- FY 2019 Request: SBIR $8,323,000; and STTR $1,170,000

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

Fusion Energy Sciences
Explanation of Major Changes ($K)

	FY 2019 Request vs FY 2017 Enacted
Burning Plasma Science: Foundations: DIII-D will emphasize completion of facility improvements that began in FY 2018, followed by 12 weeks of research operation. Funding for the NSTX-U program will support continued repair activities for the facility and enhanced collaborative research at other facilities to support NSTX-U research program priorities. SciDAC continues to make progress toward whole-device modeling, strengthening research on plasma disruptions and addressing large-scale data analysis challenges. Funding is provided for General Plant Projects/General Purpose Equipment (GPP/GPE), which supports Princeton Plasma Physics Laboratory (PPPL) infrastructure improvements, repair, and maintenance.	-21,677
Burning Plasma Science: Long Pulse: Efforts are focused on highest-priority international collaboration activities, both for tokamaks and stellarators. Materials research and fusion nuclear science research programs are focused on highest priorities. Funding will be initiated for the Materials Plasma Exposure eXperiment (MPEX) Major Item of Equipment (MIE) project, which was identified as a priority in the community workshop on Plasma Materials Interactions.	-3,069
Discovery Plasma Science: Research and operations of intermediate-scale scientific user facilities in General Plasma Science are emphasized. For High Energy Density Laboratory Plasmas, the focus remains on supporting research utilizing the Matter in Extreme Conditions instrument of the LCLS user facility at SLAC. No funding is requested for Exploratory Magnetized Plasma research and Measurement Innovation.	-40,254
Construction: The U.S. Contributions to ITER project will continue design, fabrication, and delivery of key First Plasma hardware components.	+25,000
Total Funding Change, Fusion Energy Sciences	**-40,000**

Basic and Applied R&D Coordination
FES participates in coordinated intra- and inter-agency initiatives within DOE and with other federal agencies on science and technology issues related to fusion and plasma science. Within SC, FES operates the MEC instrument at the SLAC LCLS user facility operated by BES, and supports high-performance computing research with ASCR. Within DOE, FES operates a joint program with NNSA in HEDLP physics. FESAC provides technical and programmatic advice to FES and NNSA for the joint HEDLP program. Outside DOE, FES carries out a discovery-driven plasma science research program in partnership with NSF, with research extending to a wide range of natural phenomena, including the origin of magnetic fields in the universe and the nature of plasma turbulence. The joint programs with NNSA and NSF involve coordination of solicitations, peer reviews, and workshops.

Program Accomplishments
Heating the core of fusion reactors leads to sheared rotation that can improve plasma performance – New measurements and simulations of plasma rotation at the DIII-D tokamak facility at General Atomics (GA) show that self-organized "intrinsic rotation" in tokamaks is generated by turbulence. Such self-organized flow can be beneficial for fusion reactor performance because it suppresses turbulent energy loss and magnetohydrodynamic instabilities. The experimental measurements show that simply heating the plasma core can cause it to generate a sheared flow. The computer modeling provides a quantitative understanding of the amount of sheared flow that can be generated with the use of this self-generated intrinsic torque.

Plasma instabilities can be eliminated when the heating power is increased – Alpha particles born from fusion reactions drive plasma instabilities that can cause reactors to lose heat, reducing their efficiency. Results from the NSTX-U facility at PPPL show for the first time that additional neutral beam heating can suppress plasma instabilities known as global Alfvén eigenmodes (GAE). Eliminating the GAE instabilities may be a key first step toward achieving high plasma performance in a compact spherical tokamak. The ability to predict and control these instabilities is also important for burning plasmas and future fusion reactors, which are heated by a large population of fusion-generated alpha particles and neutral beam ions.

Massively parallel simulations shed light on long-standing magnetic confinement challenge – Efficient operation of tokamak magnetic confinement fusion devices relies on attainment of the high-confinement mode (H-mode), which reduces the energy leakage from the confinement region by at least a factor of two through suppression of turbulence at the plasma edge. While the transition to H-mode has been known for at least 35 years and has been reproduced on all the world's tokamaks, a predictive understanding of this phenomenon has proved elusive. Recently, massively parallel simulations performed by scientists in the SciDAC Edge Physics Simulation Center (a partnership with ASCR) have, for the first time, modeled this transition with the use of a first-principles plasma turbulence simulation code and SC leadership computing resources. The simulations took three days and used 90% of the capacity of the Titan supercomputer at the Oak Ridge Leadership Computing Facility.

Proto-MPEX points the way to world-leading capability for plasma-material interactions research – The Prototype Material Plasma Exposure eXperiment (Proto-MPEX) at Oak Ridge National Laboratory (ORNL) successfully demonstrated a novel plasma generator aimed at enabling new experimental capabilities that are needed for plasma-material interaction research. Proto-MPEX allows the study of materials exposed to the extreme plasma conditions expected in future fusion devices. Its versatile design, based on a high-density radio frequency helicon plasma source coupled with separate ion and electron heating schemes, allows for independent control of vital plasma parameters such as density, electron temperature, and ion temperature. Although currently limited to low power and short pulse, Proto-MPEX has demonstrated the feasibility of the source concept and led to high confidence in the construction of a new world-leading experimental capability.

New approach could solve a significant challenge in the design of stellarator coils – New research has shown that the mathematical optimization methods used to compute the three-dimensional electromagnetic coil shapes for stellarators can be modified to increase the space between the coils and smooth their sharp bends, while preserving the speed and reliability of the optimization. This new method will enable stellarator designs that have smoother coil shapes and increased inter-coil spacing, which could be more feasible to construct and maintain.

U.S. international collaboration makes excellent start in optimizing the use of lithium to control fusion plasmas – For fusion to generate substantial energy, the ultra-hot plasma that fuels fusion reactions must remain stable and be kept from cooling. U.S. researchers have recently shown that lithium is effective in both respects in experiments on the Experimental Advanced Superconducting Tokamak (EAST) in Hefei, China. The recent scientific effort deployed three different lithium delivery systems in EAST. Each lithium delivery technology performed as designed and enabled improved modes of operation, including tokamak operation with external control of periodic edge instabilities, as well as control over the elemental composition of the surrounding edge plasma. These results motivate continued effort to develop sophisticated boundary control solutions that use lithium.

Laboratory experiments explain the kink behavior of the Crab Nebula Jet – Using the high-power Omega laser at the University of Rochester's Laboratory for Laser Energetics, U.S. scientists conducted experiments to understand the dynamics of the Crab Nebula jet evolution. Fusion protons from deuterium/helium-3 implosion were used to obtain spatial visualization and detailed measurements of the electromagnetic fields. The data shows that the toroidal magnetic field, embedded in the supersonic jet, triggers plasma instabilities and results in considerable deflections throughout the jet propagation, mimicking the kinks in the Crab Nebula jet.

First-ever measurement of the optical spectrum of anti-hydrogen – The study of anti-hydrogen is important because any measurable difference between its spectra and that of normal hydrogen will break basic principles of physics and help explain the puzzling matter-antimatter imbalance in the universe. However, anti-hydrogen atoms have to be synthesized from non-neutral anti-proton and positron plasmas, which is extremely challenging. Using techniques from plasma physics research, U.S. scientists in the international ALPHA team have successfully trapped nearly 500 antihydrogen atoms at the Large Hadron Collider of the European Organization for Nuclear Research (CERN). By illuminating these trapped anti-hydrogen atoms with two different wavelengths of laser light, the physicists were able to measure the optical spectrum of anti-hydrogen for the first time ever. Their results, which showed that the anti-atoms interact with light at nearly the same wavelength as for normal-matter hydrogen, received attention in the popular media.

Burning Plasma Science: Foundations

Description

The Burning Plasma Science: Foundations subprogram advances the predictive understanding of plasma confinement, dynamics, and interactions with surrounding materials. Among the activities supported by this subprogram are:

- Research at major experimental facilities aimed at resolving fundamental advanced tokamak and spherical tokamak science issues.
- Research on small-scale magnetic confinement experiments to elucidate physics principles underlying toroidal confinement and to validate theoretical models and simulation codes.
- Theoretical work on the fundamental description of magnetically confined plasmas and the development of advanced simulation codes on current and emerging high-performance computers.
- Research on technologies needed to support the continued improvement of the experimental program and facilities.
- Support for infrastructure improvements at PPPL.

Research in the Burning Plasma Science: Foundations area in FY 2019 will focus on high-priority challenges and opportunities in the areas of transients in tokamaks, plasma-material interactions, and integrated modeling, as identified by recent research needs workshops and other community-led studies.

Advanced Tokamak

The DIII-D user facility at General Atomics in San Diego, California, is the largest magnetic fusion research experiment in the U.S. and can magnetically confine plasmas at temperatures relevant to burning plasma conditions. Its extensive set of diagnostic systems, many unique in the world, and its extraordinary flexibility to explore various operating regimes make it a world-leading tokamak research facility. Researchers from the U.S. and abroad perform experiments on DIII-D for studying stability, confinement, and other properties of fusion-grade plasmas under a wide variety of conditions. The DIII-D research goal is to establish the broad scientific basis to optimize the tokamak approach to magnetic confinement fusion. Much of this research concentrates on developing the advanced tokamak concept, in which active control techniques are used to manipulate and optimize the plasma to obtain conditions scalable to robust operating points and high fusion gain for future energy-producing fusion reactors.

The Enabling Research and Development (R&D) element develops the technology to enhance the capabilities for existing and next-generation fusion research facilities, enabling these facilities to achieve higher levels of performance and flexibility needed to explore new science regimes.

Research on versatile university-led small-scale advanced tokamak projects is complementary to the efforts at the major user facilities, providing cost-effective development of new techniques and exploration of new concepts. Recent efforts are focused on improving fusion plasma control physics for advanced tokamaks through application of modern digital tokamak control theory and validation of fundamental plasma stability theory.

Spherical Tokamak

The NSTX-U user facility at PPPL has been designed to explore the physics of plasmas confined in a spherical tokamak (ST) configuration, characterized by a compact (apple-like) shape. If the predicted ST energy confinement improvements were to be experimentally realized in NSTX-U, then the ST might provide a more compact fusion reactor than other geometries. Following an extensive series of reviews (e.g., design validation and verification, extent of condition) in FY 2017 and FY 2018, NSTX-U activities will focus high-priority activities to implement repairs and corrective actions required to obtain robust, reliable research operations.

Small-scale ST plasma research involves focused experiments to provide data in regimes of relevance to the ST magnetic confinement program. This effort can help confirm theoretical models and simulation codes in support of the FES goal to develop an experimentally validated predictive capability for magnetically confined fusion plasmas. This activity also involves high-risk, but high-payoff, experimental efforts useful to advancing ST science.

Theory and Simulation

The Theory and Simulation activity is a key component of the FES program's strategy to develop the predictive capability needed for a sustainable fusion energy source. It also represents a world-leading U.S. strength and competitive advantage in fusion research. Its long-term goal is to enable a transformation in predictive power based on fundamental science and high-performance computing to minimize risk in future development steps and shorten the path toward the realization of fusion energy. This activity includes two main interrelated but distinct elements: Theory and SciDAC.

The Theory element is focused on advancing the scientific understanding of the fundamental physical processes governing the behavior of magnetically confined plasmas. The research supported ranges from foundational analytic theory to mid- and large-scale computational work using high-performance computing resources. In addition to its scientific discovery mission, the Theory activity provides the scientific grounding for the physics models implemented in the advanced simulation codes developed under the SciDAC activity described below and also supports validation efforts at major experiments.

The FES SciDAC element, a component of the SC-wide SciDAC program, is aimed at accelerating scientific discovery in fusion plasma science by capitalizing on SC investments in leadership-class computing systems and associated advances in computational science. The portfolio that emerged from the FY 2017 SC-wide SciDAC-4 re-competition consists of eight multi-institutional interdisciplinary partnerships, with seven jointly supported by FES and ASCR, and addresses the high-priority research directions identified in recent community workshops. The new portfolio emphasizes increased integration and whole-device modeling, as well as synergy with the fusion-relevant projects of the SC Exascale Computing Project (SC-ECP) to increase the readiness of the fusion community for the upcoming Exascale era.

Additional objectives of this element include the evaluation of the potential of emerging computational approaches, such as machine learning, to advance its mission and address the growing large-scale fusion data analysis challenges.

GPE/GPP/Infrastructure

This activity supports repairs of critical general infrastructure (e.g., utilities, roofs, roads, facilities) at the PPPL site.

Fusion Energy Sciences
Burning Plasma Science: Foundations

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
Advanced Tokamak $90,238,000	**$90,350,000**	**+$112,000**
DIII-D Research $40,500,000	*$40,500,000*	*$0*
DIII-D Operations $46,600,000	*$47,000,000*	*+$400,000*
Operations funding supported 17.6 weeks of research operations at the DIII-D facility. Research was conducted to prepare for burning plasmas in ITER, determine the optimal path to steady-state tokamak plasmas, and develop the plasma material interaction boundary solutions necessary for future devices. Specific research goals involved testing the predictive models of fast ion transport by multiple Alfvén eigenmodes, studying the physical processes that determine the edge pedestal density structure, and examining the impurity generation and transport from the high-Z coated tiles. Targeted enhancements to the facility involved completion and commissioning of an additional high-power microwave heating system, as well as continued work on improving the neutral beam heating control system and designing the modifications necessary for a second off-axis, co- and counter-directed neutral beam.	Operations funding will support 12 weeks of research at the DIII-D facility and the completion of a neutral beam modification to add bi-directional off-axis injection capability. Research will continue to determine the optimal path to steady-state tokamak plasmas, explore techniques to avoid and mitigate transients in tokamaks, and develop the plasma-material interaction boundary solutions necessary for future devices. Experiments will exploit additional heating and current drive systems added in FY 2018. The new neutral beam capability will be utilized to examine the physics of self-driven tokamak plasmas. Specific research goals will be aimed at further integrating the core and edge conditions in high-performance plasmas and studying the role of neutral fueling and transport in determining the edge pedestal structure.	Priority and balance of effort will be shifted from research operations toward completion of the facility improvements begun in FY 2018.
Enabling R&D $2,165,000	*$2,000,000*	*-$165,000*
Support continued to be provided for research in superconducting magnet technology and plasma fueling and heating technologies required to enhance the performance for existing and future magnetic confinement fusion devices.	Research will continue in superconducting magnet technology and plasma fueling and heating technologies required to enhance the performance for existing and future magnetic confinement fusion devices.	Research efforts in heating, fueling, and magnet technology will be focused on the highest priorities.

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
Small-scale Experimental Research $973,000	*$850,000*	*-$123,000*
Research continued to provide experimental data in regimes relevant to mainline tokamak confinement and experimental validation of models and codes.	Versatile university-led experiments will be focused on improving fusion plasma control physics for advanced tokamaks.	After the completion of diagnostic and control system enhancements in FY 2018, the emphasis will be on research operations.
Spherical Tokamak $76,789,000	**$63,000,000**	**-$13,789,000**
NSTX-U Research $32,000,000	*$27,000,000*	*-$5,000,000*
NSTX-U Operations $42,090,000	*$34,000,000*	*-$8,090,000*
Operations funding supported the recovery activities for the NSTX-U facility. Research focused on the study of ST confinement improvements observed during the FY 2016 experimental run campaign. Modeling and measurement data allowed elucidation of the detailed physical mechanisms responsible for these confinement improvements. In the absence of plasma operations at the NSTX-U facility, researchers carried out experiments on domestic and international spherical tokamaks, and continued analysis and publication of data obtained in FY 2016.	The NSTX-U Operations budget will support high-priority activities to implement repairs and corrective actions required to obtain robust, reliable research operations. The NSTX-U Research budget will fund the continued analysis of high-impact data, a focused effort on physics topics that directly support the recovery of robust NSTX-U plasma operations, and enhanced collaborative research at other facilities to support NSTX-U research program priorities.	Priority and balance of effort will be shifted from research operations toward repair and recovery of the facility.
Small-scale Experimental Research $2,699,000	*$2,000,000*	*-$699,000*
Research continued to provide experimental data in regimes relevant to mainline spherical torus confinement and experimental validation of models and codes.	Experimental studies of plasmas surrounded by liquid lithium material surfaces, which was identified as a priority research direction in the recent plasma-materials interactions workshop, will continue. Also, techniques to operate spherical tokamaks without the use of a central solenoid will continue to be experimentally tested.	After the completion of minor facility enhancements in FY 2018, activities in this category will focus on research operations.
Theory & Simulation $40,000,000	**$36,000,000**	**-$4,000,000**
Theory $22,000,000	*$18,000,000*	*-$4,000,000*
Theory continued to support theoretical and computational research addressing fundamental questions of magnetic confinement science. Emphasis was placed on projects maximizing synergy with the FES SciDAC portfolio and addressing the recommendations from the 2015 community workshops.	Theory will continue to focus on providing the scientific grounding for the physical models implemented in the large-scale simulation codes developed under SciDAC and addressing foundational problems in the science of magnetic confinement, as identified in recent community workshops.	Priority will be given to addressing the needs of the advanced simulation efforts.

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
SciDAC $18,000,000	*$18,000,000*	*$0*
The entire FES SciDAC portfolio was recompeted as part of the SC-wide SciDAC-4 review. The selected partnerships continued to focus on integrated simulations and whole device modeling, addressing the leading-priority research directions identified in the 2015 community workshops.	The SciDAC portfolio will continue to emphasize high-priority areas such as plasma disruptions, boundary physics, and plasma-materials interactions. The activities of all the partnerships will be coordinated to accelerate progress toward whole-device modeling. Synergy with whole-device modeling activities supported by the DOE Exascale Computing Project will be strengthened.	Studies will continue on highest-priority issues. In addition, research will address large-scale fusion data challenges.
GPE/GPP/Infrastructure $5,000,000	**$1,000,000**	**-$4,000,000**
Funding provided support for general infrastructure improvements for the PPPL site consistent with the PPPL Campus Modernization Plan, based upon an analysis of safety requirements, equipment reliability, and research-related infrastructure needs.	Funding will support Princeton Plasma Physics Laboratory (PPPL) infrastructure improvements, repair, and maintenance.	The focus will be on highest-priority infrastructure needs.

Description

The Burning Plasma Science: Long Pulse subprogram explores new and unique scientific regimes that can be achieved primarily with long-duration superconducting international machines, and addresses the development of the materials and technologies required to withstand and sustain a burning plasma. The key objectives of this area are to utilize these new capabilities to accelerate our scientific understanding of how to control and operate a burning plasma, as well as to develop the basis for a future fusion nuclear science facility. This subprogram includes long-pulse international tokamak and stellarator research and fusion nuclear science and materials research.

Long Pulse: Tokamak

Multi-institutional U.S. research teams will continue their successful work on advancing the physics and technology basis for long-pulse burning plasma operation via bilateral research on U.S. and international fusion facilities. Research on overseas superconducting tokamaks, conducted onsite and also via fully remote facility operation, leverages progress made in domestic devices and allows the U.S. fusion program to gain the knowledge needed to operate long-duration plasma discharges in future fusion energy devices. These efforts will be augmented by research on overseas non-superconducting tokamaks and spherical tokamaks with unique capabilities.

Long Pulse: Stellarator

Stellarators offer the promise of steady-state confinement regimes without transient events such as harmful disruptions. The three-dimensional (3-D) shaping of the plasma in a stellarator provides for a broader range in design flexibility than is achievable in a 2-D system. The participation of U.S. researchers on W7-X in Germany provides an opportunity to develop and assess 3-D divertor configurations for long-pulse, high-performance stellarators. The U.S. plans to develop control schemes to maintain plasmas with stable operational boundaries, including the challenges of control with superconducting coils and issues of the diagnosis-control cycle in long-pulse conditions. U.S. researchers will play key roles in developing the operational scenarios and hardware configuration for high-power, steady-state operation, an accomplishment that will advance the performance/pulse length frontier for fusion. The strong U.S. contributions during the W7-X construction phase have earned the U.S. formal partnership status. Accordingly, the U.S. is participating fully in W7-X research and access to data.

U.S. domestic compact stellarator research is focused on optimization of the stellarator concept through quasi-symmetric shaping of the toroidal magnetic field. A conventional stellarator lacks axial symmetry, resulting in reduced confinement of energetic ions, which are needed to heat the plasma. Quasi-symmetric shaping, invented in the U.S., offers an improved solution for stable, well confined, steady-state stellarator plasma confinement.

Materials and Fusion Nuclear Science

The Materials and Fusion Nuclear Science activity seeks to address the large scientific and technical gaps that exist between current-generation fusion experiments and future fusion reactors. Traditional materials used in present-day experiments will not be acceptable in an intense fusion nuclear environment, and the development of components for fusion power plants must be significantly improved in order to adequately provide the multiple functions of heat extraction, tritium breeding, and particle control. The scientific challenge is understanding the complex fusion environment, which combines extremely strong nuclear heating and damage, high temperatures, fluid-solid interactions, high tritium concentrations, and high magnetic fields, as well as large variations of these parameters from the first wall to the vacuum vessel, and the impact on materials and component performance. To help develop solutions for this complex scientific challenge, new experimental capabilities along with game-changing types of research will be required. Facilities with these experimental capabilities will need to duplicate or effectively simulate various aspects of the harsh fusion environment. These experimental capabilities should also lead to the development of new materials, which could be used in other applications besides fusion.

A high-priority objective for the fusion materials science effort is to continue pursuing the design and fabrication of the new world-leading experimental device, the Materials Plasma Exposure eXperiment (MPEX) at ORNL, which will allow for dedicated studies of reactor-relevant heat and particle loads on neutron-irradiated materials. The overall motivation is to gain entry into a new class of fusion materials science wherein the combined effects of fusion-relevant heat, particle, and neutron fluxes can be studied for the first time anywhere in the world.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
Long Pulse: Tokamak $10,000,000	**$9,000,000**	**-$1,000,000**
Multi-institutional U.S. research teams continued to conduct high-impact research on the international superconducting long-pulse tokamaks, taking advantage of their upgraded capabilities.	Research on the EAST and KSTAR superconducting tokamaks will continue to establish the physics bases and control tools for steady-state plasma scenarios, disruption avoidance and mitigation, and control of plasma-material interfaces. Also, a multi-institutional U.S. team will continue to develop diagnostics for the new Japanese superconducting tokamak JT-60SA. On the Joint European Torus, U.S. scientists will finish testing their shattered pellet disruption mitigation system and then collaborate on optimization of burning plasma scenarios with deuterium and tritium fuels.	Sustained funding enables continued exploitation of unique international capabilities by multi-institutional teams from the U.S.
Long Pulse: Stellarators $7,569,000	**$7,000,000**	**-$569,000**
Superconducting Stellarator Research $5,000,000	*$4,500,000*	*-$500,000*
U.S. scientists participated in W7-X research on topics important for understanding the physics of long-pulse plasma confinement in 3-D magnetic configurations. Topics included error fields, magnetic island physics, energetic-particle transport, impurity studies, plasma-material interactions, core plasma transport, and plasma control. The U.S. team collaborated in the preparation of equipment and plasma scenarios for long-pulse operation.	U.S. scientists will use data from the first major experimental campaign on W7-X to strengthen the basis for long-pulse operation with pellet fueling, test the innovative island divertor concept, investigate impurity recycling, study the effect of the U.S.-provided trim coils on fast-ion confinement and on modulation of divertor heat loads, and determine the effect of the radial electric field on impurity transport.	Sustained funding enables continued exploitation of the unique capabilities of the W7-X facility by a multi-institutional team from the U.S.
Compact Stellarator Research $2,569,000	*$2,500,000*	*-$69,000*
Research continued on experiments that are providing data in regimes relevant to mainline stellarator confinement and experimental validation of models and codes.	Research will provide experimental data in regimes of relevance to the mainline stellarator magnetic confinement efforts and help confirm theoretical models and simulation codes in support of the goal to develop an experimentally-validated predictive capability for magnetically confined fusion plasmas.	Research efforts are continued on highest-priority activities.

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
Materials & Fusion Nuclear Science $24,000,000	**$22,500,000**	**-$1,500,000**
Fusion Nuclear Science $10,252,000	*$8,500,000*	*-$1,752,000*
Utilization of existing experimental capabilities and development of new ones to conduct research in the areas of plasma-facing materials and plasma-material interactions were a key emphasis. In addition, research on understanding tritium retention, permeation and processing, neutronics, and material-corrosion issues for blankets and scoping studies on future fusion facilities continued.	Research will continue to focus on the priority areas of plasma-facing components, safety, tritium fuel cycle, and breeder blanket technologies. Opportunities will be considered for high-priority research on liquid metal plasma-facing components in response to the outcome of the systems-level study conducted during the previous two years. In addition, a study will be initiated to evaluate options for a neutron source to test materials in fusion-relevant environments.	Research efforts are focused on highest-priority activities.
Materials Research $13,748,000	*$12,000,000*	*-$1,748,000*
The program emphasized the utilization of existing experimental capabilities and development of new ones to conduct research in the area of material response to simulated fusion neutron irradiation. There was a continued focus on research toward structural materials that can withstand high levels of damage, increasing the ductility of tungsten, and modeling of helium damage in numerous materials.	Research efforts will continue to focus on the development of materials that can withstand the extreme fusion environment expected in future fusion reactors.	Research efforts are focused on supporting the initiation of design and fabrication activities for MPEX.
Projects $0	*$2,000,000*	*+$2,000,000*
	A new MIE project, the Materials Plasma Exposure eXperiment (MPEX) at ORNL will develop a world-leading capability for reactor-relevant plasma exposures of neutron irradiated materials. Detailed project engineering and design efforts and some long-lead procurements will be performed.	The Request initiates funding for the MPEX MIE.

Fusion Energy Sciences
Discovery Plasma Science

Description

The Discovery Plasma Science subprogram supports research that explores the fundamental properties and complex behavior of matter in the plasma state to improve the understanding required to control and manipulate plasmas for a broad range of applications. Plasma science is not only fundamental to understanding the nature of visible matter throughout the universe, but also to achieving the eventual production and control of fusion energy. Discoveries in plasma science are leading to an ever-increasing array of practical applications, such as nanomaterials and artificial diamond synthesis, micro- and opto-electronics fabrication, energy efficient lighting, plasma-enabled sterilization and tissue healing, combustion enhancement, and satellite communication.

The Discovery Plasma Science subprogram is organized into two principal activities: Plasma Science Frontiers and Measurement Innovation.

<u>Plasma Science Frontiers</u>

The Plasma Science Frontiers (PSF) activities involve research in largely unexplored areas of plasma science, with a combination of theory, computer modeling, and experimentation. These frontiers encompass extremes of the plasma state, ranging from the very small (several atom systems) to the extremely large (plasma structure spanning light years in length), from the very fast (attosecond processes) to the very slow (hours), from the diffuse (interstellar medium) to the extremely dense (diamond compressed to tens of gigabar pressures), and from the ultra-cold (tens of micro-kelvin degrees) to the extremely hot (stellar core). Advancing the science of these unexplored areas creates opportunities for new and unexpected discoveries with potential to be translated into practical applications. These activities are carried out on small- and mid-scale experimental collaborative research facilities.

The PSF portfolio includes coordinated research activities in the following three areas:

- *General Plasma Science* – Research in frontier areas of basic and low temperature plasma science and engineering, including advancing our understanding of the behavior of non-neutral and single-component plasmas, ultra-cold plasmas, dusty plasmas, and micro-plasmas, as well as the study of dynamical processes in classical plasmas including turbulence, thermal, radiative and particle transport, waves, structures, flows and their interactions.
- *High Energy Density Laboratory Plasmas* – Research directed at exploring the behavior of matter at extreme conditions of temperature, density, and pressure, including laboratory astrophysics and planetary science, structure and dynamic of matter at the atomic scale, laser-plasma interactions and relativistic optics, magnetohydrodynamics and magnetized plasmas, and plasma atomic physics and radiation transport.
- *Exploratory Magnetized Plasma* – Basic research involving the creation, control, and manipulation of magnetically confined plasmas to increase our understanding of terrestrial, space, and astrophysical phenomena or applications.

The PSF activity stewards world-class plasma science experiments and user facilities at small and intermediate scales. These platforms not only facilitate addressing frontier plasma science questions but also provide critical data for the verification and validation of plasma science simulation codes. This effort maintains strong partnerships with NSF and NNSA.

<u>Measurement Innovation</u>

The Measurement Innovation activity supports the development of world-leading innovative diagnostic techniques and their application to new, unexplored, or unfamiliar plasma regimes or scenarios. The challenge is to develop diagnostics with the high spatial, spectral, and temporal resolution necessary to validate plasma physics models used to predict the behavior of fusion plasmas. Advanced diagnostic capabilities successfully developed through this activity are migrated to domestic and international facilities as part of the Burning Plasma Science: Foundations and Burning Plasma: Long Pulse subprograms. The utilization of mature diagnostics systems is then supported via the research programs at major fusion facilities.

SBIR/STTR & Other

Funding for SBIR/STTR is included in this activity. Other items that are supported include research at Historically Black Colleges and Universities (HBCUs); the U.S. Burning Plasma Organization (USBPO), a national organization that coordinates research in burning plasma science; peer reviews for solicitations across the program; and FESAC.

Fusion Energy Sciences
Discovery Plasma Science

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
Plasma Science Frontiers $52,409,000	**$24,500,000**	**-$27,909,000**
General Plasma Science $24,000,000	*$14,000,000*	*-$10,000,000*
Core research areas of this activity continued, with a program focus on intermediate-scale plasma science user facilities, as well as research in areas identified in the 2015 Frontiers of Plasma Science Workshops Report.	Core research areas of this activity will continue, with focus on intermediate-scale plasma science collaborative user facilities that address questions related to plasma dynamo, magnetic reconnection, particle acceleration, turbulence, and magnetic self-organization.	Basic plasma science research on the intermediate-scale plasma science collaborative user facilities will be emphasized.
High Energy Density Laboratory Plasmas $18,000,000	*$10,500,000*	*-$7,500,000*
Research emphasized utilizing the MEC at LCLS, including continued support for the MEC beam-line science team, the experimental and theoretical HEDLP research groups at SLAC, and enhanced support of external HED science users of the MEC instrument.	Research will emphasize utilizing the MEC at LCLS for warm dense matter studies. Support will continue for the MEC beam-line science team and the experimental HEDLP research groups at SLAC. A study will be initiated to evaluate options for a MEC upgrade. Modest support is provided to make medium-scale HEDLP facilities accessible to university researchers.	Support will be focused on research and operations for the MEC.
Exploratory Magnetized Plasma $10,409,000	*$0*	*-$10,409,000*
Research efforts focused on discovery at the frontier of laboratory magnetized-plasma physics, emphasizing high-priority research as identified by the plasma science frontiers workshops held in FY 2015.	No funding is requested.	Due to higher priority activities, no funding is requested.

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
Measurement Innovation $10,255,000	**$0**	**-$10,255,000**
Measurement Innovation research activities continued with special emphasis on diagnostics for plasma transient instabilities, plasma-materials interactions, modeling validation, and basic plasma science identified in the 2015 community workshops.	No funding is requested.	Due to higher priority activities, no funding is requested.
SBIR/STTR & Other $13,740,000	**$11,650,000**	**-$2,090,000**
Funding continued to support USBPO activities, HBCUs, peer reviews for solicitations, and FESAC. SBIR/STTR funding is statutorily set at 3.65 percent of noncapital funding in FY 2017.	Support will continue for USBPO activities, HBCUs, peer reviews for solicitations, and FESAC. SBIR/STTR funding is statutorily set at 3.65 percent of noncapital funding in FY 2019.	The SBIR/STTR funding will be consistent with the FES total budget.

Fusion Energy Sciences
Construction

Description

The ITER facility, currently under construction in St. Paul-lez-Durance, France, aims to provide access to burning plasmas with fusion power output approaching reactor levels of hundreds of megawatts, for hundreds of seconds. Construction of ITER is a collaboration among the United States, European Union, Russia, Japan, India, Republic of Korea, and China, governed by an international agreement (the "ITER Joint Implementing Agreement"), through which the U.S. contributes in-kind-hardware components, personnel, and direct monetary funding to the ITER Organization (IO).

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Change FY 2019 Request vs FY 2017 Enacted
U.S. Contributions to ITER $50,000,000	**$75,000,000**	**+$25,000,000**
Funding was provided for the U.S. Contributions to ITER project to support continued progress on critical in-kind hardware contributions, including central solenoid superconducting magnet modules and structures, toroidal field magnet conductor, steady-state electrical network components, diagnostics development, tokamak cooling water system, and vacuum system.	The primary focus will be on First Plasma hardware including continued design and fabrication of the highest priority, in kind deliverables.	Funding will sustain progress on highest-priority First Plasma hardware contributions.

Fusion Energy Sciences
Performance Measures

In accordance with the GPRA Modernization Act of 2010, the Department sets targets for, and tracks progress toward, achieving performance goals for each program.

	FY 2017	FY 2018	FY 2019
Performance Goal (Measure)	**FES Facility Based Experiments - Experiments conducted on major fusion facilities [DIII-D National Fusion Facility (DIII-D) and National Spherical Torus Experiment Upgrade (NSTX)-U] leading toward predictive capability for burning plasmas and configuration optimization**		
Target	Conduct research to examine the effect of configuration on operating space for dissipative divertors. Handling plasma power and particle exhaust in the divertor region is a critical issue for future burning plasma devices. The very narrow edge power exhaust channel projected for tokamak devices that operate at high poloidal magnetic field is of particular concern. Increased and controlled divertor radiation, coupled with optimization of the divertor configuration, are envisioned as the leading approaches to reducing peak heat flux on the divertor targets and increasing the operating window for dissipative divertors. Data obtained from DIII-D and NSTX-U and archived from Alcator C-Mod will be used to assess the impact of edge magnetic configurations and divertor geometries on dissipative regimes, as well as their effect on the width of the power exhaust channel, thus providing essential data to test and validate leading boundary plasma models.	Conduct research to test predictive models of fast ion transport by multiple Alfvén eigenmodes. Fusion alphas and injected energetic neutral particle beams provide an important source of heating and current drive in advanced tokamak operating scenarios and burning plasma regimes. Alfven eigenmode instabilities can cause the redistribution or loss of fast ions and driven currents, as well as potentially decreasing fusion performance and leading to localized losses. Measured fast ion fluxes in DIII-D and NSTX-U plasmas with different levels of Alfven eigenmode activity will be used to determine the threshold for significant fast ion transport, assess mechanisms and models for such transport, and quantify the impact on beam power deposition and current drive. Measurements will be compared with theoretical predictions, including quantitative fluctuation data and fast ion density, in order to validate models and improve understanding of underlying mechanisms. Model predictions will	Conduct research to understand the role of neutral fueling and transport in determining the pedestal structure. The edge pedestal is a key component in achieving overall high confinement in a magnetic fusion device. Therefore, obtaining a physics understanding and predictive capability for the pedestal height and structure is a major goal of fusion research and requires advances in the understanding of the separate structure of density and temperature profiles in the pedestal region. A key challenge is to understand the importance of particle sources in determining the density pedestal and project to burning plasma scenarios. Experiments on DIII-D and archived data from C-Mod, DIII-D, and NSTX will be used to test how fueling, reduced recycling, and transport affect the density pedestal structure. The role of divertor geometry and its effect upon the pedestal structure will also be investigated. U.S. researchers involved in collaborative activities on other relevant

	FY 2017	FY 2018	FY 2019
		guide the development of attractive operating regimes.	experiments may also contribute to this effort.
Result	Met	TBD	TBD
Endpoint Target	Magnetic fields are the principal means of confining the hot ionized gas of a plasma long enough to make practical fusion energy. The detailed shape of these magnetic containers leads to many variations in how the plasma pressure is sustained within the magnetic bottle and the degree of control that experimenters can exercise over the plasma stability. These factors, in turn, influence the functional and economic credibility of the eventual realization of a fusion power reactor. The key to their success is a detailed physics understanding of the confinement characteristics of the plasmas in these magnetic configurations. The major fusion facilities can produce plasmas that provide a wide range of magnetic fields, plasma currents, and plasma shapes. By using a variety of plasma control tools, appropriate materials, and having the diagnostics needed to measure critical physics parameters, scientists will be able to develop optimum scenarios for achieving high performance plasmas in future burning plasma devices and, ultimately, in power plants.		
Performance Goal (Measure)	**FES Facility Operations - Average achieved operation time of FES user facilities as a percentage of total scheduled annual operation time**		
Target	≥ 90 %	≥ 90 %	≥ 90 %
Result	Met	TBD	TBD
Endpoint Target	Many of the research projects that are undertaken at the Office of Science's scientific user facilities take a great deal of time, money, and effort to prepare and regularly have a very short window of opportunity to run. If the facility is not operating as expected the experiment could be ruined or critically setback. In addition, taxpayers have invested millions or even hundreds of millions of dollars in these facilities. The greater the period of reliable operations, the greater the return on the taxpayers' investment.		
Performance Goal (Measure)	**FES Theory and Simulation - Performance of simulations with high physics fidelity codes to address and resolve critical challenges in the plasma science of magnetic confinement**		
Target	Lower hybrid current drive (LHCD) will be indispensable for driving off-axis current during long-pulse operation of future burning plasma experiments, since it offers important leverage for controlling damaging transients caused by magnetohydrodynamic instabilities. However, the experimentally	The interaction of the boundary plasma with the material surfaces in magnetically confined plasmas is among the most critical problems in fusion energy science. In FY 2018, perform high-performance computational simulations with coupled boundary plasma physics and materials surface models to predict the fuel	Understanding the relevant turbulent transport mechanisms at the edge of a high-performance tokamak is essential for predicting and optimizing the H-mode pedestal structure in future burning plasma devices. Global electromagnetic gyrokinetic simulations will be performed based on representative experimental

	FY 2017	FY 2018	FY 2019
	demonstrated high efficiency of LHCD is incompletely understood. In FY 2017, massively parallel, high-resolution simulations with 480 radial elements and 4095 poloidal modes will be performed using full-wave radiofrequency field solvers and particle Fokker-Planck codes to elucidate the roles of toroidicity and full-wave effects. The simulation predictions will be compared with experimental data from the superconducting EAST tokamak.	recycling and tritium retention of the divertor for deuterium-tritium burning plasma conditions, accounting for erosion, re-deposition and impurity transport in the plasma boundary, and an initial evaluation of the influence of material deposition on the recycling and retention.	pedestal scenarios in order to clarify which instabilities are most important for each of the particle and heat transport channels. Edge transport modeling will be performed in order to estimate and bound the particle and heat sources—e.g., the ionization density source and the atomic energy loss channels due to ionization, charge exchange, and radiation. Comparisons will be made with data from the DIII-D, JET, C-Mod and NSTX or MAST experiments.
Result	Met	TBD	TBD
Endpoint Target	Advanced simulations based on high physics fidelity models offer the promise of advancing scientific discovery in the plasma science of magnetic fusion by exploiting the Office of Science high performance computing resources and associated advances in computational science. These simulations are able to address the multiphysics and multiscale challenges of the burning plasma state and contribute to the FES goal of advancing the fundamental science of magnetically confined plasmas to develop the predictive capability needed for a sustainable fusion energy source.		

Fusion Energy Sciences
Capital Summary ($K)

	Total	Prior Years	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Capital Operating Expenses Summary						
Capital equipment	n/a	n/a	971	—	4,600	+3,629
General plant projects (GPP)	n/a	n/a	3,535	—	321	-3,214
Total, Capital Operating Expenses	**n/a**	**n/a**	**4,506**	—	**4,921**	**+415**
Capital Equipment						
Major items of equipment[b]						
Materials Plasma Exposure eXperiment (MPEX)	40,000–60,000	0	0	—	2,000	+2,000
Total Non-MIE Capital Equipment	n/a	n/a	971	—	2,600	+1,629
Total, Capital equipment	**n/a**	**n/a**	**971**	—	**4,600**	**+3,629**
General Plant Projects						
General Plant Projects under $5 million TEC	n/a	n/a	3,535	—	321	-3,214

Major Items of Equipment Descriptions

Materials Plasma Exposure eXperiment (MPEX): FES has conducted substantial research and development over the past five years to identify and develop an innovative linear, high intensity plasma source capable of producing the extreme plasma parameters required to simulate a burning plasma environment. FES is now building on this research to develop a first of a kind, world-leading, experimental capability which will be used to explore materials solutions to the daunting plasma materials interactions challenge. MPEX, which will be located at ORNL, will allow dedicated studies of reactor-relevant heat and particle loads on neutron-irradiated materials. The overall motivation is to gain entry into a new class of fusion materials science wherein the combined effects of fusion-relevant heat, particle, and neutron fluxes can be studied for the first time anywhere in the world. The preliminary total project cost range is estimated to be $40–60M.

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

[b] Each MIE located at a DOE facility Total Estimated Cost (TEC) >$5M and each MIE not located at a DOE facility TEC > $2M.

Construction Projects Summary ($K)

	Total	Prior Years	FY 2017 Enacted	FY 2018 Annualized CR	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
14-SC-60, U.S. Contributions to ITER						
Total Estimated Cost (TEC)	TBD	1,057,244	50,000	49,660	75,000	+25,000
Other Project Cost (OPC)	TBD	80,641	0	—	0	0
Total, Project Cost (TPC), 14-SC-60	**TBD**	**1,137,885**	**50,000**	**49,660**	**75,000**	**+25,000**

Funding Summary ($K)

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Research	236,310	—	181,000	-55,310
Scientific user facility operations	88,690	—	81,000	-7,690
Major Item of Equipment	0	—	2,000	+2,000
Other (GPP, GPE, and Infrastructure)	5,000	—	1,000	-4,000
Construction	50,000	49,660	75,000	+25,000
Total, Fusion Energy Sciences	**380,000**	**377,419**	**340,000**	**-40,000**

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

Scientific User Facility Operations and Research ($K)

The treatment of user facilities is distinguished between two types: TYPE A facilities that offer users resources dependent on a single, large-scale machine; TYPE B facilities that offer users a suite of resources that is not dependent on a single, large-scale machine.

Definitions:

Achieved Operating Hours – The amount of time (in hours) the facility was available for users.

Planned Operating Hours –

- For Past Fiscal Year (PY), the amount of time (in hours) the facility was planned to be available for users.
- For Current Fiscal Year (CY), the amount of time (in hours) the facility is planned to be available for users.
- For the Budget Fiscal Year (BY), based on the proposed budget request the amount of time (in hours) the facility is anticipated to be available for users.

Optimal Hours – The amount of time (in hours) a facility will be available to satisfy the needs of the user community if unconstrained by funding levels.

Percent of Optimal Hours – An indication of utilization effectiveness in the context of available funding; it is not a direct indication of scientific or facility productivity.

- For BY and CY, Planned Operating Hours divided by Optimal Hours expressed as a percentage.
- For PY, Achieved Operating Hours divided by Optimal Hours.

Unscheduled Downtime Hours – The amount of time (in hours) the facility was unavailable to users due to unscheduled events. NOTE: For type "A" facilities, zero Unscheduled Downtime Hours indicates Achieved Operating Hours equals Planned Operating Hours.

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
TYPE A FACILITIES				
DIII-D National Fusion Facility	**$87,100**	**—**	**$87,500**	**+$400**
Number of Users	603	—	640	+37
Achieved operating hours	704	—	N/A	N/A
Planned operating hours	680	—	480	-200
Optimal hours	1,000[b]	—	480[b]	-520
Percent optimal hours	70.4%	—	100.0%	+29.6%
Unscheduled downtime hours	N/A	—	N/A	N/A

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

[b] Optimal hours in FY 2017 and FY 2019 are less than the standard 1,000 hours due to a planned outage for facility modifications and enhancements.

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
National Spherical Torus Experiment—Upgrade	**$74,090**	**—**	**$61,000**	**-$13,090**
Number of Users	292	—	307	+15
Achieved operating hours	N/A	—	N/A	N/A
Planned operating hours	0	—	0	0
Optimal hours	0	—	0	0
Percent optimal hours	N/A	—	N/A	N/A
Unscheduled downtime hours	N/A	—	N/A	N/A
Total Facilities	**$161,190**	**—**	**$148,500**	**-$12,690**
Number of Users	895	—	947	+52
Achieved operating hours	704	—	N/A	N/A
Planned operating hours	680	—	480	-200
Optimal hours	1,000	—	480	-520
Percent of optimal hours[b]	70.4%	—	100.0%	0.0%
Unscheduled downtime hours	N/A	—	N/A	N/A

Scientific Employment

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Number of permanent Ph.D.'s (FTEs)	765	—	597	-168
Number of postdoctoral associates (FTEs)	96	—	76	-20
Number of graduate students (FTEs)	239	—	197	-42
Other[c]	1,161	—	895	-266

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

[b] For total facilities only, this is a "funding weighted" calculation FOR ONLY TYPE A facilities: $\frac{\sum_{1}^{n}[(\%OH\ for\ facility\ n)\times(funding\ for\ facility\ n\ operations)]}{Total\ funding\ for\ all\ facility\ operations}$

[c] Includes technicians, engineers, computer professionals, and other support staff.

14-SC-60, U.S. Contributions to ITER

1. Significant Changes and Summary

Significant Changes

This Construction Project Data Sheet (CPDS) is an update of the FY 2018 CPDS and does not include a new start for FY 2019.

The DOE Order 413.3B approved Critical Decision (CD) CD-1, "Approve Alternative Selection and Cost Range," was approved on January 25, 2008, with a preliminary cost range of $1.45–$2.2 billion. Since 2008, the estimated cost range for the project increased such that the upper bound of the approved CD-1 cost range increased by more than 50%, triggering the need for a reassessment of the project cost range and re-approval by the Project Management Executive (PME). The PME for the U.S. ITER project is the Deputy Secretary of Energy. The cost range reassessment was completed in November 2016 and it was then subsequently approved by the PME on January 13, 2017. The CD-1 Revised cost range is now $4.7B to $6.5B.

As outlined in the May 2016 Secretary of Energy's Report to Congress, DOE was to baseline the "First Plasma" portion of the U.S. ITER project. As such, DOE has divided the U.S. ITER project hardware scope into two distinct subprojects, which represent the two phases of the project; First Plasma (FP) subproject (SP-1) and Post-First Plasma subproject (SP-2). The FP subproject scope consists of: 1) completing the design for all twelve systems the U.S. is contributing to ITER; 2) complete fabrication and delivery of the Toroidal Field (TF) superconductor; the Steady-State Electrical Network (SSEN), and the Central Solenoid (CS) superconducting magnet modules, assembly tooling, and associated structures; and 3) partial fabrication and delivery of seven other subsystems: Tokamak Cooling Water, Roughing Pumps, Vacuum Auxiliary, Pellet Injection, Ion Cyclotron Heating, Electron Cyclotron Heating, and two of seven Diagnostics. A review of CD-2, "Approve Performance Baseline" for the SP-1 was completed in November 2016 and then subsequently approved by the PME on January 13, 2017, with a total project cost of $2.5B, and a CD-4, "Project Completion" date of December 2027. In addition, the PME also approved CD-3, "Approve the Start of Construction" for the SP-1 on January 13, 2017. This CPDS focuses on the First Plasma subproject activities. Funding for the SP-2 will not be requested until FY 2020.

Establishment of an approved baseline for SP-2 will follow once the Administration has made a determination as to whether the U.S. will continue its participation in ITER. No procurements for SP-2 scope are anticipated until at the earliest FY 2021. Outyear numbers for this datasheet are shown as TBD. In addition to SP-1 and SP-2, and U.S. monetary resources (i.e., cash contributions) to support the ITER Organization (IO) construction-phase activities comprise the third and final element of the U.S. ITER project scope. The source of funds for all three project elements is the annual U.S. Contributions to ITER Congressional Line-Item appropriations.

Summary

SP-1 is more than 50% complete, as are the fabrication and delivery of two of the twelve subsystems the U.S. is to provide to ITER, specifically the Toroidal Field coil superconductor, and the Steady-State Electrical Network. The FY 2019 Request will focus on the continued design and fabrication of the highest priority, in kind deliverables. ITER is a major fusion research facility being constructed in St. Paul-lez-Durance, France by an international partnership of seven governments. Since it will not result in a facility owned by the U.S. or located in the U.S., the U.S. Contributions to ITER (U.S. ITER) project is not classified as a Capital Asset project, but is classified as a Major System Project. The U.S. ITER project is a U.S. Department of Energy project to provide the U.S. share of ITER construction (in-kind hardware i.e., subsystems, equipment, and components, as well as monetary resources to support the IO in France). Sections of this CPDS have been tailored accordingly to reflect the nature of this project.

The U.S. ITER project is managed as a DOE Office of Science (SC) project through the U.S. ITER Project Office (USIPO). The USIPO is managed by Oak Ridge National Laboratory, in partnership with Princeton Plasma Physics Laboratory and the Savannah River National Laboratory. The project began as a Major Item of Equipment (MIE) in FY 2006, and was changed to a Congressional control point Line-Item beginning in FY 2014. As with all SC projects, the principles of DOE Order 413.3B are applied in the effective management of the project, including critical decision milestones and their supporting prerequisite activities. Requirements for project documentation, monitoring and reporting, change control, and regular independent project reviews (IPRs) are being applied with the same degree of rigor as other SC line-item projects. Progress and performance are reported regularly in monthly performance metrics and project status reports.

Fabrication is underway in three of the U.S. hardware systems (CS magnet modules, structures, and assembly tooling) Tokamak Cooling Water System [TCWS] and Vacuum Auxiliary Systems [VAS]). The U.S. ITER project has subcontracted with General Atomics (GA) for the fabrication of the world's largest pulsed superconducting magnets for the ITER CS magnet system. CS magnet module fabrication includes six production and one spare. From 2006 through 2017, the U.S. ITER project has awarded and obligated over $957 million to U.S. industry, universities, and DOE laboratories.

The U.S ITER Federal Project Director with certification level 3 has been assigned to this Project and has approved this CPDS.

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2006	7/5/2005		TBD	TBD		TBD	N/A	TBD
FY 2007	7/5/2005		TBD	TBD		TBD	N/A	2017
FY 2008	7/5/2005		1/25/2008	4Q FY 2008		TBD	N/A	2017
FY 2009	7/5/2005	09/30/2009[a]	1/25/2008	4Q FY 2010		TBD	N/A	2018
FY 2010	7/5/2005	07/27/2010[b]	1/25/2008	4Q FY 2011		TBD	N/A	2019
FY 2011	7/5/2005	05/30/2011[c]	1/25/2008	4Q FY 2011	04/12/2011[d]	TBD	N/A	2024
FY 2012	7/5/2005	07/10/2012[e]	1/25/2008	3Q FY 2012	05/02/2012[f]	TBD	N/A	2028
FY 2013	7/5/2005	12/11/2012[g]	1/25/2008	TBD[h]	04/10/2013[i]	TBD	N/A	2033

[a] Electron Cyclotron Heating (ECH) Transmission lines (TL) (06/22/2009); Tokamak Cooling Water System (07/21/2009); CS Modules, Structures, and Assembly Tooling (AT) (09/30/2009).
[b] Ion Cyclotron Heating Transmission Lines (ICH) (10/14/2009); Tokamak Exhaust Processing (TEP) (05/17/2010); Diagnostics: Residual Gas Analyzer (RGA) (07/14/2010), Upper Visible Infrared Cameras (VIR) (07/27/2010).
[c] Vacuum Auxiliary System (VAS) – Main Piping (12/13/2010); Diagnostics Low-Field-Side Reflectometer (LFS) (05/30/2011).
[d] Cooling Water Drain Tanks (04/12/2011).
[e] Diagnostics: Upper Port (10/03/2011), Electron Cyclotron Emission (ECE) (12/06/2011), Equatorial Port E-9 and Toroidal Interferometer Polarimeter (TIP) (01/02/2012), Equatorial Port E-3 (07/10/2012).
[f] Steady State Electrical Network (05/02/2012).
[g] VAS Supply (11/13/2012); Disruption Mitigation (12/11/2012); Pellet Injection (04/29/2013); Diagnostics: Motional Stark Effect Polarimeter (MSE) (05/29/2013), Core Imaging X-ray Spectrometer (CIXS) (06/01/2013).
[h] The CD-2 date will be determined upon acceptable resolution of issues related to development of a high-confidence ITER Project Schedule and establishment of an approved funding profile.
[i] RGA Divertor Sampling Tube (07/28/14); CS AT, Early Items (09/17/14).

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2014	7/5/2005		1/25/2008	TBD	12/10/2013[a]	TBD	N/A	2034
FY 2015	7/5/2005		1/25/2008	TBD		TBD	N/A	2036
FY 2016[b]	7/5/2005		1/25/2008	TBD		TBD	N/A	TBD
FY 2017[c]	7/5/2005		1/25/2008	TBD		TBD	N/A	TBD

CD-0 – Approve Mission Need

CD-1 – Approve Alternative Selection, Cost Range, and Start of Long-lead Procurements

CD-2 – Approve Performance Baseline

CD-3 – Approve Start of Fabrication

CD-4 – Approve Project Completion

		CD-1 Cost Range Update	CD-2/3		CD-4	
			SP-1	SP-2	SP-1	SP-2
FY 2018[d]	7/5/2005	1/13/17	1/13/17	2019	1Q2027	2034-2038
FY 2019	7/5/2005	1/13/17	1/13/17	TBD	1Q2027	2034-2038

3. Project Cost History

At the time of CD-1 approval in January 2008, the preliminary cost range was $1.45–$2.2 billion. Until recently, however, it has not been possible to confidently baseline the project due to past delays in the international ITER construction schedule. Various factors (e.g., schedule delays, design and scope changes, funding constraints, regulatory requirements, risk mitigations, and project management and leadership issues in the ITER Organization) have affected the project cost. In response to a 2013 Congressional request, a DOE Office of Science IPR Committee assessed the project and determined that the existing cost range estimate of $4.0 to $6.5B would likely encompass the final TPC. This range, recommended in 2013, was included in subsequent Presidents Budget Requests and in the May 2016 DOE "Report on the Continued U.S. Participation in the ITER Project" to Congress. In preparation for baselining SP-1, based on the results of the IPR, a decision was made to update the lower end of this range to reflect updated cost estimates resulting in the current approved CD-1R range of $4.7 to $6.5B. This updated CD-1R range incorporates increases in the projects hardware estimate that have occurred since August 2013. The SP-1 TPC has been baselined at $2.5B.

4. Project Scope and Justification

Introduction

ITER is an international partnership among seven Member governments (China, the European Union, India, Japan, the Republic of Korea, the Russian Federation, and the United States) aimed at demonstrating the scientific and technological feasibility of fusion energy for peaceful purposes. The *Agreement on the Establishment of the ITER International Fusion Energy Organization for the Joint Implementation of the ITER Project* (ITER Agreement), signed on November 21, 2006, provides the legal framework for the four phases of the program: construction, operation, deactivation, and

[a] CS Modules and Structures (11/18/2013); VAS Main Piping B-2, L-1, L-2 (12/10/2013).

[b] CS AT Remaining Items (12/02/2015).

[c] Roughing Pumps (03/2017); VAS 03 Supply (06/2017); Roughing Pumps I&C (06/2017); VAS 03 Supply I&C (04/2017); CS AT Bus Bar Alignment and Coaxial Heater (04/2017); VAS Main Piping L3/L4 (03/2017); VAS 02 CGVS (&C Part 1 (06/2017).

[d] VAS 02 Supply Part 1 (05/2018); ICH RF Building and I&C (11/2017); TCWS Captive Piping and First Plasma (10/2017); ICH RF components supporting INDA/IO testing (01/2018).

decommissioning. Through participation in the agreement, the European Union, as the host, will bear five-elevenths (45.45%) of the ITER facility's construction cost, while the other six Members, including the U.S., will each support one-eleventh (9.09%) of the ITER facilities cost. Operation, deactivation, and decommissioning of the facility are to be funded through a different cost-sharing formula in which the U.S. will contribute a 13% share, which is not a part of the U.S. ITER project funding. Responsibility for ITER integration, management, design, licensing, installation, and operation rests with the IO, which is an international legal entity located in France.

Scope

U.S. Contributions to ITER – Construction Project Scope

The overall U.S. ITER project includes three major elements:

- Hardware components, built under the responsibility of the U.S., then shipped to the ITER site for IO assembly, installation, and operation.
- Funding to the IO to support common expenses, including ITER research and development (R&D), IO staff and infrastructure, IO-provided hardware, on-site assembly/installation/testing of all ITER components, and IO Central Reserve.
- Other project costs, including R&D and conceptual design related activities.

The U.S. is to contribute the following hardware to ITER:

- Tokamak Cooling Water System (TCWS): manages the thermal energy generated during the operation of the tokamak.
- 15% of ITER Diagnostics: provides the measurements necessary to control, evaluate, and optimize plasma performance and to further the understanding of plasma physics.
- Disruption Mitigation (DM) Systems: limits the impact of plasma disruptions to the tokamak vacuum vessel, blankets, and other components.
- Electron Cyclotron Heating (ECH) Transmission Lines: brings additional power to the plasma and deposits power in specific areas of the plasma to minimize instabilities and optimize performance.
- Tokamak Exhaust Processing (TEP) System: separates hydrogen isotopes from tokamak exhaust.
- Tokamak Fueling System (Pellet Injection): injects fusion fuels in the form of deuterium-tritium ice pellets into the vacuum chamber.
- Ion Cyclotron Heating (ICH) Transmission Lines: bring additional power to the plasma.
- Central Solenoid (CS) Magnet System: confines, shapes and controls the plasma inside the vacuum vessel. All CS workscope is SP-1.
- 8% of Toroidal Field (TF) Conductor: component of the TF magnet that confines, shapes, and controls the plasma. All TF work scope was completed in FY 2017.
- 75% of the Steady-State Electrical Network (SSEN): supplies the electricity needed to operate the entire plant, including offices and the operational facilities. All SSEN work scope was completed in FY 2017.
- Vacuum Auxiliary System (VAS): creates and maintains low gas densities in the vacuum vessel and connected vacuum components.
- Roughing Pumps: evacuate the tokamak, cryostat, and auxiliary vacuum chambers prior to and during operations.

Justification

The purpose of ITER is to investigate and conduct research in the so-called "burning plasma" regime—a performance region that exists beyond the current experimental state of the art. Creating a self-sustaining burning plasma will provide essential scientific knowledge necessary for practical fusion power. There are two parts of this need that will be achieved by ITER. The first part is to investigate the fusion process in the form of a "burning plasma," in which the heat generated by the fusion process exceeds that supplied from external sources (i.e., self-heating). The second part of this need is to sustain the burning plasma for a long duration (e.g., several hundred to a few thousand seconds), during which time equilibrium conditions can be achieved within the plasma and adjacent structures. ITER is the necessary next step to establish the confidence in proceeding with development of a demonstration fusion power plant.

Although not classified as a Capital Asset, the U.S. ITER project is being conducted in accordance with the project management principles of DOE Order 413.3B, Program and Project Management for the Acquisition of Capital Assets.

5. Financial Schedule

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Total Estimated Cost (TEC)			
Hardware			
FY 2006	13,754	13,754	6,169
FY 2007	34,588	34,588	24,238
FY 2008	25,500	25,500	24,122
FY 2009	85,401	85,401	26,278
FY 2010	85,266	85,266	46,052
FY 2011	63,875	63,875	84,321
FY 2012[b]	91,441	91,407	99,215
FY 2013	107,635	107,669	110,074
FY 2014[c]	161,605	161,605	153,368
FY 2015	128,682	128,682	105,908
FY 2016[d]	115,000	115,000	106,519
FY 2017	50,000	50,000	123,117
FY 2018	63,000	63,000	116,366
FY 2019	75,000	75,000	75,000
Subtotal	1,100,747	1,100,747	1,100,747
Total, Hardware	TBD	TBD	TBD
Cash Contributions[e]			
FY 2006	2,112	2,112	2,112
FY 2007	7,412	7,412	7,412
FY 2008	2,644	2,644	2,644
FY 2009	23,599	23,599	23,599
FY 2010	29,734	29,734	29,734
FY 2011	3,125	3,125	3,125
FY 2012	13,214	13,214	13,214
FY 2013	13,805	13,805	13,805
FY 2014[b]	32,895	32,895	32,895
FY 2015	15,957	15,957	15,957
FY 2016[f]	0	0	0
FY 2017	0	0	0
FY 2018	0	0	0
FY 2019	0	0	0
Subtotal	144,497	144,497	144,497
Total, Cash Contributions	TBD	TBD	TBD
Total, TEC	TBD	TBD	TBD

[a] Costs through FY 2017 reflect actual costs; costs for FY 2018 and the outyears are estimates.
[b] Prior actuals adjusted to incorporate project funds utilized at PPPL and DOE. Obligation adjusted to reflect year-end PPPL settlement funding.
[c] Appropriations prior to FY 2014 reflect major item of equipment funding. Starting in FY 2014, this project is funded as a Congressional control point.
[d] FY 2016 funding for taxes and tax support is included in the FY 2017 Hardware funding amount.
[e] Includes cash payments, secondees, taxes and tax support.
[f] No FY 2016 funding is provided to support the ITER organization.

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Other project costs (OPC)			
FY 2006	3,449	3,449	1,110
FY 2007	18,000	18,000	7,607
FY 2008	-2,074	-2,074	7,513
FY 2009	15,000	15,000	5,072
FY 2010	20,000	20,000	7,754
FY 2011	13,000	13,000	10,032
FY 2012[a]	345	345	22,336
FY 2013	2,560	2,560	5,984
FY 2014[b]	5,000	5,000	2,717
FY 2015	5,361	5,361	5,500
FY 2016	0	0	3,958
FY 2017	0	0	1,058
FY 2018	0	0	0
FY 2019	0	0	0
Subtotal	80,641	80,641	80,641
Total, OPC	TBD	TBD	TBD
Total Project Costs (TPC)			
FY 2006	19,315	19,315	9,391
FY 2007	60,000	60,000	39,257
FY 2008	26,070	26,070	34,279
FY 2009	124,000	124,000	54,949
FY 2010	135,000	135,000	83,540
FY 2011	80,000	80,000	97,478
FY 2012[a]	105,000	104,966	134,765
FY 2013	124,000	124,034	129,863
FY 2014[b]	199,500	199,500	188,980
FY 2015	150,000	150,000	127,365
FY 2016	115,000	115,000	110,477
FY 2017	50,000	50,000	124,175
FY 2018	63,000	63,000	116,366
FY 2019	75,000	75,000	75,000
Subtotal	1,325,885	1,325,885	1,325,885
Total, TPC	TBD	TBD	TBD

6. Details of the 2018 Project Cost Estimate

The project has an approved updated Critical Decision-1 Cost Range and DOE has chosen to divide the project hardware scope into two distinct subprojects (First Plasm subproject (SP-1) and Post- First Plasma subproject SP-2). The baseline for SP-1 was approved in January 2017. Baselining of SP-2 will follow Administration has made a decision on whether the U.S. will continue its participation in ITER. No procurements for SP-2 scope are anticipated until FY 2021 at the earliest. An IPR of U.S. ITER was conducted on November 14-17, 2016, to consider the project’s readiness for CD-2 (Performance Baseline) and CD-3 (Begin/Continue Fabrication) for SP-1 as well as the proposed updated CD-1 Cost Range. Outcomes from the IPR indicated that the project was ready for approval of SP-1 CD-2/3 following a reassessment of contingency to account for risk

[a] Prior actuals adjusted to incorporate project funds utilized at PPPL and DOE. Obligation adjusted to reflect year-end PPPL settlement funding.
[b] Appropriations prior to FY 2014 reflect major item of equipment funding. Starting in FY 2014, this project is funded as a Congressional control point.

in the areas of escalation and currency exchange. This recommendation has been addressed. In addition, the IPR committee found no compelling reason to deviate from the cost range identified in the May 2016 Report to Congress ($4.0B to $6.5B) and recommended that this range be adopted and approved as the Updated CD-1 cost range. However, as noted above, in preparation for baselining SP-1 and based on the outcome of the IPR, a decision was made to update the lower end of this range to reflect updated cost estimates resulting in the current approved CD-1R range of $4.7 to 6.5B.

7. Schedule of Appropriation Requests

(dollars in thousands)

		Prior Years	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	Outyears	Total
FY 2006	TEC	1,038,000	0	0	0	0	0	0	0	1,038,000
	OPC	84,000	0	0	0	0	0	0	0	84,000
	TPC	1,122,000	0	0	0	0	0	0	0	1,122,000
FT 2007	TEC	1,047,051	30,000	0	0	0	0	0	0	1,077,051
	OPC	44,949	0	0	0	0	0	0	0	44,949
	TPC	1,092,000	30,000	0	0	0	0	0	0	1,122,000
FY 2008	TEC	1,048,230	30,000	0	0	0	0	0	0	1,078,230
	OPC	43,770	0	0	0	0	0	0	0	43,770
	TPC	1,092,000	30,000	0	0	0	0	0	0	1,122,000
FY 2009[a]	TEC	266,366	0	0	TBD	TBD	TBD	TBD	TBD	TBD
	OPC	38,075	0	0	TBD	TBD	TBD	TBD	TBD	TBD
	TPC	304,441	0	0	TBD	TBD	TBD	TBD	TBD	TBD
FY 2010	TEC	294,366	0	0	TBD	TBD	TBD	TBD	TBD	TBD
	OPC	70,019	0	0	TBD	TBD	TBD	TBD	TBD	TBD
	TPC	364,385	0	0	TBD	TBD	TBD	TBD	TBD	TBD
FY 2011	TEC	379,366	0	0	TBD	TBD	TBD	TBD	TBD	TBD
	OPC	65,019	0	0	TBD	TBD	TBD	TBD	TBD	TBD
	TPC	444,385	0	0	TBD	TBD	TBD	TBD	TBD	TBD
FY 2012[b]	TEC	394,566	0	0	TBD	TBD	TBD	TBD	TBD	TBD
	OPC	75,019	0	0	TBD	TBD	TBD	TBD	TBD	TBD
	TPC	469,585	0	0	TBD	TBD	TBD	TBD	TBD	TBD
FY 2013[c]	TEC	617,261	0	0	TBD	TBD	TBD	TBD	TBD	TBD
	OPC	82,124	0	0	TBD	TBD	TBD	TBD	TBD	TBD
	TPC	699,385	0	0	TBD	TBD	TBD	TBD	TBD	TBD
FY 2014[d]	TEC	581,868	225,000	0	TBD	TBD	TBD	TBD	TBD	TBD
	OPC	73,159	0	0	TBD	TBD	TBD	TBD	TBD	TBD
	TPC	655,027	225,000	0	TBD	TBD	TBD	TBD	TBD	TBD
FY 2015	TEC	603,105	194,500	144,639	TBD	TBD	TBD	TBD	TBD	TBD
	OPC	70,280	5,000	5,361	TBD	TBD	TBD	TBD	TBD	TBD
	TPC	673,385	199,500	150,000	TBD	TBD	TBD	TBD	TBD	TBD

[a] The Prior Years column for FY 2009 through FY 2012 reflects the total of appropriations and funding requests only through the year of that row. Thus, for example, in the FY 2010 row, it reflects only funding from FY 2006 to FY 2012.
[b] The FY 2012 request was submitted before a full-year appropriation for FY 2011 was in place, and so FY 2011 was TBD at that time. Hence, the Prior Years column for FY 2012 reflects appropriations for FY 2006 through FY 2010 plus the FY 2012 request.
[c] The FY 2013 amount shown in the FY 2014 request reflected a short-term continuing resolution level annualized to a full year and based on the FY 2012 funding level for ITER.
[d] Prior to FY 2015, the requests were for a major item of equipment broken out by TEC, OPC, and TPC.

		(dollars in thousands)								
		Prior Years	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	Outyears	Total
FY 2016	TEC	603,105	194,500	144,639	150,000	TBD	TBD	TBD	TBD	TBD
	OPC	70,280	5,000	5,361	0	TBD	TBD	TBD	TBD	TBD
	TPC	673,385	199,500	150,000	150,000	TBD	TBD	TBD	TBD	TBD
FY 2017	TEC	603,105	194,500	144,639	115,000	125,000	TBD	TBD	TBD	TBD
	OPC	70,280	5,000	5,361	0	0	TBD	TBD	TBD	TBD
	TPC	673,385	199,500	150,000	115,000	125,000	TBD	TBD	TBD	TBD
FY 2018	TEC	603,105	194,500	144,639	115,000	50,000	63,000	TBD	TBD	TBD
	OPC	70,280	5,000	5,361	0	0	0	TBD	TBD	TBD
	TPC	673,385	199,500	150,000	115,000	50,000	63,000	TBD	TBD	TBD
FY 2019	TEC	603,105	194,500	144,639	115,000	50,000	63,000	75,000	TBD	TBD
	OPC	70,280	5,000	5,361	0	0	0	0	TBD	TBD
	TPC	673,385	199,500	150,000	115,000	50,000	63,000	75,000	TBD	TBD

8. Related Operations and Maintenance Funding Requirements

The U.S. Contributions to ITER operations is assumed to begin with initial integrated commissioning activities and continue for a period of 15 to 25 years. The fiscal year in which commissioning activities begin depends on the international ITER project schedule which currently indicates 2025.

Start of Operation or Beneficial Occupancy (fiscal quarter or date)	12/2025
Expected Useful Life (number of years)	15–25
Expected Future start of D&D for new construction (fiscal quarter)	TBD

9. D&D Funding Requirements

Since ITER is being constructed in France by a coalition of countries and will not be a DOE asset, the "one-for-one" requirement is not applicable to this project.

The U.S. Contributions to ITER Decommissioning are assumed to begin when operations commence and continue for a period of 20 years. The U.S. is responsible for 13 percent of the total decommissioning cost.

The U.S. Contributions to ITER Deactivation are assumed to begin 20 years after commissioning and continue for a period of 5 years. The U.S. is responsible for 13 percent of the total deactivation cost.

10. Acquisition Approach for U.S. Hardware Contributions

The U.S. ITER Project Office (USIPO) at Oak Ridge National Laboratory, with its two partner laboratories (Princeton Plasma Physics Laboratory and Savannah River National Laboratory), will procure and deliver in-kind hardware in accordance with the Procurement Arrangements established with the international IO. The USIPO will subcontract with a variety of research and industry sources for design and fabrication of its ITER components, ensuring that designs are developed that permit fabrication, to the maximum extent possible, under fixed-price subcontracts (or fixed-price arrangement documents with the IO) based on performance specifications, or more rarely, on build-to-print designs. USIPO will use cost-reimbursement type subcontracts only when the work scope precludes accurate and reasonable cost contingencies being gauged and established beforehand. USIPO will utilize best value, competitive source selection procedures to the maximum extent possible, including foreign firms on the tender/bid list where appropriate. Such procedures shall allow for cost and technical trade-offs during source selection. For the large-dollar-value subcontracts (and critical path subcontracts as appropriate), USIPO will utilize unique subcontract provisions to incentivize cost control and schedule performance. In addition, where it is cost effective and it reduces risk, the USIPO will participate in common procurements led by the IO, or request the IO to perform activities that are the responsibility of the U.S.

High Energy Physics

Overview

The High Energy Physics (HEP) program's mission is to understand how the universe works at its most fundamental level by discovering the elementary constituents of matter and energy, probing the interactions between them, and exploring the basic nature of space and time.

Our current understanding of the elementary constituents of matter and energy is captured in what is called the Standard Model of particle physics. It describes the elementary particles that comprise ordinary matter and the forces that govern them with very high precision. However, recent observations that are not explained by the Standard Model suggest that it is incomplete and new physics may be discovered by future experiments. Astronomical observations indicate that ordinary matter makes up only about 5% of the universe, the remainder being 70% dark energy and 25% dark matter, both "dark" because they are either nonluminous or unknown. The observation of very small but non-zero masses of the elementary particles known as neutrinos provides further hints of new physics beyond the Standard Model.

A world-wide program of particle physics research is underway to discover what lies beyond the Standard Model. To guide U.S. investments, the U.S. particle physics community developed a long-term strategic plan through a multi-year process that culminated in the May 2014 report of the Particle Physics Project Prioritization Panel (P5), "Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context."[a] The P5 report was unanimously approved by the High Energy Physics Advisory Panel (HEPAP) to serve the DOE and National Science Foundation (NSF) as the ten-year strategic plan for U.S. high energy physics in the context of a 20-year global vision. The P5 report identified five intertwined science drivers of particle physics that provide compelling lines of inquiry with great promise for discovery:

- Use the Higgs boson as a new tool for discovery
- Pursue the physics associated with neutrino mass
- Identify the new physics of dark matter
- Understand cosmic acceleration: dark energy and inflation
- Explore the unknown: new particles, interactions, and physical principles

The HEP program enables scientific discovery through three experimental frontiers of particle physics research aligned with three HEP subprograms:

- Energy Frontier, where researchers accelerate particles to the highest energies ever made by humanity and collide them to produce and study the fundamental constituents of matter. This requires some of the largest machines ever built. The Large Hadron Collider (LHC) at the European Organization for Nuclear Research, known as CERN, is 17 miles in circumference and accelerates and collides high-energy protons, while sophisticated detectors, some the size of apartment buildings, observe newly produced particles that provide insight into fundamental forces of nature and the conditions of the early universe.
- Intensity Frontier, where researchers use a combination of intense particle beams and highly sensitive detectors to make extremely precise measurements of particle properties, study some of the rarest interactions predicted by the Standard Model, and search for new physics. Measurements of the mass and other properties of neutrinos may have profound consequences for understanding the evolution and ultimate fate of the universe.
- Cosmic Frontier, where researchers use naturally occurring cosmic particles and phenomena to reveal the nature of dark matter, understand the cosmic acceleration caused by dark energy and inflation, infer certain neutrino properties, and explore the unknown. The highest-energy particles ever observed have come from cosmic sources, and the ancient light from the early universe and distant galaxies allows the distribution of dark matter to be mapped and perhaps the nature of dark energy and inflation to be unraveled. Ultra-sensitive detectors deep underground may glimpse the dark matter passing through Earth. Observations of the cosmic frontier may reveal a universe far stranger than ever thought possible.

[a] High Energy Physics Advisory Panel, Department of Energy. Report of the Particle Physics Project Prioritization Panel (P5). Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context. May 2014.
https://science.energy.gov/~/media/hep/hepap/pdf/May-2014/FINAL_P5_Report_053014.pdf

DOE's support of the Theoretical and Computational Physics and the Advanced Technology Research and Development (R&D) subprograms formulates and enables this program of scientific discovery. The Theoretical and Computational Physics subprogram provides the framework to explain experimental observations and gain a deeper understanding of nature. Theoretical physicists take the lead in the interpretation of a broad range of experimental results and synthesize new ideas as they search for deep connections and develop testable models. Computational Physics provides advanced computing tools and simulations that are necessary for designing, operating, and interpreting experiments across the frontiers and enables discovery research via new techniques. Quantum Information Science (QIS) is a rapidly-developing field involving understanding and manipulating quantum phenomena, and opens prospects for new capabilities in sensing, simulation, and computing. HEP activities will be a part of a larger national effort involving interagency coordination of programs. The Advanced Technology R&D subprogram fosters fundamental research into particle acceleration and detection techniques and instrumentation. These enabling technologies and new research methods advance scientific knowledge in high energy physics and a broad range of related fields, advancing the DOE's strategic goals for science.

The Accelerator Stewardship subprogram supports R&D efforts that are synergistic with the HEP mission but also impacts activities outside the traditional HEP boundaries. The activities of the Stewardship subprogram include: improving access to Office of Science (SC) accelerator R&D infrastructure for the private sector and other users; near-term translational R&D to adapt HEP accelerator technology for potential uses in medical, industrial, security, and defense applications; and long-term R&D for science and technology needed to build future generations of accelerators, with a focus on transformational opportunities.

HEP supports individual investigators and small-scale collaborations, as well as very large international collaborations, chosen for their scientific merit and potential for significant impact. More than 20 HEP-supported physicists have received the Nobel Prize in physics. Moreover, many of the advanced technologies, research tools, and analysis techniques originally developed for high energy physics have proved widely applicable to other scientific disciplines as well as for health services, national security, and the private sector.

Highlights of the FY 2019 Request

The P5 report identified the LHC upgrades, including the High-Luminosity Large Hadron Collider (HL-LHC) accelerator and A Toroidal LHC Apparatus (ATLAS) and Compact Muon Solenoid (CMS) Detector Upgrade Projects, as the highest priority in the near-term, and the Long Baseline Neutrino Facility and Deep Underground Neutrino Experiment (LBNF/DUNE) as the highest-priority large project in the P5 report's timeframe. To maintain the strong international partnership with CERN, the FY 2019 Request will increase support to these high-priority projects. The FY 2019 Request will support the planned funding profiles of LBNF/DUNE, HL-LHC Accelerator Upgrade Project, Muon to Electron Conversion Experiment (Mu2e), the Large Underground Xenon (LUX)-ZonEd Proportional scintillation in LIquid Noble gases (ZEPLIN) experiment (LZ), the Super Cryogenic Dark Matter Search at Sudbury Neutrino Observatory Laboratory (SuperCDMS-SNOLAB), and the Dark Energy Spectroscopic Instrument (DESI). The Mu2e and LZ projects will receive final funding needed to complete all remaining project deliverables. The FY 2019 Request will support design and fabrication for the Facility for Advanced Accelerator Experimental Tests II (FACET-II) project, and preliminary design and prototyping for the planned Proton Improvement Plan II (PIP-II) project. The FY 2019 Request will include funding for two new Major Items of Equipment (MIEs), the HL-LHC ATLAS Detector Upgrade and the HL-LHC CMS Detector Upgrade projects. The FY 2019 Request will focus support for HEP research on the laboratory research programs that are critical to executing the P5 recommendations, and on world-leading R&D efforts that require long-term investments, including General Accelerator R&D (GARD), Detector R&D, Accelerator Stewardship, and QIS.

<u>Energy Frontier Experimental Physics</u>

The FY 2019 Request will support U.S. responsibilities and leadership roles on the LHC ATLAS and CMS experiments. The installation of the upgrades to the ATLAS and CMS detectors (MIE project funding for both completed in FY 2017) began in early FY 2018, and will continue during a two-year long technical stop of the LHC, which will start in 2019, to prepare the accelerator and detectors for a ramp up to the particle collision energy of 14 teraelectronvolts (TeV). In FY 2019, HEP will continue to invest in the future LHC program by contributing to the U.S. share of the HL-LHC Accelerator Upgrade Project and the HL-LHC ATLAS and CMS Detector Upgrade Projects to increase the particle collision rate by a factor of three times to explore new physics beyond the reach of the current LHC program.

Intensity Frontier Experimental Physics

The FY 2019 Request will support activities necessary to establish a U.S.-hosted, world-leading neutrino physics program, consisting of LBNF/DUNE, the related Short-Baseline Neutrino (SBN) program at Fermilab, and R&D efforts surrounding the prototypes for DUNE (protoDUNE) at CERN. The SBN program consists of a coordinated set of liquid-argon neutrino detector experiments, including the Short Baseline Neutrino Detector (SBND) and the Imaging Cosmic and Rare Underground Signals (ICARUS) detector, that will advance neutrino science and serve as an international R&D neutrino platform for LBNF/DUNE. The protoDUNE detectors at the CERN Neutrino Platform are testing full-scale elements of the DUNE detectors, using single-phase and dual-phase liquid-argon detector technologies. Both SBN and protoDUNE will begin taking data in FY 2019. The FY 2019 Request will support preliminary design and prototyping for the PIP-II project, which will upgrade the Fermilab linear accelerator to increase beam power and sustain high reliability of the Fermilab Accelerator Complex. PIP-II will provide the world's highest proton beam intensity of greater than 1.2 megawatts for LBNF/DUNE, which is necessary to enable the science program envisioned in the P5 report. The FY 2019 Request will support operations of the Fermilab Accelerator Complex at 75% of the optimal hours of service and two accelerator improvement projects (AIP) at Fermilab. The Neutrinos at the Main Injector (NuMI) Target System AIP will replace or refurbish the NuMI production target, replace its cooling systems, and upgrade critical infrastructure to make the overall system more robust and reliable for beam powers up to 1.0 megawatt. The Booster Intensity AIP will fabricate and install new components to the Booster accelerator to control the greater beam losses due to the increased proton beam intensity.

Cosmic Frontier Experimental Physics

The FY 2019 Request will support two complementary next-generation experiments that will advance our understanding of dark energy. The three billion pixel Large Synoptic Survey Telescope camera (LSSTcam), which will be installed on the LSST facility under construction by NSF in Chile, will scan half of the sky repeatedly with optical and near-infrared imaging sensors, building up a "cosmic cinematography" of the changing universe. DESI, on the Mayall Telescope in Arizona, will measure the distances of 30 million galaxies and quasars and create three-dimensional maps of the distribution of matter over two-thirds of the age of the universe. The LSSTcam and DESI projects will be in their fabrication phases in FY 2019. Commissioning and pre-operations activities for the overall LSST and DESI experiments will take place in FY 2019. The FY 2019 Request will support two second-generation direct-detection dark matter experiments, LZ and SuperCDMS-SNOLAB, which will carry out complementary searches for dark matter candidates over a broad range of masses. LZ will use a liquid xenon based detector located at the Sanford Underground Research Facility (SURF) in Lead, South Dakota, and will receive final funding in FY 2019 to complete fabrication. SuperCDMS-SNOLAB, done in partnership with NSF, will use low-temperature solid-state detectors located at SNOLAB in Sudbury, Canada and will be in its fabrication phase in FY 2019. Pre-operations activities for the LZ and SuperCDMS-SNOLAB experiments will take place in FY 2019.

Theoretical and Computational Physics

The FY 2019 Request will support major theoretical research thrusts that focus on the P5 science drivers, intertwining the physics of the Higgs boson, neutrino masses, the dark universe, and exploring the unknown. Computational physics efforts will focus on advancing emerging computational science techniques, models, and technology necessary to meet the projected computing and data management needs of the HEP program. The FY 2019 Request will increase funding for QIS to accelerate discovery in particle physics while advancing the national program. HEP QIS efforts will focus on opportunities to address the P5 science drivers via foundational research including field theory and analog simulations, advanced technology including quantum controls and precision sensors, and computing approaches including optimization and machine learning.

Advanced Technology R&D

The FY 2019 Request will support world-leading Advanced Technology R&D that will enable transformative technology for the next-generation of accelerators and particle detectors. The FACET-II project at SLAC National Accelerator Laboratory (SLAC) will continue fabrication of the electron-beam driven plasma wakefield acceleration system. The Berkeley Laboratory Laser Accelerator (BELLA) at the Lawrence Berkeley National Laboratory (LBNL) will continue its world-leading program in laser-driven plasma wakefield accelerator research. Funding to initiate an AIP at LBNL will add a second beamline that can deliver an independently controlled laser pulse to a second laser-driven plasma wakefield acceleration structure, enabling tests of multistage particle acceleration. The HEP General Accelerator R&D (GARD) activity will continue the Traineeship Program for Accelerator Science and Technology, launched in FY 2017, to revitalize graduate level training and innovation in the physics of particle accelerators for the benefit of HEP and other SC programs that rely on these enabling technologies. The Detector R&D subprogram will be developing cutting-edge instrumentation to enable experimental research at the forefront of the field while training the next generation of detector experts.

Accelerator Stewardship

The FY 2019 Request will support R&D to develop the fundamental building blocks of new technological advances in accelerator technology, to empower the private sector to accelerate research discoveries from the laboratory to the marketplace, and to support the mission of other federal agencies. Funding to initiate an AIP at Brookhaven National Laboratory (BNL) Accelerator Test Facility (ATF) is requested to upgrade the Carbon Dioxide (CO_2) laser to a world-leading peak power of 20 Terawatts (TW).

Construction

The FY 2019 Request will include funding for the LBNF/DUNE project to continue the Critical Decision (CD)-3A approved scope for the far site civil construction for the excavation of the underground equipment caverns and connecting drifts (tunnels), and for the continued design work for the near site, cryogenic systems, and the DUNE detectors. The Muon to Electron Conversion Experiment (Mu2e) will complete the procurements and installation of the accelerator beam and detector equipment in FY 2019 according to its approved baseline funding profile.

High Energy Physics
Funding ($K)

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Energy Frontier Experimental Physics				
Research	74,911	—	56,119	-18,792
Facility Operations and Experimental Support	52,420	—	44,309	-8,111
Projects	24,017	—	77,000	+52,983
SBIR/STTR	5,185	—	3,804	-1,381
Total, Energy Frontier Experimental Physics	**156,533**	**—**	**181,232**	**+24,699**
Intensity Frontier Experimental Physics				
Research	55,245	—	41,246	-13,999
Facility Operations and Experimental Support	153,066	—	125,916	-27,150
Projects	24,569	—	26,000	+1,431
SBIR/STTR	7,768	—	7,008	-760
Total, Intensity Frontier Experimental Physics	**240,648**	—	**200,170**	**-40,478**
Cosmic Frontier Experimental Physics				
Research	48,750	—	31,506	-17,244
Facility Operations and Experimental Support	12,335	—	11,320	-1,015
Projects	74,400	—	30,850	-43,550
SBIR/STTR	2,330	—	1,770	-560
Total, Cosmic Frontier Experimental Physics	**137,815**	—	**75,446**	**-62,369**
Theoretical and Computational Physics				
Research				
Theory	48,429	—	35,053	-13,376
Computational HEP	7,696	—	8,727	+1,031
Quantum Information Science	0	—	27,500	+27,500
Total, Research	56,125	—	71,280	+15,155
Projects	2,000	—	0	-2,000
SBIR/STTR	2,206	—	2,700	+494
Total, Theoretical and Computational Physics	**60,331**	—	**73,980**	**+13,649**

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Advanced Technology R&D				
Research				
HEP General Accelerator R&D	44,050	—	38,043	-6,007
HEP Directed Accelerator R&D	22,800	—	0	-22,800
Detector R&D	16,989	—	15,240	-1,749
Total, Research	83,839	—	53,283	-30,556
Facility Operations and Experimental Support	30,450	—	25,525	-4,925
Projects	3,500	—	2,000	-1,500
SBIR/STTR	4,293	—	2,947	-1,346
Total, Advanced Technology R&D	**122,082**	—	**83,755**	**-38,327**
Accelerator Stewardship				
Research	6,703	—	8,032	+1,329
Facility Operations and Experimental Support	6,891	—	3,950	-2,941
SBIR/STTR	497	—	435	-62
Total, Accelerator Stewardship	**14,091**	—	**12,417**	**-1,674**
Subtotal, High Energy Physics	**731,500**	**726,532**	**627,000**	**-104,500**
Construction				
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment	50,000	49,660	113,000	+63,000
11-SC-41, Muon to Electron Conversion Experiment	43,500	43,205	30,000	-13,500
Total, Construction	**93,500**	**92,865**	**143,000**	**+49,500**
Total, High Energy Physics	**825,000**	**819,397**	**770,000**	**-55,000**

SBIR/STTR Funding:

- FY 2017 Enacted: SBIR $19,532,000; and STTR: $2,747,000
- FY 2019 Request: SBIR $16,363,000; and STTR $2,301,000

High Energy Physics
Explanation of Major Changes ($K)

	FY 2019 Request vs FY 2017 Enacted
Energy Frontier Experimental Physics: The Request includes funding to support the new MIE starts for the HL-LHC ATLAS and HL-LHC CMS Detector Upgrade Projects, which will begin long-lead procurements, and an increase for the HL-LHC Accelerator Upgrade Project to begin full production of focusing magnets. This increase will be partially offset by the planned conclusion of the LHC ATLAS and CMS Detector Upgrade projects initiated in FY 2015. The Request prioritizes support to laboratory research activities critical to executing the P5 projects recommended to address Higgs boson science. The Request includes funding for commissioning of the LHC ATLAS and CMS Detector Upgrade projects.	+24,699
Intensity Frontier Experimental Physics: The Request prioritizes delivering particle beams and providing experimental operations at the Fermilab Accelerator Complex. Research support places higher priority on laboratory activities critical to executing the P5 projects recommended to address the neutrino mass and explore the unknown science drivers and carry out the early physics data analyses from operating experiments. The Request includes funding to work with international partners on the preliminary design and prototyping for the PIP-II project and to SURF operations that will support LBNF/DUNE construction.	-40,478
Cosmic Frontier Experimental Physics: The Request includes funding to complete the fabrication and installation of the LZ project, and continues the fabrication of the DESI and SuperCDMS-SNOLAB projects. The LSSTcam project funding concludes as planned. The FY 2019 Request prioritizes support to laboratory research activities critical to executing the P5 projects recommended to address the dark matter and dark energy science drivers. The Request includes funding for the installation, commissioning, and pre-operations activities for LSST, DESI, LZ, and SuperCDMS-SNOLAB.	-62,369
Theoretical and Computational Physics: The Request increases funding for Quantum Information Science (QIS) research, with a focus on quantum computing, algorithms, controls and sensors. The Request prioritizes support to theoretical research that addresses the neutrino mass science driver and to advanced computing research for HEP future needs. The Lattice Quantum Chromodynamics (LQCD) project received final funding in FY 2017.	+13,649
Advanced Technology R&D: The Request prioritizes support for world-leading, long-term R&D efforts at the national laboratories. The Request includes funding that focuses on accelerator, test beam and detector facilities that support the highest priority activities in the P5 report. The start of the LBNL BELLA Second Beamline accelerator improvement project (AIP) will offset the completion of the SLAC Sector 10 Injector Infrastructure AIP. The Muon Accelerator Program (MAP) completed its R&D goals in FY 2017, and the LHC Accelerator Research Program (LARP) anticipates completing its R&D goals before FY 2019.	-38,327
Accelerator Stewardship: The Request prioritizes support for long-term R&D for the science and technology needed to build future generations of accelerators with broad applicability and provides support to an AIP to upgrade the BNL ATF's Carbon Dioxide (CO_2) laser to a world-leading peak power of 20 Terawatt (TW).	-1,674
Construction: The Request increases funding to LBNF/DUNE in support of far site civil construction and excavation of the underground equipment caverns and connecting drifts. This increase will be partially offset by a planned decrease in funding to Mu2e for its final year of construction funding.	+49,500
Total, High Energy Physics	**-55,000**

Basic and Applied R&D Coordination

Accelerator Stewardship provides the fundamental building blocks of new technological advances in accelerator applications, including advanced proton and ion beams for the treatment of cancer, in coordination with the National Institutes of Health (NIH). HEP developed the Accelerator Stewardship subprogram based on input from accelerator R&D experts drawn from other federal agencies, universities, national laboratories, and the private sector to help identify specific research areas and infrastructure gaps where HEP investments would have sizable impacts beyond the SC research mission. This program is closely coordinated with the SC's Basic Energy Sciences (BES) and Nuclear Physics (NP) programs and partner agencies to ensure federal stakeholders have input in crafting funding opportunity announcements, reviewing applications, and evaluating the efficacy and impact of funded activities. Use-inspired accelerator R&D for medical applications has been closely coordinated with the NIH/National Cancer Institute (NCI); ultrafast laser technology R&D with the Department of Defense (DOD) and the National Aeronautics and Space Administration (NASA); and microwave and high power accelerator R&D coordinated with the DOD, the Department of Homeland Security's Domestic Nuclear Detection Office (DHS/DNDO), the NSF/Chemical, Bioengineering, Environmental and Transport (CBET) Systems Division, and the DOE's Office of Environmental Management (EM). Discussions with the National Nuclear Security Administration (NNSA) on mission needs and R&D coordination in laser technology, radioactive source replacement, and particle detector technologies are underway.

The Accelerator Stewardship subprogram conducts use-inspired basic R&D to provide the fundamental building blocks of new technological advances. Ensuring that the investments result in high-impact applications requires close coordination with other agencies who will carry on the later-stage development. The implementation strategy is to work with applied R&D agencies to jointly define priority research directions at Basic Research Needs Workshops, and then guide R&D and facility investments through joint participation of applied agency program managers in merit reviews and in the operations review of the Brookhaven National Laboratory Accelerator Test Facility. Where an eventual marketable use is envisioned, R&D collaborations are expected to involve a U.S. company to guide the early-stage R&D.

Specific funded examples include collaborative R&D on proton therapy delivery systems (joint with Varian Medical Systems), advanced proton sources for therapy (joint with ProNova Solutions), advanced detectors for cancer therapy (joint with Best Medical International) advanced microwave source development (joint with Communications Power Industries), and technical design studies for high power accelerators for wastewater treatment (joint with Metropolitan Water Reclamation District of Greater Chicago). Funded R&D awards have drawn an average of 20% of voluntary cost sharing over the first two years of the program, providing evidence of the potential impact.

Program Accomplishments

Record-breaking LHC performance continues, enabling new avenues to explore the Higgs boson and perform precision tests of the Standard Model (Energy Frontier). The LHC is the highest energy particle collider in the world and continues to break performance records and exceed its goals for producing particle collisions. The CMS experiment produced the first direct observation of the Higgs boson decaying to tau leptons, the heaviest known cousin of an electron. These first results are consistent with the prediction of the Standard Model of particle physics, but open a new window to exploring the universe through precision tests of the Higgs boson. The ATLAS experiment measured the mass of the W boson, a carrier particle of the weak nuclear force, to a precision of 2.4%, matching the precision of the best previous measurement. This new measurement enables important tests of the self-consistency of the Standard Model. The LHC aims to continue running at its record pace through 2018, before a two-year long technical stop to perform machine and detector upgrades, which will enable more detailed measurements of the Higgs boson and more sensitive searches for new physics.

COHERENT experiment uses the world's smallest neutrino detector to make the first observation of coherent scattering of low-energy neutrinos off nuclei (Intensity Frontier). In coherent scattering, a neutrino interacts with the entire atomic nucleus at once, not just one of the protons or neutrons within. The research performed at the Oak Ridge National Laboratory's (ORNL) Spallation Neutron Source (SNS) by a collaboration of 80 researchers from 19 institutions and 4 nations confirms the process originally predicted by theorists in 1974. Coherent scattering dominates neutrino dynamics during neutron star formation and supernovae explosions. Understanding coherent scattering will improve the scientific reach of future neutrino and dark matter experiments.

The Dark Energy Survey (DES) experiment produced its first precision measurements of dark energy (Cosmic Frontier). DES released the first dark energy results based on its imaging measurements of 26 million galaxies from the 570 million pixel Dark Energy camera on the Blanco telescope in Chile. The data was from the first year of the five-year wide-area survey, scheduled to end in 2018. The weak gravitational lensing effect, where gravity slightly distorts images of distant galaxies, was used to construct the largest-ever map of the distribution of ordinary and dark matter in the universe and its evolution over time. The results, within the 5% measurement uncertainty, are consistent with dark energy being an inherent property of the universe as opposed to a new kind of force. The full wide-area survey will cover approximately four times the area of the sky, include measurements of 300 million galaxies and thousands of supernovae, and enable precision cosmology results using a variety of methods to yield further insight into the dark universe.

First demonstration of laser-controlled injection in a beam-driven plasma wakefield accelerator at the Facility for Advanced Accelerator Experimental Tests (FACET) (Advanced Technology R&D). An experiment at FACET successfully used a laser pulse to generate an electron bunch within a plasma wakefield. FACET experiments previously demonstrated the high gradient and highly efficient wakefield acceleration of particles “surfing” on electromagnetic waves in plasma by using externally injected electron bunches. The demonstration of laser-controlled injection shows that unprecedented beam control and quality are feasible in plasma wakefield accelerators. This technology may drastically improve the performance of particle accelerators, with applications ranging from modern light sources to high energy colliders for future particle physics research.

First beam delivered to the Muon g-2 experiment at the Fermilab Muon Campus (Intensity Frontier). The Fermilab Muon Campus will host precision experiments, including the Muon-to-Electron Conversion (Mu2e) and Fermilab Muon g-2 experiments, which will search for new physics using beams of muons, heavy cousins of electrons. In May 2017, the Muon g-2 experiment received its first muon beam from the Fermilab Accelerator Complex, marking the start of three year campaign to measure an intrinsic property of the muon called the magnetic moment with unprecedented precision. The muons circulated in a 50-foot wide magnetic storage ring at Fermilab in Illinois. In the summer of 2013, the storage ring traveled a 3,200 mile route from Brookhaven National Laboratory in New York, where it was used for a previous Muon g-2 experiment in the 1990s.

Groundbreaking ceremony for the Long-Baseline Neutrino Facility and Deep Underground Neutrino Experiment (LBNF/DUNE) (Intensity Frontier). A new era in international particle physics research began on July 21, 2017, with a unique groundbreaking ceremony held a mile underground at the Sanford Underground Research Facility in South Dakota. Dignitaries, scientists, and engineers from around the world gathered to mark the start of initial far-site construction for the international science facility that will host massive experiments that may change our understanding of the universe. When complete, LBNF/DUNE will be the largest experiment ever built in the United States to study the properties of neutrinos, which may hold the key to understanding why matter and not antimatter dominates the universe today.

High Energy Physics
Energy Frontier Experimental Physics

Description

The Energy Frontier subprogram's focus is on the Large Hadron Collider (LHC). The LHC hosts two large multi-purpose particle detectors, ATLAS and CMS, which are partially supported by DOE and the NSF and used by large international collaborations of scientists. U.S. researchers account for approximately 20% and 25% of the ATLAS and CMS collaborations respectively, and play critical leadership roles in all aspects of each experiment. Data collected by ATLAS and CMS will be used to address at least three of the five science drivers identified by the P5 report:

- *Use the Higgs boson as a new tool for discovery*
  In the Standard Model of particle physics, the Higgs boson is responsible for generating the mass for all fundamental particles. Since the 2012 Nobel-winning discovery, experiments at the LHC continue to actively measure the Higgs's properties to establish its exact character and discover if there are additional effects that are the result of new physics beyond the Standard Model.
- *Explore the unknown: new particles, interactions, and physical principles*
  Researchers at the LHC probe for evidence of what lies beyond the Standard Model or significantly constrain postulated modifications to it, such as supersymmetry, mechanisms for black hole production, extra dimensions, and other exotic phenomena. The LHC detectors will be increasingly more sensitive to potential deviations from the Standard Model that may be exposed by the highest energy collisions in the world.
- *Identify the new physics of dark matter*
  If dark matter particles are light enough, they may be produced in LHC collisions and their general properties may be measured indirectly through the behavior of the accompanying normal matter. This indirect detection of dark matter is complementary to, and a powerful cross-check on, the ultra-sensitive direct detection experiments in the Cosmic Frontier and Intensity Frontier.

Research

The Energy Frontier experimental research activity consists of groups at U.S. academic and research institutions and physicists from national laboratories. These groups, as part of the ATLAS and CMS collaborations, typically have a broad portfolio of responsibilities and leadership roles in support of R&D, experimental design, fabrication, commissioning, operations, and maintenance, and they perform scientific simulations and physics data analyses. DOE selects research efforts with the highest scientific impact and potential based on a competitive peer-review process. An external peer review of the Energy Frontier laboratory research groups was conducted in 2015; the next review will be in 2019. The findings from this review are being used to inform the funding decisions in subsequent years.

Facility Operations and Experimental Support

U.S. LHC Detector Operations funding supports the maintenance of U.S.-supplied detector systems for the ATLAS and CMS detectors at the LHC, and the U.S.-based computer infrastructure used by U.S. physicists to analyze LHC data, including Tier 1 computing centers at Fermilab and BNL. The Tier 1 centers provide around-the-clock support for the LHC Computing Grid; are responsible for storing a portion of raw and processed data; perform large-scale data reprocessing; and store the corresponding output.

Projects

During the next decade, CERN will undergo a major upgrade to the LHC machine to further increase the particle collision rate by a factor of three times to explore new physics beyond the reach of the current LHC program. Through the HL-LHC Accelerator Upgrade Project, HEP will contribute to this upgrade by constructing and delivering the next-generation of superconducting accelerator components in which U.S. scientists have critical expertise. After the upgrade, the HL-LHC beam will make the conditions in which the ATLAS and CMS detectors must operate very challenging. As a result, the HL-LHC ATLAS and HL-LHC CMS Detector Upgrades (new MIE starts) are critical investments to enable the experiments to operate for an additional decade and collect more data by a factor of ten.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Energy Frontier Experimental Physics $156,533,000	**$181,232,000**	**+$24,699,000**
Research $74,911,000	**$56,119,000**	**-$18,792,000**
Funding supported U.S. scientists leading high-profile analysis topics using the data collected by the ATLAS and CMS experiments at the LHC.	The FY 2019 Request will support U.S. leadership roles in all aspects of the ATLAS and CMS experiments.	Higher priority will be given to support laboratory research activities critical to executing the P5 projects recommended to address the Higgs boson science driver, and to carry out the final analyses on the data collected prior to the two-year long technical stop of the LHC, which will start in 2019.
Facility Operations and Experimental Support $52,420,000	**$44,309,000**	**-$8,111,000**
Funding supported ATLAS and CMS detector maintenance and operations including the U.S.-based computing infrastructure and resources used by U.S. scientists to analyze LHC data.	The FY 2019 Request will support ATLAS and CMS detector maintenance activities, including those related to commissioning of U.S.-built detector components during the two-year long technical stop of the LHC, which will start in 2019.	Focus of support will be on the commissioning following the installation of the LHC ATLAS and CMS Detector Upgrade projects initiated in FY 2015. Reduced support for compute nodes and data storage will be anticipated as a result of lower demand on the U.S.-based computing infrastructure during the two-year long technical stop of the LHC.
Projects $24,017,000	**$77,000,000**	**+$52,983,000**
Funding supported the fabrication and component installation for the LHC ATLAS Detector Upgrade and the LHC CMS Detector Upgrade projects. Funding supported the conceptual design activities for the HL-LHC Accelerator Upgrade Project and the HL-LHC ATLAS and HL-LHC CMS Detector Upgrade Projects.	The FY 2019 Request will support the procurement of solid-state detecting components for the HL-LHC ATLAS and HL-LHC CMS Detector Upgrade Projects (new MIE starts), and the production of focusing magnets for the HL-LHC Accelerator Upgrade Project.	Funding will support new MIE starts for the HL-LHC ATLAS and HL-LHC CMS Detector Upgrade Projects and the planned increase for the HL-LHC Accelerator Upgrade Project. The funding for the LHC ATLAS Detector Upgrade and the LHC CMS Detector Upgrade projects concluded as planned in FY 2017.
SBIR/STTR $5,185,000	**$3,804,000**	**-$1,381,000**
In FY 2017, SBIR/STTR funding was at 3.65% of non-capital funding.	In FY 2019, SBIR/STTR funding will be at 3.65% of non-capital funding.	A decrease in funding will represent mandated percentages for non-capital funding.

High Energy Physics
Intensity Frontier Experimental Physics

Description

The Intensity Frontier subprogram investigates some of the rarest processes in nature including unusual interactions of fundamental particles or subtle effects requiring large data sets to observe and measure. This HEP subprogram focuses on using high-power particle beams or other intense particle sources to make precision measurements of fundamental particle properties. These measurements in turn probe for new phenomena that cannot be directly observed at the Energy Frontier, either because they occur at much higher energies and their effects can only be seen indirectly, or because they are due to interactions that are too weak to be detected in high-background conditions at the LHC. Data collected from Intensity Frontier experiments during this period will be used to address at least three of the five science drivers identified by the P5 report:

- *Pursue the physics associated with neutrino mass*
  Of all known particles, neutrinos are perhaps the most enigmatic and certainly the most elusive. HEP researchers working at U.S. facilities discovered all of the three known varieties of neutrinos. HEP supports research into fundamental neutrino properties that may reveal important clues about the unification of forces and the very early history of the universe. The Intensity Frontier-supported portfolio of neutrino experiments will advance neutrino physics while serving as an international platform for the R&D activities necessary to establish the U.S.-hosted international LBNF/DUNE.
- *Explore the unknown, new particles, interactions, and physical principles*
  A number of observed phenomena are not described by the Standard Model, including the imbalance of matter and antimatter in the universe today. Precision measurements of the properties of known particles can reveal information about what new particles and forces could explain these discrepancies and whether the known forces unify at energies beyond the reach of the LHC.
- *Identify the new physics of dark matter*
  The lack of experimental evidence from current generation dark matter detectors has led to proposed theoretical models with new particles and forces that rarely interact with normal matter. These theoretical particles and forces are effectively invisible to conventional experiments, but may be connected to the cosmic dark matter. Experiments use intense accelerator beams at national laboratories outfitted with highly efficient high-rate detectors to explore these theoretical models.

<u>Research</u>

The Intensity Frontier experimental research activity consists of groups at U.S. academic and research institutions and national laboratories that perform experiments. These groups, as part of scientific collaborations, typically have a broad portfolio of responsibilities and leadership roles in support of R&D, experimental design, fabrication, commissioning, operations, and maintenance, as well as perform scientific simulations and physics data analyses on the experiments in the subprogram. DOE selects research efforts with the highest scientific merit and potential impact based on a competitive peer-review process. An external peer review of the Intensity Frontier laboratory research groups is planned for 2018. The findings from this review will inform the funding decisions in subsequent years.

The largest component of the Intensity Frontier subprogram is the support for research in accelerator-based neutrino physics centered at Fermilab with multiple experiments running concurrently in two separate neutrino beams with different beam energies. The flagship NuMI Off-Axis ν_e Appearance (NOvA) experiment uses the Neutrinos at the Main Injector (NuMI) beam, and the Booster Neutrino Beam (BNB) are used to study different aspects of neutrino physics and muon physics. The SBN program, which includes the Imaging Cosmic and Rare Underground Signals (ICARUS) and Short Baseline Neutrino Detector (SBND) experiments, use the BNB to definitively address hints of additional neutrinos types beyond the three currently described in the Standard Model. The protoDUNE detectors are testing single-phase and dual-phase liquid-argon detector technologies to inform the design efforts for DUNE. LBNF/DUNE will be the centerpiece of a U.S.-hosted world-leading neutrino program, using the world's most intense neutrino beam and large, sensitive underground detectors to make transformative discoveries.

The Intensity Frontier muon program at Fermilab studies rare processes in muons to detect physics beyond the reach of the LHC. The Muon g-2 experiment, with four times better precision, is following up on hints of new physics from an earlier experiment, while the Mu2e experiment searches for extremely rare muon decays that (if detected) will be clear evidence of new physics. The Intensity Frontier subprogram supports U.S. physicists to participate in select experiments at foreign facilities, including neutrino experiments in China and Japan. There is a U.S. contingent studying heavy particles containing b-quarks using the Belle II experiment at the High Energy Accelerator Research Organization (KEK) in Japan.

Facility Operations and Experimental Support

There are several distinct facility operations and experimental support efforts in the Intensity Frontier subprogram. The largest is the Fermilab Accelerator Complex User Facility. This activity includes the operations of all accelerators and beamlines at Fermilab and the operation of the detectors that use those accelerators as well as computing support needed by both the accelerators and detectors. General Plant Project (GPP) and Accelerator Improvement Project (AIP) funding supports improvements to Fermilab facilities.

Fermilab contracts with the South Dakota Science and Technology Authority (SDSTA), an agency of the State of South Dakota, for services at the Sanford Underground Research Facility (SURF) to support DOE experiments being conducted there. The Nuclear Physics-supported Majorana Demonstrator is currently operating and the HEP-supported LZ experiment is being installed at SURF, which will be the home of the DUNE far detectors built by the LBNF/DUNE project.

Projects

In support of LBNF/DUNE, a lease with SDSTA provides the framework for DOE and Fermilab to construct federally funded buildings and facilities on non-federal land, and to establish a long-term (multi-decade) arrangement for DOE and Fermilab to use SDSTA space to host the DUNE neutrino detector. Other Project Costs (OPC) funding has been identified for SURF plant support costs provided by SDSTA.

The planned PIP-II will provide a 1.2 megawatt beam to LBNF/DUNE, which is higher than the 0.7 megawatt beam used by NOvA. The front-end is the oldest part of the Fermilab Accelerator Complex and needs to be replaced to improve reliability and to produce higher intensity muon and neutrino beams. Fermilab is developing a conceptual design and establishing partnerships with institutions in India, Italy, and the United Kingdom to contribute to the project.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Intensity Frontier Experimental Physics $240,648,000	**$200,170,000**	**-$40,478,000**
Research $55,245,000	**$41,246,000**	**-$13,999,000**
Funding supported research efforts to analyze data from operating long- and short-baseline neutrino experiments, beam-based dark matter experiments, precision measurement experiments that explore the unknown, and for design and physics optimization for projects in their fabrication phase.	The FY 2019 Request will support U.S. leadership on all aspects of the neutrino and muon experiments including NOvA, ICARUS and Muon g-2, and the future projects including LBNF/DUNE and Mu2e. The first physics data results from Belle II will be anticipated.	Higher priority will be given to support laboratory research activities critical to executing the P5 projects recommended to address the neutrino mass and explore the unknown science drivers, and to carry out the early physics data analyses from Muon g-2, Belle II, SBN program and protoDUNE.
Facility Operations and Experimental Support $153,066,000	**$125,916,000**	**-$27,150,000**
Funding supported the operation of the Fermilab Accelerator Complex and the neutrino and muon experiments. The refurbishment of the Linac and BNB continued. Construction of an addition to the Industrial Center Building (ICB) began as a new GPP. SURF operations supported the ongoing Majorana demonstrator activities and preparations for the LZ experiment and LBNF/DUNE construction.	The FY 2019 Request will support the operation of the Fermilab Accelerator Complex and the neutrino and muon experiments, while the running time of the Main Injector and Booster accelerators will be shortened to 75% of optimal. SURF operations will continue to support the LBNF/DUNE construction and the commissioning of the LZ experiment. The Fermilab NuMI Target System and Booster Intensity AIPs will begin.	Support will prioritize delivering the particle beams and providing experimental operations for ongoing experiments, including NOvA, the SBN program, and Muon g-2, in a manner that will optimize addressing the P5 science drivers.
Projects $24,569,000	**$26,000,000**	**+$1,431,000**
Funding supported the fabrication of the Muon g-2 beamline and detectors, OPC to continue the conceptual design for the PIP-II project, and subsystems integration and infrastructure for the SBN program.	The FY 2019 Request will support OPC for the preliminary design and prototyping of the most technologically advanced accelerator components for the PIP-II project, and the OPC for plant support costs at SURF during LBNF/DUNE construction.	Focus of support will be on working with international partners on preliminary design and prototyping for the PIP-II project. Funding for Muon g-2 project concluded as planned. OPC will begin for LBNF/DUNE with the ramp-up of CD-3A construction.
SBIR/STTR $7,768,000	**$7,008,000**	**-$760,000**
In FY 2017, SBIR/STTR funding was at 3.65% of non-capital funding.	In FY 2019, SBIR/STTR funding will be at 3.65% of non-capital funding.	A decrease in funding will represent mandated percentages for non-capital funding.

Description

The Cosmic Frontier subprogram uses measurements of naturally occurring cosmic particles and observations of the universe to probe fundamental physics questions and offer new insight about the nature of dark matter, dark energy, and inflation in the early universe, constraints on neutrinos and other phenomena. The activities in this subprogram use diverse tools and technologies, from ground-based telescopes and space-based missions to large detectors deep underground to address four of the five science drivers identified in the P5 report:

- *Identify the new physics of dark matter*
  Overwhelming evidence through the years, starting with measurements of motions within galaxies first made in the 1930s, show that dark matter accounts for five times as much matter in the universe as ordinary matter. Direct-detection experiments provide the primary method to search for cosmic dark matter particles' rare interactions with ordinary matter, while indirect-detection experiments search for the products of dark matter annihilation in the core of galaxies. A staged series of direct-detection experiments search for the leading theoretical candidate particles using multiple technologies to cover a wide range in mass with increasing sensitivity. Accelerator-based dark matter searches performed in the Intensity Frontier and the Energy Frontier subprograms are complementary to these direct-detection experiments.
- *Understand cosmic acceleration: dark energy and inflation*
  Since its 1999 discovery and subsequent 2011 Nobel Prize in Physics, the nature of dark energy, which drives the accelerating expansion of the universe, continues to be one of the most perplexing questions in science. Together, dark energy and dark matter comprise 95% of the matter and energy in the universe, leaving approximately 5% ordinary matter, from which all the stars and galaxies, and we, are made. Steady progress continues in a staged set of dark energy experiments, using complementary fast sky-scanning surveys and deep, high-accuracy surveys, which provide ever-increasing precision. Experiments studying the oldest observed light in the universe, the cosmic microwave background (CMB), are increasing their sensitivity to target the era of cosmic inflation, the rapid expansion in the early universe shortly after the Big Bang.
- *Pursue the physics associated with neutrino mass*
  Remarkably, the study of the largest physical structures in the Universe can reveal the properties of particles with the smallest known cross-section, the neutrinos. Experiments studying dark energy and the CMB will put constraints on the number of neutrino species and their masses. The properties of neutrinos affected the evolution of matter distribution in the universe, leading to changes in the CMB observables when measured in different directions. These measurements are complementary to, and a powerful cross check of, the ultra-sensitive measurements made in the Intensity Frontier.
- *Explore the unknown: new particles, interactions, and physical principles*
  High-energy cosmic rays and gamma rays probe energy scales well beyond what can be produced with man-made particle accelerators, albeit not in a controlled experimental setting. Searches for new phenomena and indirect signals of dark matter in these surveys may yield surprising discoveries about the fundamental nature of the universe.

Research

The Cosmic Frontier experimental research activity consists of groups at U.S. academic and research institutions and national laboratories who perform experiments using instruments on the surface, deep underground, and in space. These groups, as part of scientific collaborations, typically have a broad portfolio of responsibilities and leadership roles in support of R&D, experimental design, fabrication, commissioning, operations, and maintenance, as well as perform scientific simulations and physics data analyses on the experiments in the subprogram. DOE selects research efforts with the highest scientific merit and potential impact based on a competitive peer-review process. An external peer review of the Cosmic Frontier laboratory research groups was conducted in 2016; the next review will be in 2020. The findings from this review are being used to inform the funding decisions in subsequent years.

Facility Operations and Experimental Support

This activity support the DOE share of personnel, data processing, and other expenses necessary for the successful pre-operations planning activities and maintenance, operations, and data production during the operating phase of Cosmic Frontier experiments. These experiments are typically not sited at national laboratories. They are located at ground-based telescopes and observatories, in space, or deep underground. Support is provided for the experiments currently operating as well as for planning and pre-operations activities for the next generation experiments in the design or fabrication phase. HEP conducted a peer review of Cosmic Frontier operations in early FY 2015; the next review is planned for FY 2019. In the interim, HEP has held subsequent status reviews and operations planning reviews. HEP uses the findings from the reviews to monitor the experiments and inform decisions concerning the level of operations support needed in subsequent years.

Projects

P5 recommended a robust suite of next-generation dark energy and dark matter projects, with a potential CMB project starting later in the ten-year plan. Two experiments will use different survey types and methods to measure the effect of dark energy on the expansion of the universe, which allows differentiation between models of dark energy. The LSSTcam that will be installed on the LSST facility will scan half of the sky repeatedly with optical and near-infrared imaging sensors, building up a "cosmic cinematography" of the changing universe, while DESI will study 30 million galaxies and quasars with spectroscopy over two-thirds of the age of the universe. Two experiments will use different technologies to search for dark matter: LZ will use a liquid xenon detector and SuperCDMS-SNOLAB will use low-temperature solid-state detectors. LZ is better at detecting heavier dark matter particles while SuperCDMS-SNOLAB will be sensitive to lighter dark mass particles, so the two combine to provide the largest search currently feasible.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Cosmic Frontier Experimental Physics $137,815,000	**$75,446,000**	**-$62,369,000**
Research $48,750,000	**$31,506,000**	**-$17,244,000**
Funding supported research efforts to analyze current dark matter and dark energy experiments and for design and physics optimization for projects in their fabrication phase.	The FY 2019 Request will support world-leading research efforts in support of design and optimization on dark matter and dark energy experiments in their fabrication and commissioning phases, as well as on planning for future experiments, including CMB-S4.	Higher priority will be given to support laboratory research activities critical to executing the P5 projects recommended to address the dark matter and dark energy science drivers, and to carry out the final data analyses on Cosmic Frontier experiments completing in FY 2019.
Facility Operations and Experimental Support $12,335,000	**$11,320,000**	**-$1,015,000**
Funding supported the start of the early operations activities necessary for projects near completion, such as LSSTcam, and the operations of on-going experiments in the physics data-taking phase.	The FY 2019 Request will support the start of installation and commissioning activities for the LSSTcam, as well as early planning for the LSST facility and science operations. Planning, commissioning, and pre-operations activities will begin for DESI, LZ, and SuperCDMS-SNOLAB. Support for the currently operating experiments will continue.	Focus of support will be on the installation, commissioning and pre-operations activities for LSSTcam, DESI, LZ, and SuperCDMS-SNOLAB as these projects will begin the transition to experimental operations.
Projects $74,400,000	**$30,850,000**	**-$43,550,000**
Funding supported continued fabrication for the LSSTcam, LZ and DESI projects, and design work towards SuperCDMS-SNOLAB project baseline.	The FY 2019 Request will support the completion of fabrication and installation of the LZ dark matter project, and will support the fabrication of the DESI dark energy project and the SuperCDMS-SNOLAB dark matter project.	Priority will be given to support the fabrication and installation of the DESI, LZ, and SuperCDMS-SNOLAB projects. The LSSTcam project funding will conclude as planned.
SBIR/STTR $2,330,000	**$1,770,000**	**-$560,000**
In FY 2017, SBIR/STTR funding was at 3.65% of non-capital funding.	In FY 2019, SBIR/STTR funding is at 3.65% of non-capital funding.	A decrease in funding will represent mandated percentages for non-capital funding.

Description

The Theoretical and Computational Physics subprogram provides the mathematical, phenomenological, and computational framework to understand and extend our knowledge of the dynamics of particles and fields, and the nature of space and time. This research is essential for proper interpretation and understanding of the experimental research activities described in other HEP subprograms. Theory and computation cut across all five P5 science drivers and the Energy, Intensity, and Cosmic Frontier Experimental Physics subprograms.

Theory

The HEP theory activity supports world-leading research groups at U.S. academic and research institutions and national laboratories. Both university and laboratory research groups play important roles in addressing the leading research areas discussed above. Laboratory groups are typically more focused on data-driven theoretical investigations and precise calculations of experimentally observable quantities. University groups usually focus on building models of physics beyond the Standard Model and studying their phenomenology as well as on formal and mathematical theory. DOE selects research efforts with the highest scientific impact and potential based on a competitive peer-review process. An external peer review of the Theory laboratory research groups is planned for 2018. The findings from this review will inform the funding decisions in subsequent years.

Computational HEP

Computation is necessary at all stages of HEP experiments—from planning and constructing accelerators and detectors, to theoretical modeling, to supporting computationally intensive experimental research and large-scale data analysis. Computational HEP priorities are to advance computing research for HEP future needs across the program, including exploiting latest architectures. HEP partners with the Advanced Scientific Computing Research (ASCR), including via the Scientific Discovery through Advanced Computing (SciDAC) program, to optimize the HEP computing ecosystem for the near and long term future.

In addition to supporting the science and technology thrusts, Computational HEP fosters advanced simulations and computational science that extends the boundaries of scientific discovery to regions not directly accessible by experiments, observations, or traditional theory. Computational HEP activities have fostered HEP connections with the national effort on Quantum Information Science (QIS) and sponsored reports and pilot projects in support of the P5 science drivers and to advance discovery.

Quantum Information Science

The HEP QIS efforts will focus on foundational research on techniques and algorithms, quantum computing for HEP experiments and modeling, development and use of specialized quantum controls, and precision sensors that may yield information on fundamental physics beyond the Standard Model. This research area is part of an SC initiative that will be conducted in coordination with SC programs, other federal agencies, and the private sector where relevant.

Projects

The Projects activity funds acquisition of dedicated hardware for the Lattice Quantum Chromodynamics (LQCD) computing effort. This activity received final funding in FY 2017.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Theoretical and Computational Physics $60,331,000	**$73,980,000**	**+$13,649,000**
Theory $48,429,000	**$35,053,000**	**-$13,376,000**
Funding supported the theoretical research program at universities and national laboratories for the interpretation of experimental results, the development of new ideas for future projects, and the advancement of the theoretical understanding of nature.	The FY 2019 Request will support world-leading theoretical research program at universities and national laboratories.	Higher priority will be given to research that addresses the neutrino mass science driver.
Computational HEP $7,696,000	**$8,727,000**	**+$1,031,000**
Funding supported the computational science efforts focused at the national laboratories and the HEP contributions to the SciDAC 4 projects which were competed in FY 2017.	The FY 2019 Request will support transformative computational science and SciDAC 4 activities.	Higher priority will be given to advance computing research for HEP future needs, and working with ASCR to optimize the high performance computing for the near and long term future.
Quantum Information Science $0	**$27,500,000**	**+$27,500,000**
N/A	The FY 2019 Request will support new foundational QIS research and supporting technology. HEP will employ the latest developments in QIS from the private sector, contribute to the national effort, and promote American competiveness.	Focus of support will be on QIS research techniques and algorithms, quantum computing for HEP experiments and modeling, development and use of specialized quantum controls and precision sensors.
Projects $2,000,000	**$0**	**-$2,000,000**
Funding was provided for the acquisition of new LQCD hardware.	No funding will be requested for this activity.	LQCD received final funding in FY 2017.
SBIR/STTR $2,206,000	**$2,700,000**	**+$494,000**
In FY 2017, SBIR/STTR funding was at 3.65% of non-capital funding.	In FY 2019, SBIR/STTR funding will be at 3.65% of non-capital funding.	An increase in funding will represent mandated percentages for non-capital funding.

High Energy Physics
Advanced Technology R&D

Description

The Advanced Technology Research and Development (R&D) subprogram fosters cutting-edge research in the physics of particle beams, accelerator R&D, and particle detection—all of which are necessary for continued progress in high energy physics. Advanced Technology R&D cuts across all five P5 science drivers and the Energy, Intensity, and Cosmic Frontier Experimental subprograms. Long-term multi-purpose accelerator research, applicable to fields beyond HEP, is carried out under the Accelerator Stewardship subprogram.

HEP General Accelerator R&D

HEP General Accelerator R&D (GARD) focuses on understanding the science underlying the technologies used in particle accelerators and storage rings, as well as the fundamental physics of charged particle beams. Long-term research goals include developing technologies to enable breakthroughs in particle accelerator size, cost, beam intensity, and control. The GARD program consists of groups at U.S. academic and research institutions and national laboratories performing research activity categorized into five thrust areas: accelerator and beam physics; advanced acceleration concepts; particle sources and targetry; radio-frequency acceleration technology; and superconducting magnet and materials. GARD prioritizes research topics based on input from the April 2015 HEPAP Accelerator R&D subpanel report[a]. DOE selects research efforts with the highest scientific impact and potential based on a competitive peer-review process. An external peer review of the GARD laboratory research groups is planned for 2018. The findings from this review will inform the funding decisions in subsequent years.

GARD supports the Traineeship Program for Accelerator Science and Technology, launched in FY 2017 to revitalize education, training, and innovation in the physics of particle accelerators for the benefit of HEP and other SC programs that rely on these enabling technologies. A component of this program allows graduate students to participate in mentored accelerator research and technology development and enable leveraging the capabilities and assets of DOE laboratories. HEP holds a competition for traineeship awards to increase workforce development in areas of critical need. These traineeships leverage existing GARD research programs to develop new curricula and course materials in areas of workforce needs. The Traineeship Program is aimed at a university and national laboratory consortium to provide the academic training and research experience needed to meet DOE's anticipated workforce needs.

HEP Directed Accelerator R&D

HEP Directed Accelerator R&D supports strategic investments in innovative technologies for possible future HEP accelerator projects, with proof-of-principle demonstrations, prototype component development, and advancing technical readiness. The Muon Accelerator Program (MAP) completed its R&D goals in FY 2017 by delivering and then commissioning components for the Muon Ionization Cooling Experiment at Rutherford Appleton Laboratory in the United Kingdom. The LHC Accelerator Research Program (LARP) is anticipated to complete its R&D goals to produce prototypes for U.S. deliverables to the HL-LHC Accelerator Upgrade Project at CERN before FY 2019.

Detector R&D

Detector R&D addresses the need for continuing development of the next generation instrumentation and particle detectors to keep scientific leadership in a worldwide experimental program that is broadening into new research areas. To meet this challenge, HEP aims to foster a program appropriately balanced between evolutionary, near-term, low-risk detector R&D and revolutionary, long-term, high-risk detector R&D, while training the next generation of experts. The Detector R&D subprogram consists of groups at U.S. academic and research institutions and national laboratories performing research into the fundamental physics underlying the interactions of particles and radiation in detector materials as well as the development of technologies that turn these insights into working detectors. DOE selects research efforts with the highest scientific impact and potential based on a competitive peer-review process. An external peer review of the Detector R&D laboratory research groups was conducted in 2016; the next review will be in 2020. The findings from this review are being used to inform the funding decisions in subsequent years.

[a] http://science.energy.gov/~/media/hep/hepap/pdf/Reports/Accelerator_RD_Subpanel_Report.pdf

Facility Operations and Experimental Support

This activity provides funding for GARD laboratory experimental and test facilities, including BELLA, the laser-driven plasma wakefield acceleration facility at LBNL, and the facility for studying intense beam dynamics, the superconducting radio-frequency accelerator facilities, and the magnet facilities at Fermilab. This activity funds detector test beams at SLAC National Accelerator Laboratory (SLAC) and Fermilab, and detector test and fabrication facilities like the Microsystems Laboratory at LBNL and the Silicon Detector Facility at Fermilab. Accelerator Improvement Project (AIP) funding supports improvements to GARD facilities.

Projects

The Advanced Technology R&D subprogram supports the development of new tools for particle physics through the development of more advanced accelerators and detectors. Plasma wakefield accelerators may have a transformative impact on the size, capabilities, and cost of future machines. FACET-II will support the continuation of the plasma wakefield acceleration research started at FACET which was displaced by the construction of Linac Coherent Light Source II (LCLS-II). FACET-II fabrication and installation will occur at SLAC during the LCLS shutdown in FY 2019 in preparation for LCLS-II.

High Energy Physics
Advanced Technology R&D

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Advanced Technology R&D $122,082,000	**$83,755,000**	**-$38,327,000**
HEP General Accelerator R&D $44,050,000	**$38,043,000**	**-$6,007,000**
Funding supported research activities following the roadmap developed with the Accelerator R&D community, with focus in the areas of advanced accelerator concepts and superconducting magnets. The Traineeship Program for Accelerator Science and Technology was started.	The FY 2019 Request will support world-leading research activities in the areas of accelerator and beam physics, advanced acceleration concepts, particle sources and targetry, radio-frequency acceleration technology and superconducting magnet and materials. The Traineeship Program for Accelerator Science and Technology will be supported.	High priority will be given to world-leading efforts supported at national laboratories, and to research programs recommended by the HEPAP Accelerator Subpanel.
HEP Directed Accelerator R&D $22,800,000	**$0**	**-$22,800,000**
Funding supported LARP to continue the R&D needed to produce prototypes for U.S. deliverables to the HL-LHC Accelerator Upgrade Project at CERN. MAP delivered the final components in FY 2017.	No funding will be provided as LARP anticipates completing its goals before FY 2019, and MAP completed its goals in FY 2017.	The LARP and MAP goals will have been met.
Detector R&D $16,989,000	**$15,240,000**	**-$1,749,000**
Funding supported research activities at universities and national laboratories, with increased emphasis on long-term, high-risk, and high potential impact Detector R&D efforts and strengthening of the university efforts.	The FY 2019 Request will support world-leading Detector R&D activities at universities and national laboratories, with increased emphasis on long-term, high-risk, and high potential impact R&D efforts.	Near-term Detector R&D activities will be ramped down.
Facility Operations and Experimental Support $30,450,000	**$25,525,000**	**-$4,925,000**
Funding supported operation of accelerator, test beam and detector facilities at Fermilab, LBNL and SLAC. The SLAC Sector 10 Injector Infrastructure AIP began.	The FY 2019 Request will support the operation of accelerator, test beam and detector facilities at Fermilab, LBNL and SLAC. The LBNL BELLA Second Beamline AIP will begin.	Funding support will be focused on the accelerator, test beam, and detector facilities at Fermilab. Funding for LBNL and SLAC will support the highest priority research and fabrication activities informed by the P5 report. The LBNL BELLA Second Beamline AIP will begin, offset by the completion of the SLAC Sector 10 Injector Infrastructure AIP.

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Projects $3,500,000	**$2,000,000**	**-$1,500,000**
Funding supported the start of fabrication for FACET-II.	The FY 2019 Request will support continued fabrication for FACET-II.	Focus of support will be on the critical FACET-II infrastructure that needs to be installed during the shutdown of the linac for the LCLS-II installation.
SBIR/STTR $4,293,000	**$2,947,000**	**-$1,346,000**
In FY 2017, SBIR/STTR funding was at 3.65% of non-capital funding.	In FY 2019, SBIR/STTR funding will be at 3.65% of non-capital funding.	A decrease in funding will represent mandated percentages for non-capital funding.

High Energy Physics
Accelerator Stewardship

Description

The Accelerator Stewardship subprogram has three principal activities: facilitating access to unique state-of-the-art SC accelerator R&D infrastructure for the private sector and other users; supporting innovative early-stage applied research to adapt accelerator technology for medical, industrial, security, and defense applications; and driving a limited number of specific accelerator applications towards practical, testable prototypes in a five to seven year timeframe. HEP manages this program as a coordinated interagency initiative, consulting with other SC programs (principally NP and BES), other DOE program offices (principally EM and NNSA), and other federal stakeholders[a] of accelerator technology, most notably NIH, DOD, NSF, and DHS.

Accelerator Stewardship pursues targeted R&D to develop new uses of accelerator technology with broad applicability. Initial workshops and a request for information identified target application areas with broad impact in accelerator technologies for ion beam therapy of cancer and laser technologies for accelerators. Ongoing interagency consultation guides R&D investments, ensuring agency priorities are addressed and exploiting synergies where possible. As the program evolves, it will identify new cross-cutting areas of research based on input from the federal stakeholders, R&D performers, and the U.S. private sector.

Research

Accelerator Stewardship research is conducted at national laboratories, universities, and in the private sector. The stewardship program supports both near-term translational R&D and long-term basic accelerator R&D. The needs for applications chosen for this category have been specifically identified by federal stakeholders and developed further by technical workshops. Near-term R&D funding opportunities are specifically structured to foster strong partnerships with the private sector to improve health outcomes while lowering cost, develop technologies that can destroy pollutants and pathogens, detect contraband and radioactive material, and support new tools of science. Long-term R&D funding is targeted at scientific innovations enabling breakthroughs in particle accelerator size, cost, beam intensity, and control.

Facility Operations and Experimental Support

The Accelerator Stewardship subprogram supports the Brookhaven National Laboratory (BNL) Accelerator Test Facility (ATF), which is an SC User Facility providing a unique combination of high quality electron and infrared laser beams in a well-controlled user-friendly setting. Beam time at the BNL ATF is awarded based on merit-based peer review process. The facility remains at the cutting edge of science and works to increase its cost efficiency through an ongoing program of facility R&D. Accelerator Improvement Project (AIP) funding supports improvements to Accelerator Stewardship facilities.

[a] Partner agencies for the Accelerator Stewardship program currently are: the National Institutes of Health's National Cancer Institute; the Department of Defense's Office of Naval Research and Air Force Office of Scientific Research; the NSF's Physics Division and Chemical, Bioengineering, Environmental and Transport Systems Division; Department of Homeland Security's Domestic Nuclear Detection Office.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Accelerator Stewardship $14,091,000	**$12,417,000**	**-$1,674,000**
Research $6,703,000	**$8,032,000**	**+$1,329,000**
Funding supported a robust program of early-stage translational R&D at laboratories, universities, and industry for technology R&D areas such as laser, ion-beam therapy, and accelerator technology.	The FY 2019 Request will support new research activities at laboratories, universities, and in the private sector for technology R&D areas such as accelerator technology for industrial and security uses, laser, and ion-beam therapy.	Priority will be given to long-term R&D for the science and technology needed to build future generations of accelerators.
Facility Operations and Experimental Support $6,891,000	**$3,950,000**	**-$2,941,000**
Funding supported the BNL ATF operations. The ATF II Upgrade AIP was completed.	The FY 2019 Request will support the BNL ATF operations. The 20TW CO2 Laser Upgrade AIP will begin.	The ATF II Upgrade AIP, completed under budget, will be partially offset by the start of the 20TW CO2 Laser Upgrade AIP.
SBIR/STTR $497,000	**$435,000**	**-$62,000**
In FY 2017, SBIR/STTR funding was at 3.65% of non-capital funding.	In FY 2019, SBIR/STTR funding will be at 3.65% of non-capital funding.	A decrease in funding will represent mandated percentages for non-capital funding.

Description

This subprogram supports all line-item construction for the entire HEP program. All Total Estimated Costs (TEC) are funded in this subprogram, including both engineering design and construction.

Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment (LBNF/DUNE)

The LBNF/DUNE construction project is a federal, state, private, and international partnership developing and implementing the technologies of particle accelerators and detectors to enable world-leading research into the fundamental physics of neutrinos, which are the most ubiquitous particles in the universe while at the same time among the most mysterious. Neutrinos are intimately involved in nuclear decay processes and high energy nuclear reactions. LBNF/DUNE will study the transformations of muon neutrinos that occur as they travel to a large detector in South Dakota, 800 miles away from Fermilab, where they are produced in a high-energy beam. The experiment will analyze the rare, flavor-changing transformations of neutrinos in flight, from one lepton flavor to another, which are expected to help explain the fundamental physics of neutrinos and the imbalance of matter and antimatter in the universe today.

The LBNF/DUNE is being managed as a single project that encompasses the construction of a particle beam at Fermilab and the infrastructure for DUNE detectors at SURF. Fermilab, as host, will oversee all LBNF/DUNE construction and is responsible for design, construction, and operation of the LBNF beamline; design, construction, and operation of the conventional facilities and experiment infrastructure on the Fermilab site required for the near detector; and design, construction, and operation of the conventional facilities and experiment infrastructure at SURF, including the cryostats and cryogenics systems, required for the far detector. DUNE is an international collaboration that has formed to carry out the neutrino experiment enabled by the LBNF facility. The DUNE collaboration will be responsible for: the definition of the scientific goals; the design, construction, commissioning, and operation of the near detector at Fermilab and the far detectors at SURF; and the scientific research program conducted with the DUNE detectors. The DUNE collaboration currently consists of about 1,000 scientists and engineers from over 160 institutes in over 30 countries. Each of the collaborating institutions is responsible for delivering in-kind detector components that they have proven to have the expertise to build and install. Presently, the DOE contribution to the detectors will be a minority portion of the scope.

The near-term critical path item for LBNF/DUNE is excavation of the equipment caverns. Installation of the cryogenic systems and detectors cannot start until the caverns are ready. Critical site preparations such as safety and reliability refurbishments for the underground infrastructure as well as a waste-rock handling system must be completed before excavation can begin. CD-3A approval for excavation of the underground equipment caverns at SURF was approved September 1, 2016. The FY 2019 Request of $113,000,000 will support the excavation of the underground equipment caverns and connecting drifts (tunnels), and support continued design work for the near site, cryogenic systems, and the DUNE detectors.

Muon to Electron Conversion Experiment (Mu2e)

Mu2e, under construction at Fermilab, will search for evidence that a muon can change directly into an electron, a process that probes energy scales beyond the collision energy of the Large Hadron Collider. If observed, this major discovery would signal the existence of new particles or new forces beyond the Standard Model. The Mu2e project completed its technical design phase (CD-3) on July 14, 2016 and moved into full construction at that time. Civil construction of the underground detector housing and the surface building for the experiment were completed in 2017. The FY 2019 Request of $30,000,000 will conclude the planned funding for this project and will support the completion of the procurements and equipment installation.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Construction $93,500,000	**$143,000,000**	**+$49,500,000**
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment $50,000,000	**$113,000,000**	**+$63,000,000**
Funding supported the completion of site preparation activities, and initiated the procurement of civil construction for excavation of the underground equipment caverns. Funding supported design activities for the cryogenics system, detectors, and neutrino beam.	The FY 2019 Request will support the far site civil construction for the excavation of the underground equipment caverns and connecting drifts (tunnels). In addition, the project will continue to do design work for the near site, cryogenic systems, and the DUNE detectors.	Far site civil construction for the excavation of the caverns will ramp up to its full level in FY 2019. The excavation will take approximately four years to complete.
11-SC-41, Muon to Electron Conversion Experiment $43,500,000	**$30,000,000**	**-$13,500,000**
Funding supported the continued accelerator modifications and procurement of technical components for the experiment.	The FY 2019 Request will support the completion of the procurements and the beginning of equipment installation.	FY 2019 will be the last year of funding for this line item construction project, and support will be in accordance with the approved funding plan.

High Energy Physics
Performance Measures

In accordance with the GPRA Modernization Act of 2010, the Department sets targets for, and tracks progress toward, achieving performance goals for each program.

	FY 2017	FY 2018	FY 2019
Performance Goal (Measure)	**HEP Construction/MIE Cost & Schedule - Cost-weighted mean percentage variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects**		
Target	< 10 %	< 10 %	< 10 %
Result	Met	TBD	TBD
Endpoint Target	Adhering to the cost and schedule baselines for a complex, large scale, science project is critical to meeting the scientific requirements for the project and for being good stewards of the taxpayers' investment in the project.		
Performance Goal (Measure)	**HEP Facility Operations - Average achieved operation time of HEP user facilities as a percentage of total scheduled annual operation time**		
Target	≥ 80 %	≥ 80 %	≥ 80 %
Result	Met	TBD	TBD
Endpoint Target	Many of the research projects that are undertaken at the Office of Science's scientific user facilities take a great deal of time, money, and effort to prepare and regularly have a very short window of opportunity to run. If the facility is not operating as expected the experiment could be ruined or critically setback. In addition, taxpayers have invested millions or even hundreds of millions of dollars in these facilities. The greater the period of reliable operations, the greater the return on the taxpayers' investment.		
Performance Goal (Measure)	**HEP Neutrino Model - Carry out series of experiments to test the standard 3-neutrino model of mixing**		
Target	Fermilab switches operations mode over from neutrino beam to antineutrino beam delivery to the NOvA experiment. NOvA accumulates physics data in antineutrino mode.	MicroBooNE data taking will complete final year of phase-1. NOvA will publish the first muon and electron anti-neutrino oscillation results. ICARUS data taking will begin. SBND physics commissioning will continue.	NOvA will present important results on whether neutrino mixing is "maximal" and the mass ordering of neutrino states. MicroBooNE will address the low-energy anomalies observed in neutrino interactions. First results from ICARUS will be presented.

	FY 2017	FY 2018	FY 2019
Result	Met	TBD	TBD
Endpoint Target	Similar to quarks, the mixing between neutrinos is postulated to be described by a unitary matrix. Measuring the independent parameters of this matrix in different ways and with adequate precision will demonstrate whether this model of neutrinos is correct. Such a model is needed to correctly extract evidence for CP violation in the neutrino sector.		

High Energy Physics
Capital Summary ($K)

	Total	Prior Years	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Capital Operating Expenses Summary						
Capital equipment	n/a	n/a	98,946	—	106,450	+7,504
General plant projects (GPP)	n/a	n/a	7,400	—	1,500	-5,900
Accelerator improvement projects (AIP) (<$5M)	n/a	n/a	7,925	—	7,700	-225
Total, Capital Operating Expenses	**n/a**	**n/a**	**114,271**	—	**115,650**	**+1,379**
Capital Equipment						
Major items of equipment[b]						
Energy Frontier Experimental Physics						
LHC ATLAS Detector Upgrades[c]	20,821	12,321	8,500	—	0	-8,500
LHC CMS Detector Upgrades[d]	22,629	14,662	7,967	—	0	-7,967
HL-LHC Accelerator Upgrade Project[e]	200,000	0	0	—	42,000	+42,000
HL-LHC ATLAS Detector Upgrade[f]	128,485	0	0	—	17,500	+17,500
HL-LHC CMS Detector Upgrade[g]	128,500	0	0	—	17,500	+17,500
Intensity Frontier Experimental Physics						
Muon g-2 Experiment[h]	27,549	21,200	6,349	—	0	-6,349

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

[b] Each MIE located at a DOE facility Total Estimated Cost (TEC) > $5M and each MIE not located at a DOE facility TEC > $2M.

[c] Critical Decisions CD-2 and 3 for the LHC ATLAS Detector Upgrade Project were approved on November 12, 2014. The TPC is $33,250,000.

[d] Critical Decisions CD-2 and 3 for the LHC CMS Detector Upgrade Project were approved on November 12, 2014. The TPC is $33,217,000.

[e] Critical Decision CD-1/3a for HL-LHC Accelerator Upgrade Project was approved October 13, 2017. The estimated cost range was $208,600,000 to $252,400,000.

[f] Critical Decision CD-0 for HL-LHC ATLAS Detector Upgrade Project was approved April 13, 2016. The estimated cost range was $125,000,000 to $155,000,000.

[g] Critical Decision CD-0 for HL-LHC CMS Detector Upgrade Project was approved April 13, 2016. The estimated cost range was $125,000,000 to $155,000,000.

[h] Critical Decision CD-4 for Muon g-2 Experiment was approved January 16, 2018. The TPC is $46,400,000.

	Total	Prior Years	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Cosmic Frontier Experimental Physics						
Large Synoptic Survey Telescope Camera (LSSTcam)[a]	150,300	95,500	45,000	—	0	-45,000
Dark Energy Spectroscopic Instrument[b] (DESI)	45,450	10,300	12,000	—	7,500	-4,500
LUX-ZEPLIN[c] (LZ)	52,050	11,000	12,500	—	14,450	+1,950
SuperCDMS-SNOLAB[d]	18,725	2,375	3,400	—	5,000	+1,600
Advanced Technology R&D						
FACET II[e]	17,400	0	500	—	2,000	+1,500
Total MIEs	n/a	n/a	96,216	—	105,950	+9,734
Total Non-MIE Capital Equipment	n/a	n/a	2,730	—	500	-2,230
Total, Capital equipment	**n/a**	**n/a**	**98,946**	—	**106,450**	**+7,504**
General Plant Projects (GPP)						
Industrial Center Building addition	8,250	0	6,750	—	0	-6,750
Central Utility Building (CUB) Improvement	8,839	0	0	—	1,500	+1,500
Other projects under $5 million TEC	n/a	n/a	650	—	0	-650
Total, Plant Project (GPP)	**n/a**	**n/a**	**7,400**	—	**1,500**	**-5,900**

[a] Critical Decision CD-3 for the LSSTcam project was approved on August 27, 2015. The TPC is $168,000,000.

[b] Critical Decision CD-3 for DESI project was approved on June 22, 2016, with a TPC of $56,328,000.

[c] Critical Decision CD-3 for LZ project was approved February 9, 2017. The TPC is $55,500,000.

[d] The estimated cost range for SuperCDMS-SNOLAB at Critical Decision CD-1 approved December 21, 2015 was $16,000,000–$21,500,000.

[e] The estimated cost range for FACET II at CD-1 approved on December 21, 2015 was $46,000,000–$60,000,000. Funding at the proposed FY 2019 request level would require an evaluation of the project scope from CD-1.

	Total	Prior Years	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Accelerator Improvement Projects (AIP)						
Muon Campus Cryogenics	9,600	8,200	1,400	—	0	-1,400
Sector 10 Injector Infrastructure	5,025	0	3,525	—	0	-3,525
20TW CO2 Laser Upgrade	9,000	0	0	—	500	+500
NuMI Target System	6,100	0	0	—	3,700	+3,700
Booster Intensity	6,200	0	0	—	3,000	+3,000
Bella Second Beamline	7,795	0	0	—	500	+500
Other projects under $5 million TEC[a]	n/a	n/a	3,000	—	0	-3,000
Total, Accelerator Improvement Projects	**n/a**	**n/a**	**7,925**	**—**	**7,700**	**-225**

[a] ATF II Upgrade was previously estimated to be $5,000,000 and was listed as a separate line in the FY 2018 Congressional submission. The project was completed under budget in FY 2017 and is now included in the Other projects under $5 Million TEC line.

Major Items of Equipment Descriptions

Energy Frontier Experimental Physics MIEs:

The *LHC ATLAS Detector Upgrade Project* was baselined (CD-2) and approved on November 12, 2014, for a fabrication start (CD-3), with a total project cost of $33,250,000 and a project completion date in FY 2019. The U.S. scope includes upgrades to the muon subsystem, the liquid-argon calorimeter detector, and the trigger and data acquisition system to take advantage of the increased LHC luminosity. The project is producing subsystem components for installation beginning in 2018. The FY 2019 Request will not include funding for this project, as it will have sufficient funds to complete all remaining deliverables.

The *LHC CMS Detector Upgrade Project* was baselined (CD-2) and approved on November 12, 2014, for a fabrication start (CD-3), with a total project cost of $33,217,000 and a project completion date in FY 2020. The planned U.S. scope includes upgrades to the pixelated inner tracking detector, the hadron calorimeter detector, and the trigger system to take advantage of the increased LHC luminosity. The project has successfully installed the pixelated inner tracking detector and portions of the trigger and hadron calorimeter; the remaining components are being produced and for installation in FY 2018. The FY 2019 Request will not include funding for this project, as it will have sufficient funds to complete all remaining deliverables.

The *High Luminosity Large Hadron Collider Accelerator Upgrade Project (HL-LHC Accelerator Upgrade Project)* requested to start as a new MIE in the FY 2018 President's Budget Request with $27,000,000 of initial TEC funding. The HL-LHC Accelerator Upgrade Project received CD-1/3a approval on October 13, 2017 with an estimated cost range of $208,600,000 to $252,400,000. Following the major upgrade, the CERN LHC machine will further increase the particle collision rate by a factor of three times to explore new physics beyond the reach of the current LHC program. The project will deliver components for which the U.S. scientists have critical expertise: interaction region focusing quadrupole magnets, and special superconducting RF crab cavities that are capable of generating transverse electric fields. The magnets will be assembled at Lawrence Berkeley National Laboratory, Brookhaven National Laboratory, and Fermilab, exploiting special expertise and unique capabilities at each laboratory. The FY 2019 Request of TEC funding will be $42,000,000 supporting the production of quadrupole magnets and crab cavities.

The *High Luminosity Large Hadron Collider ATLAS Detector Upgrade Project (HL-LHC ATLAS)* will start as a new MIE in FY 2019 with $17,500,000 of initial TEC funding. The HL-LHC ATLAS Detector Upgrade Project received CD-0 approval on April 13, 2016 with an estimated cost range of $125,000,000 to $155,000,000. The ATLAS detector is expected to integrate a factor of ten higher amount of data per run, compared to the period prior to the HL-LHC upgrades, making the physical conditions in which the detectors run very challenging. To operate for an additional decade in these new conditions, the ATLAS detector will require upgrades to the silicon pixel and strip tracker detectors, the muon detector systems, the calorimeter detectors and associated electronics, and the trigger and data acquisition systems. The National Science Foundation (NSF) is preparing a Major Research Equipment and Facility Construction (MREFC) Project to provide different scope to the HL-LHC ATLAS detector. DOE and NSF are coordinating their contributions to avoid duplication. The FY 2019 Request of TEC funding will be $17,500,000 supporting the procurement of solid-state detecting components for the ATLAS inner tracking detectors.

The *High Luminosity Large Hadron Collider CMS Detector Upgrade Project (HL-LHC CMS)* will start as a new MIE in FY 2019 with $17,500,000 of initial TEC funding. The HL-LHC CMS Detector Upgrade Project received CD-0 approval on April 13, 2016 with an estimated cost range of $125,000,000 to $155,000,000. The CMS detector is expected to integrate a factor of ten higher amount of data per run, compared to the period prior to the HL-LHC upgrades, making the physical conditions in which the detectors run very challenging. To operate for an additional decade in these new conditions, the CMS detector will require upgrades to the silicon pixel tracker detectors, outer tracker detector, the muon detector systems, the calorimeter detectors and associated electronics, and the trigger and data acquisition systems. NSF is preparing a MREFC Project to provide different scope to the HL-LHC CMS detector. DOE and NSF are coordinating their contributions to avoid duplication. The FY 2019 Request of TEC funding will be $17,500,000 supporting the procurement of solid-state detecting components for the CMS inner tracking detectors.

Intensity Frontier Experimental Physics MIE:

The *Muon g-2 Project* completion date will be in FY 2019. The FY 2019 Request will not include funding for this project, as it will have sufficient funds to complete all remaining deliverables.

Cosmic Frontier Experimental Physics MIEs:
The *Large Synoptic Survey Telescope Camera (LSSTcam*) project received CD-2 approval on January 7, 2015, with a DOE TPC of $168,000,000 and a project completion date in FY 2022. CD-3 was approved on August 27, 2015. LSSTcam is fabricating a state-of-the-art three billion pixel digital imaging camera for the next-generation, wide-field, ground-based optical and near-infrared LSST facility, located in Chile. LSST is designed to provide deep images of half the sky every few nights, enabling study of the nature of dark energy. LSSTcam is DOE's responsibility in the collaboration with the NSF, which leads the LSST project, along with private and foreign contributions. The project is currently producing many of the camera components, which are being tested and integrated before shipment to Chile in 2020. The FY 2019 Request will not include funding for this project, as it will have sufficient funds to complete all remaining deliverables.

The *Dark Energy Spectroscopic Instrument (DESI)* project received CD-2 approval on September 17, 2015 with a TPC of $56,328,000, and a project completion date of FY 2021. CD-3 was approved on June 22, 2016. DESI will fabricate a next-generation, fiber-fed, ten-arm spectrograph to be operated on Mayall 4-meter telescope at Kitt Peak National Observatory in Arizona, with operations of the telescope supported by DOE. DESI will measure the effects of dark energy on the expansion of the universe using dedicated spectroscopic measurements and will provide a strong complement to the LSST imaging survey. The FY 2019 Request of TEC funding will be $7,500,000, which will enable the project to continue its fabrication phase, producing and testing the instrument components, along with integration of the components on the telescope.

The *LUX-ZEPLIN (LZ)* project received CD-2 approval on August 8, 2016 with a TPC of $55,500,000, and a project completion date in FY 2022. CD-3 was approved on February 9, 2017. LZ is one of two MIEs selected to meet the Dark Matter Second Generation Mission Need and the concept for the experiment was developed by a merger of the LUX and ZEPLIN collaborations from the U.S. and the U.K. respectively. The project will fabricate a detector using seven tons of liquid xenon inside a time projection chamber to search for xenon nuclei that recoil in response to collisions with an impinging flux of dark matter particles known as Weakly Interacting Massive Particles (WIMPs). The detector will be located 4,850 feet deep in the Sanford Underground Research Facility (SURF) in Lead, South Dakota. The FY 2019 Request of TEC funding will be $14,450,000, which will support final procurement, fabrication, testing, and integration of detector components at SURF. This will be the final funding request for the LZ MIE.

The *Super Cryogenic Dark Matter Search at Sudbury Neutrino Observatory Laboratory (SuperCDMS-SNOLAB)* project received CD-1 approval on December, 21, 2015 with an estimated cost range of $16,000,000 to $21,500,000. SuperCDMS-SNOLAB is one of the two MIEs selected to meet the Dark Matter Second Generation Mission Need. The project will fabricate instrumentation that uses ultra-clean, cryogenically-cooled silicon (Si) and germanium (Ge) detectors to search for Si or Ge nuclei recoiling in response to collisions with WIMPs, and will be optimized to detect low mass WIMPs to cover a range of masses complementary to that of LZ's sensitivity. The detector will be located 2 km deep in the SNOLAB facility in Sudbury, Ontario, Canada. The FY 2019 Request of TEC funding for SuperCDMS-SNOLAB will be $5,000,000, which will enable the project, in its fabrication phase, to continue producing and testing the instrument components, along with integration of the components at SNOLAB.

Advanced Technology R&D MIE:
The *Facility for Accelerator and Experimental Tests II (FACET-II)* project started MIE fabrication in FY 2017. CD-1 was approved December 21, 2015 with an estimated cost range of $46,000,000–$60,000,000. FACET-II will succeed FACET as the world's premier beam driven plasma wakefield facility and provide intense ultra-short electron beams for other applications in accelerator and related sciences. The successful FACET program ended due to the construction of the Linac Coherent Light Source II (LCLS-II) in the portion of the SLAC tunnel used by FACET. FACET-II is being designed to deliver beams using only one third of the SLAC linac. The FY 2019 Request of TEC funding for FACET-II will be $2,000,000. In FY 2019, work will continue on fabricating the beamline components that needs to be installed during the shutdown of the linac for the LCLS-II installation.

High Energy Physics
Construction Project Summary ($K)

	Total	Prior Years	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment						
TEC	1,465,000	61,781	50,000	49,660	113,000	+63,000
OPC	95,000	85,625	0	—[b]	1,000	+1,000
TPC	1,560,000	121,320	50,000	51,660	114,000	+64,000
11-SC-41, Muon to Electron Conversion Experiment						
TEC	250,000	132,100	43,500	43,205	30,000	-13,500
OPC	23,677	23,677	0	—	0	0
TPC	273,677	115,677	43,500	43,205	30,000	-13,500
Total, Construction						
TEC	n/a	n/a	93,500	92,865	143,000	+49,500
OPC	n/a	n/a	0	—	1,000	+1,000
TPC	n/a	n/a	93,500	94,865	144,000	+50,500

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).
[b] $2,000,000 is planned for FY 2018 Annualized CR.

Funding Summary ($K)

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Research	**347,852**	**—**	**280,130**	**-67,722**
Facilities Operations				
Scientific User Facilities Operations	136,472	—	111,150	-25,322
Other Facilities	118,690	—	99,870	-18,820
Total, Facilities Operations	**255,162**	—	**211,020**	**-44,142**
Projects				
Major Items of Equipment[b]	107,566	—	109,850	+2,284
Other Projects	5,700	—	0	-5,700
Construction[b]	108,720	—	169,000	+60,280
Total, Projects	**221,986**	—	**278,850**	**+56,864**
Total, High Energy Physics	**825,000**	**819,397**	**770,000**	**-55,000**

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

[b] Includes Other Project Costs.

Scientific User Facility Operations ($K)

The treatment of user facilities is distinguished between two types: TYPE A facilities that offer users resources dependent on a single, large-scale machine; TYPE B facilities that offer users a suite of resources that is not dependent on a single, large-scale machine.

Definitions:

Achieved Operating Hours – The amount of time (in hours) the facility was available for users.

Planned Operating Hours –

- For Past Fiscal Year (PY), the amount of time (in hours) the facility was planned to be available for users.
- For Current Fiscal Year (CY), the amount of time (in hours) the facility is planned to be available for users.
- For the Budget Fiscal Year (BY), based on the proposed Budget Request the amount of time (in hours) the facility is anticipated to be available for users.

Optimal Hours – The amount of time (in hours) a facility would be available to satisfy the needs of the user community if unconstrained by funding levels.

Percent of Optimal Hours – An indication of utilization effectiveness in the context of available funding; it is not a direct indication of scientific or facility productivity.

- For BY and CY, Planned Operating Hours divided by Optimal Hours expressed as a percentage.
- For PY, Achieved Operating Hours divided by Optimal Hours.

Unscheduled Downtime Hours - The amount of time (in hours) the facility was unavailable to users due to unscheduled events. NOTE: For type "A" facilities, zero Unscheduled Downtime Hours indicates Achieved Operating Hours equals Planned Operating Hours.

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
TYPE A FACILITIES				
Fermilab Accelerator Complex	**$130,781**	**—**	**$107,200**	**-$23,581**
Number of Users	2,246	—	2,096	-150
Achieved operating hours	4,823	—	N/A	N/A
Planned operating hours	4,800	—	3,600	-1,200
Optimal hours	4,800	—	4,800	0
Percent optimal hours	100.5%	—	75.0%	-25.5%
Unscheduled downtime hours	658	—	N/A	N/A

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Accelerator Test Facility (BNL)	**$5,691**	—	**$3,950**	**-$1,741**
Number of Users	97	—	64	-33
Achieved operating hours	2,273	—	N/A	N/A
Planned operating hours	2,060	—	1,751	-309
Optimal hours	2,500	—	2,050	-450
Percent optimal hours	90.9%	—	85.4%	-5.5%
Unscheduled downtime hours	256	—	N/A	N/A
Total Facilities	**$136,472**	—	**$111,150**	**-$25,322**
Number of Users	2,343	—	2,160	-183
Achieved operating hours	7,096	—	N/A	N/A
Planned operating hours	6,860	—	5,351	-1,509
Optimal hours	7,300	—	6,850	-450
Percent of optimal hours[a]	100.1%	—	75.4%	-24.7%
Unscheduled downtime hours	914	—	N/A	N/A

Scientific Employment

	FY 2017 Enacted	FY 2018 Annualized CR[b]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Number of permanent Ph.D.'s (FTEs)	895	—	740	-155
Number of postdoctoral associates (FTEs)	335	—	260	-75
Number of graduate students (FTEs)	495	—	395	-100
Other[c]	1,870	—	1,785	-85

[a] For total facilities only, this is a "funding weighted" calculation FOR ONLY TYPE A facilities: $\frac{\sum_1^n[(\%OH\ for\ facility\ n)\times(funding\ for\ facility\ n\ operations)]}{Total\ funding\ for\ all\ facility\ operations}$

[b]A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

[c] Includes technicians, engineers, computer professionals, and other support staff.

11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment (LBNF/DUNE)
Fermi National Accelerator Laboratory, Batavia, Illinois
Project is for Design and Construction

1. Significant Changes and Summary

Significant Changes

This Construction Project Data Sheet (CPDS) is an update of the FY 2018 CPDS and does not include a new start for FY 2019.

Development of the design and cost estimates have been refined since the FY 2018 Budget Request to Congress, resulting in an increase to the TPC point estimate from $1,536,000 to $1,560,000 as the U.S. DOE contributions to the multinational effort are now better understood. Additional design activities and prototypes have been identified by the project team and are being incorporated in development of the project design. A Construction Manager/General Contractor (CM/GC) was selected in FY 2017 for delivery of the Far Site conventional facilities scope that was approved at the end of FY 2016.

Summary

The FY 2019 Request for Long Baseline Neutrino Facility (LBNF)/Deep Underground Neutrino Experiment (DUNE) is $113,000,000. The most recent approved DOE Order 413.3B is CD-3A, approval for Initial Far Site Construction: initiating excavation and construction for the LBNF Far Site conventional facilities in order to mitigate risks and minimize delays for providing a facility ready to accept detectors for installation. CD-3A was approved September 1, 2016 with a preliminary total project cost (TPC) range of $1,260,000,000 to $1,860,000,000 and CD-4 date of 4Q FY 2030. The range includes the full cost of the LBNF host facility excluding foreign contributions, as well as the full cost of the DOE contribution to the DUNE experimental apparatus.

The LBNF/DUNE construction project is a federal, state, private, and international partnership developing and implementing the technologies of particle accelerators and detectors to enable world-leading research into the fundamental physics of neutrinos, which are the most ubiquitous particles in the universe while at the same time among the most mysterious. Neutrinos are intimately involved in nuclear decay processes and high energy nuclear reactions. LBNF/DUNE will study the transformations of muon neutrinos that occur as they travel to a large detector in South Dakota, 800 miles away from Fermilab where they are produced in a high-energy beam. The experiment will analyze the rare, flavor-changing transformations of neutrinos in flight, from one lepton flavor to another, which are expected to help explain the fundamental physics of neutrinos and the puzzling matter-antimatter asymmetry that enables our existence in a matter-dominated universe.

The LBNF/DUNE project comprises a national flagship particle physics initiative. LBNF/DUNE will be the first-ever large-scale international science facility hosted by the United States. As part of implementation of High Energy Physics Advisory Panel-Particle Physics Project Prioritization Panel (P5) recommendations, the LBNF/DUNE project consists of two multinational collaborative efforts:

- LBNF is responsible for the beamline at Fermilab and other experimental and civil infrastructure at Fermilab and at the Sanford Underground Research Facility (SURF) in South Dakota. It is currently operated by the South Dakota Science and Technology Authority (SDSTA), an agency of the State of South Dakota, and hosts experiments supported by DOE, NSF, and major research universities.

  DOE entered into a land lease with the SDSTA on May 20, 2016 covering the area on which the DOE funded facilities will be housed and the LBNF and DUNE detector will be built. The lease provides the framework for DOE and Fermilab to construct federally funded buildings and facilities on non-federal land, and to establish a long-term (multi-decade) arrangement for DOE and Fermilab to use SDSTA space to host the neutrino detector. Other Project Costs (OPC) funding has been identified in years FY 2018-FY 2026 for plant support costs provided by SDSTA.

- DUNE is an international scientific collaboration responsible for defining the scientific goals & technical requirements for the beam and detectors, as well as the design, construction & commissioning of the detectors and subsequent research program.

DOE's High Energy Physics program manages both activities as a single, line-item construction project—LBNF/DUNE. LBNF, with DOE/Fermilab leadership and minority participation by a small number of international partners including CERN, will construct a megawatt-class neutrino source and related facilities at Fermilab (the "near site"), as well as underground caverns and cryogenic facilities in South Dakota (the "far site) needed to house the DUNE detectors. DUNE has international leadership and participation by about 1,000 scientists and engineers from over 160 institutions in over 30 countries. The mass of the detectors totaling 40 kilotons will be distributed in four cryostats housed in large caverns at SURF. An additional cavern at SURF will accommodate the cryogenic and other utility systems. DOE will fund less than a third of DUNE. Development of the design and cost estimates have been refined and the U.S. DOE contributions to the multinational effort are now better understood. Additional design activities and prototypes have been identified.

Contributions from the international partners to LBNF/DUNE are currently being negotiated by Fermilab and DOE. The DOE and CERN signed an agreement in May 2017 that CERN will provide in-kind contributions worth $165,000,000 for LBNF/DUNE. In September 2017, the United Kingdom announced an $88,000,000 grant to a UK collaboration that will provide in-kind contributions to LBNF/DUNE and the Proton Improvement Plan II project. The detailed distribution between the projects is still being finalized. For the DUNE detectors, the collaboration has put in place a process to complete a technical design of the detectors and divide the work of building the detectors between the collaborating institutions. The first review of the design will take place in summer of 2018 and the final design report with a complete set of funding responsibilities will be reviewed by the Long Baseline Neutrino Committee in spring of 2019. All DOE contributions to the facility and the detectors will be managed according to DOE Order 413.3B, and Fermilab will provide unified project management reporting.

Fermilab has initiated site preparation at SURF with maintenance and refurbishment activities to the mine shaft, hoists, ventilation systems, and general support infrastructure to allow for safe and reliable access prior to initiating excavation and underground construction.

The FY 2019 Request will support the far site civil construction for the excavation of the underground equipment caverns and connecting drifts (tunnels), which will be initiated late in FY 2018 and will ramp up to its full level in FY 2019. The excavation will take approximately four years to complete.

A Federal Project Director with a certification level 4 has been assigned to this project and has approved this CPDS.

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2011	1/8/2010		1Q FY 2011	TBD	4Q FY 2013	TBD	TBD	TBD
FY 2012	1/8/2010		2Q FY 2012	TBD	2Q FY 2015	TBD	TBD	TBD
FY 2016[a]	1/8/2010	12/10/2012	12/10/2012	4Q FY 2017	4Q FY 2019	4Q FY 2019	N/A	4Q FY 2027
FY 2017	1/8/2010	11/5/2015[b]	11/5/2015[b]	1Q FY 2020	1Q FY 2020	1Q FY 2020	N/A	4Q FY 2030
FY 2018	1/8/2010	11/5/2015[b]	11/5/2015[b]	1Q FY 2021	1Q FY 2022	1Q FY 2022	N/A	4Q FY 2030
FY 2019	1/8/2010	11/5/2015[b]	11/5/2015[b]	1Q FY 2021	1Q FY 2022	1Q FY 2022	N/A	4Q FY 2030

CD-0 – Approve Mission Need
Conceptual Design Complete – Actual date the conceptual design was completed
CD-1 – Approve Design Scope and Project Cost and Schedule Ranges
CD-2 – Approve Project Performance Baseline
Final Design Complete – Estimated date the project design will complete
CD-3 – Approve Start of Construction
D&D Complete – Completion of D&D work (see section 9)
CD-4 – Approve Start of Operations or Project Closeout

(fiscal quarter or date)

	CD-1R	CD-3A	CD-3B	CD-3(C)	Performance Baseline Validation
FY 2017	11/5/2015	2Q FY 2016	3Q FY 2018	1Q FY 2020	1Q FY 2020
FY 2018	11/5/2015	9/1/2016	1Q FY 2021	1Q FY 2022	1Q FY 2021
FY 2019	11/5/2015	9/1/2016	1Q FY 2021	1Q FY 2022	1Q FY 2021

CD-1R – Refresh of CD-1 approval for the new Conceptual Design.
CD-3A – Approve Initial Far Site Construction: initiating excavation and construction for the LBNF Far Site conventional facilities in order to mitigate risks and minimize delays for providing a facility ready to accept detectors for installation.
CD-3B – Approve Start of Far Site Construction: procurement of the remaining Far Site scope for conventional facilities, cryogenic systems and detectors.
CD-3(C) – Approve Start of Near Site Construction: procurement of Near Site scope and any remaining LBNF/DUNE scope. (Same as CD-3.)

[a] No CPDS was submitted for FY 2013, FY 2014 or FY 2015 because no TEC funds were requested; however, design funds were provided in each year's appropriation.
[b] Critical Decision CD-1 was approved for the new conceptual design by an ESAAB approval (CD-1R) on November 5, 2015.

3. Project Cost History

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC Except D&D	OPC, D&D	OPC, Total	TPC
FY 2011	102,000	TBD	TBD	22,180	TBD	TBD	TBD
FY 2012	133,000	TBD	TBD	42,621	TBD	TBD	TBD
FY 2016[a]	127,781	655,612	783,393	89,539	N/A	89,539	872,932
FY 2017	123,781	1,290,680	1,414,461	85,539	N/A	85,539	1,500,000
FY 2018	234,375	1,199,000	1,433,375	102,625	N/A	102,625	1,536,000
FY 2019[bc]	231,000	1,234,000	1,465,000	95,000	N/A	95,000	1,560,000

4. Project Scope and Justification

Scope

LBNF/DUNE will be composed of a neutrino beam created by new construction as well as modifications to the existing Fermilab accelerator complex, massive neutrino detectors (at least 40,000 tons in total) and associated cryogenics infrastructure located in one or more large underground caverns to be excavated at least 800 miles “downstream” from the neutrino source, and a much smaller neutrino detector at Fermilab for monitoring the neutrino beam near its source. A primary beam of protons will produce a neutrino beam directed into a target for converting the protons into a secondary beam of particles (pi mesons and muons) that decay into neutrinos, followed by a decay tunnel hundreds of meters long where the decay neutrinos will emerge and travel through the earth to the massive detector. The Neutrinos at the Main Injector (NuMI) beam at Fermilab is an existing example of this type of configuration for a neutrino beam facility. The new LBNF beam line will provide a neutrino beam of lower energy and greater intensity than the NuMI beam, and would point to a far detector at a greater distance than is used with NuMI experiments.

For the LBNF/DUNE project, Fermilab will be responsible for design, construction and operation of the major components of LBNF including: the primary proton beam, neutrino production target, focusing structures, decay pipe, absorbers and corresponding beam instrumentation; the conventional facilities and experiment infrastructure on the Fermilab site required for the near detector; and the conventional facilities and experiment infrastructure at SURF for the large detectors including the cryostats and cryogenics systems.

Justification

Recent international progress in neutrino physics, celebrated by the Nobel Prizes for Physics in 1988, 1995, 2002, and 2015, provides the basis for further discovery opportunities. Determining relative masses and mass ordering of the three known neutrinos will give guidance and constraints to theories beyond the Standard Model of particle physics. The study and observation of the different behavior of neutrinos and antineutrinos will offer insight into the dominance of matter over antimatter in our universe and therefore, the very structure of our universe. The only other source of the matter-antimatter asymmetry, in the quark sector, is too small to account for the observed matter dominance.

Among the technical issues addressed in the alternatives analysis were the preferred detector technology and the neutrino beamline design. After a thorough study, both technologies were found to be capable of meeting the performance requirements if located underground, only liquid argon could work on the surface, and is less expensive. A low energy

[a] No CPDS was submitted for FY 2013, FY 2014 or FY 2015 because no TEC funds were requested; however, design funds were provided in each year’s appropriation.
[b] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The preliminary TPC range at CD-1 is $1,260,000,000 to $1,860,000,000. The TPC point estimate is $1,560,000,000.
[c] No construction, other than site preparation, approved civil construction or long-lead procurement will be performed prior to validation of the Performance Baseline and approval of CD-3.

neutrino beam to SURF and the current NuMI beam were compared. The new LBNF beam with its lower energy and longer distance to the detector was shown to be superior.

The preliminary Key Performance Parameters (KPPs) for project completion that were approved by CD-1 in FY 2015 include the primary beam and neutrino beam production systems as well as underground caverns excavated for four separate, 10 kton detectors (of liquid-argon, time-projection detectors) at the SURF site, 1000-1500 km from the neutrino source. The DOE contribution for DUNE will include technical components for two of the four detectors, which will be installed and tested with cosmic rays, and components of the cryogenic systems for the detectors, which will be installed and pressure tested. The KPPs will be finalized at CD-2.

Preliminary Key Performance Parameters

Scope	Threshold KPP	Objective KPP
Primary Beam to produce neutrinos directed to the far detector site	Beamline hardware commissioning complete and demonstration of protons delivered to the target	In addition to Threshold KPPs, system enhancements to maximize neutrino flux, enable tunability in neutrino energy spectrum or to improve neutrino beam capability
Far Site-Conventional Facilities	Caverns excavated for 40 kiloton fiducial detector mass[a]; beneficial occupancy granted for cavern space to house 20 kiloton fiducial detector mass[a]	In addition to Threshold KPPs, Beneficial Occupancy granted for remaining cavern space
Detector Cryogenic Infrastructure	DOE-provided components for Cryogenic subsystems installed and pressure tested for 20 kiloton fiducial detector mass	In addition to Threshold KPPs, additional DOE contributions to cryogenic subsystems installed and pressure tested for additional 20 kiloton fiducial detector mass; DOE contributions to cryostats
Long-Baseline Distance between neutrino source and far detector	1,000-1,500 kilometers	1,000-1,500 kilometers
Far Detector	DOE-provided components installed in cryostats to support 20 kiloton fiducial detector mass, with cosmic ray interactions detected in each detector module	In addition to Threshold KPPs, additional DOE contributions to support up to 40 kiloton fiducial detector mass

[a] Fiducial detector mass pertains to the mass of the interior volume of the detection medium (liquid argon) that excludes the external portion of the detection medium where most background events would occur.

5. Financial Schedule[a]

	(dollars in thousands)			
	Appropriations	Obligations	Recovery Act Costs	Costs[b]
Total Estimated Cost (TEC)				
Design Only[c]				
FY 2012	4,000	4,000	0	0[d]
FY 2013	3,781	3,781	0	801
FY 2014	16,000	16,000	0	7,109
FY 2015	12,000	12,000	0	15,791
FY 2016	0	0	0	12,080
Subtotal, Design Only	35,781	35,781	0	35,781
Design (Design and Construction)				
FY 2016	N/A	N/A	0	14,356[e]
FY 2017	N/A	N/A	0	37,257
FY 2018	N/A	N/A	0	11,000[f]
FY 2019	N/A	N/A	0	20,000
Outyears	N/A	N/A	0	112,606
Subtotal, Design (Design and Construction)	N/A	N/A	0	195,219
Total, Design	N/A	N/A	0	231,000
Construction				
FY 2017	N/A	N/A	0	13,000
FY 2018	N/A	N/A	0	43,900[g]
FY 2019	N/A	N/A	0	93,000
Outyears	N/A	N/A	0	1,084,100
Total, Construction	N/A	N/A	0	1,234,000

[a] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The preliminary TPC range at CD-1 is $1,260,000,000 to $1,860,000,000. The TPC point estimate is $1,560,000,000. Design and international collaboration plans are currently being developed; outyears are preliminary.
[b] Costs through FY 2017 reflect actual costs; costs for FY 2018 and the outyears are estimates.
[c] Design Only CPDS was prepared in FY 2012; no CPDS was prepared FY 2013-2015. Funding amounts shown for traceability. FY 2016 and onward CPDS prepared as Design and Construction.
[d] $1,078,000 was erroneously costed to this project in FY 2012, the accounting records were adjusted in early FY 2013.
[e] Costs were for Far Site preparation including safety and reliability refurbishment of the underground infrastructure, which is needed prior to initiating excavation of the equipment caverns.
[f] Estimated costs are for continuing project engineering design in preparation for CD-2.
[g] Estimated costs are for initiating excavation of the equipment caverns at the Far Site as approved by CD-3A.

	(dollars in thousands)			
	Appropriations	Obligations	Recovery Act Costs	Costs[b]
TEC				
FY 2012	4,000	4,000	0	0
FY 2013	3,781	3,781	0	801
FY 2014	16,000	16,000	0	7,109
FY 2015	12,000	12,000	0	15,791
FY 2016	26,000	26,000	0	26,436
FY 2017	50,000	50,000	0	50,257
FY 2018	54,900	54,900	0	54,900
FY 2019	113,000	113,000	0	113,000
Outyears	1,185,319	1,185,319	0	1,196,706
Total, TEC	1,465,000	1,465,000	0	1,465,000
Other Project Cost (OPC)				
OPC except D&D				
FY 2009 Recovery Act	12,486[a]	12,486	0	0
FY 2010	14,178	14,178	4,696	6,336
FY 2011	7,768	7,750	7,233	11,321
FY 2012	17,000	17,018[b]	557[c]	17,940
FY 2013	14,107	14,107	0	13,232
FY 2014	10,000	10,000	0	11,505
FY 2015	10,000	10,000	0	10,079
FY 2016	86	86	0	2,284
FY 2017	0	0	0	120
FY 2018	100	100	0	100
FY 2019	1,000	1,000	0	1,000
Outyears	8,275	8,275	0	8,597
Total, OPC	95,000	95,000	12,486	82,514
Total Project Cost (TPC)				
FY 2009 Recovery Act	12,486	12,486	0	0
FY 2010	14,178	14,178	4,696	6,336
FY 2011	7,768	7,750	7,233	11,321
FY 2012	21,000	21,018	557	17,940
FY 2013	17,888	17,888	0	14,033
FY 2014	26,000	26,000	0	18,614
FY 2015	22,000	22,000	0	25,870

[a] $13,000,000 of Recovery Act funding was originally planned for the conceptual design; the difference of $512,000 relates to pre-conceptual design activities needed prior to approval of mission need (CD-0).
[b] $18,000 of FY 2011 funding was attributed towards the Other Project Costs activities in FY 2012.
[c] During FY 2012, $1,000 of Recovery Act funding was recategorized from pre-conceptual design and so became part of the OPC. $3,000 was deobligated and expired because Recovery Act funds are no longer available for obligation.

	(dollars in thousands)			
	Appropriations	Obligations	Recovery Act Costs	Costs[b]
FY 2016	26,086	26,086	0	28,720
FY 2017	50,000	50,000	0	50,377
FY 2018	55,000	55,000	0	55,000
FY 2019	114,000	114,000	0	114,000
Outyears	1,193,594	1,193,594	0	1,205,303
Total, TPC	1,560,000	1,560,000	12,486	1,547,514

6. Details of Project Cost Estimate

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	208,000	201,375	N/A
Contingency	23,000	33,000	N/A
Total, Design	231,000	234,375	N/A
Construction			
Far Site Civil Construction[a]	360,375	300,000	N/A
Fermilab Site Civil Construction[b]	317,375	281,000	N/A
Far Site Technical Infrastructure[c]	108,125	98,000	N/A
Fermilab Site Beamline[c]	125,125	110,000	N/A
DUNE Detectors	82,000	75,000	N/A
Contingency	241,000	335,000	N/A
Total, Construction	1,234,000	1,199,000	N/A
Total, TEC	1,465,000	1,433,375	N/A
Contingency, TEC	264,000	368,000	N/A
Other Project Cost (OPC)			
OPC except D&D			
R&D	20,625	20,625	N/A
Conceptual Planning	30,000	30,000	N/A
Conceptual Design	35,000	35,000	N/A
Plant Support Costs	9,375	17,000	N/A
Total, OPC	95,000	102,625	N/A
Total, TPC	1,560,000	1,536,000	N/A
Total, Contingency	264,000	368,000	N/A

[a] Far Site civil construction involves excavation of caverns at SURF, 4850 ft. below the surface, for technical equipment including particle detectors and cryogenic systems.
[b] Fermilab Site civil construction involves construction of the housing for the neutrino-production beam line and the near detector.
[c] Technical equipment in the DOE scope, estimated here, will be supplemented by in-kind contributions of additional technical equipment, for the accelerator beam and particle detectors, from non-DOE partners as described in Section 1.

7. Schedule of Appropriation Requestsa

(dollars in thousands)

Request Year		Prior Years	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	Outyears	Total
FY 2011	TEC	102,000	0	0	0	0	0	0	102,000
	OPC	22,180	0	0	0	0	0	0	22,180
	TPC	124,180	0	0	0	0	0	0	124,180
FY 2012	TEC	91,000	42,000	0	0	0	0	0	133,000
	OPC	42,621	0	0	0	0	0	0	42,621
	TPC	133,621	42,000	0	0	0	0	0	175,621
FY 2016	TEC	23,781	12,000	16,000	TBD	TBD	TBD	TBD	783,393
	OPC	75,539	10,000	4,000	TBD	TBD	TBD	TBD	89,539
	TPC	99,320	22,000	20,000	TBD	TBD	TBD	TBD	872,932
FY 2017	TEC	23,781	12,000	26,000	45,021	TBD	TBD	1,307,659	1,414,461
	OPC	75,539	10,000	0	0	0	TBD	0	85,539
	TPC	99,320	22,000	26,000	45,021	TBD	TBD	1,307,659	1,500,000
FY 2018	TEC	23,781	12,000	26,000	50,000	54,900	0	1,266,694	1,433,375
	OPC	75,539	10,000	86	0	100	0	16,900	102,625
	TPC	99,320	22,000	26,086	50,000	55,000	0	1,283,594	1,536,000
FY 2019[b]	TEC	23,781	12,000	26,000	50,000	54,900	113,000	1,185,319	1,465,000
	OPC	75,539	10,000	86	0	100	1,000	8,275	95,000
	TPC	99,320	22,000	26,086	50,000	55,000	114,000	1,193,594	1,560,000

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	FY 2030
Expected Useful Life	20 years
Expected Future Start of D&D of this capital asset	FY 2050

Operations and maintenance funding of this experiment will become part of the existing Fermilab accelerator facility. Annual related funding estimates include the incremental cost of 20 years of full operation, utilities, maintenance and repairs with the accelerator beam on. The estimates also include operations and maintenance for the remote site of the large detector.

(Related Funding Requirements)

(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Current Total Estimate	Previous Total Estimate	Current Total Estimate	Previous Total Estimate
Operations	9,000	9,000	180,000	180,000
Utilities	8,000	8,000	160,000	160,000
Maintenance & Repair	1,000	1,000	20,000	20,000
Total	18,000	18,000	360,000	360,000

[a] Design and international collaboration plans are currently being developed; outyears are preliminary.

[b] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The preliminary TPC range at CD-1 was $1,260,000,000 to $1,860,000,000. The TPC point estimate is $1,560,000,000.

9. Required D&D Information

	Square Feet
Area of new construction	142,000 SF
Area of existing facility being replaced and D&D'd by this project	0
Area of other D&D outside the project	0
Area of any additional D&D space to meet the "one-for-one" requirement taken from the banked area.	142,000 SF

The one-for-one replacement has been met through banked space. A waiver from the one-for-one requirement to eliminate excess space at Fermilab to offset the LBNF/DUNE project was approved by DOE Headquarters on November 12, 2009. The waiver identified and transferred to Fermilab 575,104 square feet of excess space to accommodate the new LBNF/DUNE facilities and other as yet unbuilt facilities from space that was banked at other DOE facilities.

10. Acquisition Approach

The acquisition approach is documented in the Acquisition Strategy approved as part of CD-1. DOE is acquiring design, construction, fabrication, and operation of LBNF through the M&O contractor responsible for Fermilab, Fermi Research Alliance (FRA). FRA and Fermilab, through the LBNF Project based at Fermilab, is responsible to DOE to manage and complete construction of LBNF at both the near and remote site locations. FRA and Fermilab are assigned oversight and management responsibility for execution of the international DUNE project, to include management of the DOE contributions to DUNE. The basis for this choice and strategy is that:

- Fermilab is the site of the only existing neutrino beam facility in the U.S. and, in addition to these facilities, provides a source of existing staff and expertise to be utilized for beamline and detector construction.
- Fermilab can best ensure that the design, construction, and installation of key LBNF and DUNE components are coordinated effectively and efficiently with other research activities at Fermilab.
- Fermilab has a DOE-approved procurement system with established processes and acquisition expertise needed to obtain the necessary components and services to build the scientific hardware, equipment and conventional facilities for the accelerator beamline, and detectors for LBNF and DUNE.
- Fermilab has extensive experience in managing complex construction, fabrication, and installation projects involving multiple national laboratories, universities, and other partner institutions, building facilities both on-site and at remote off-site locations.
- Fermilab, through the LBNF Project, has established a close working relationship with SURF and the South Dakota Science and Technology Authority (SDSTA), organizations that manage and operate the remote site for the far detector in Lead, SD;
- Fermilab has extensive experience with management and participation in international projects and international collaborations, including most recently the LHC and CMS projects at CERN, as well as in the increasingly international neutrino experiments and program.

The LBNF/DUNE construction project is a federal, state, private and international partnership. Leading the LBNF/DUNE Project, Fermilab will collaborate and work with many institutions, including several DOE national laboratories (BNL, LBNL and LANL), dozens of universities, foreign research institutions, SURF, and the SDSTA. Fermilab will be responsible for overall project management, near site conventional facilities, and the beamline. Fermilab will work with SDSTA and SURF to complete the conventional facilities construction at the remote site needed to house and outfit the DUNE far detector. With the DUNE collaboration, Fermilab is also responsible for technical and resource coordination to support the DUNE far and near detector design and construction. DOE will be providing in-kind contributions to the DUNE collaboration for detector systems, as agreed upon with the international DUNE collaboration.

International participation in the design, construction, and operation of LBNF and DUNE will be of essential importance because the field of High Energy Physics is international by nature; necessary talent and expertise are globally distributed, and DOE does not have the procurement or technical resources to self-perform all of the required construction and fabrication work. Contributions from other nations will be predominantly through the delivery of components built in their own countries by their own researchers. DOE will negotiate agreements in cooperation with the Department of State on a bilateral basis with all contributing nations to specify their expected contributions and the working relationships during the construction and operation of the experiment. For the DUNE detector, the process of developing in-kind contributions is being driven by the principal investigators and being reviewed by their funding agencies.

DOE funding for the LBNF/DUNE Project will be provided directly to Fermilab and collaborating DOE national laboratories via approved financial plans, and under management control of the LBNF Project Office. The LBNF Project Office will also manage and control DOE funding to the other LBNF/DUNE institutions contributing to detector design and construction. In addition to the work performed by DOE national laboratories, a combination of university subcontracts and direct fixed-price purchases with vendors is anticipated to design, fabricate, and install the LBNF and DUNE technical components. The DUNE-U.S. Project Office at Fermilab will manage and control DOE funding to the other U.S. institutions contributing to DUNE detector design and construction. All actions will be in accordance with the DOE approved procurement policies and procedures.

Much of the neutrino beamline component design, fabrication, assembly, and installation will be done by Fermilab staff or by subcontract temporary staff working directly with Fermilab personnel. The acquisition approach includes both new procurements based on existing designs, and re-purposed equipment from the Fermilab accelerator complex. Some highly specialized components will be designed and fabricated by or in consultation with long-standing Fermilab collaborators having proven experience with such components.

Delivery of LBNF conventional facilities at the Fermilab near site and SURF far site will be via the Construction Manager/General Contractor (CM/GC) model. This strategy was chosen to reduce risk, enhance quality and safety performance, provide a more collaborative approach to construction, and offer the opportunity for reduced cost and shortened construction schedules.

For the LBNF near site conventional facilities at Fermilab, procurement is through existing Fermilab master subcontracts with national architect/engineering (A/E) companies for design services and contracts will be incrementally phase-funded since they will span multiple years.

For the LBNF far site conventional facilities at SURF, Fermilab will work with SDSTA, the owner of the site and land, which has been donated to SDSTA by the Homestake Mining Company for the sole purpose of facilitating scientific and technological research and development. Fermilab will contract directly with SDSTA to provide pre-construction services and with an A/E firm for design of LBNF far site conventional facilities at SURF. Fermilab will solicit bids for CM/GC services to manage the construction of LBNF far site facilities. The CM/GC subcontractor will furnish all labor, equipment and materials for far site conventional facilities construction management. Work includes pre-construction construction management services and an option for executing the construction and management of the construction. The CM/GC subcontractor staff will have proven experience in the area of construction management and construction of industrial and heavy construction projects. The CM/GC firm will provide support services to the LBNF and A/E teams, including input regarding the selection of materials, building systems and equipment, construction feasibility, value engineering, and factors related to construction, plus cost estimates and schedules, including estimates of alternative designs or materials. The CM/GC will also provide recommendations of actions designed to minimize adverse effects of labor or material shortages, time requirements for procurement and installation and construction completion.

The overall approach to both near and far site enables Fermilab to gain construction management expertise early in the design phase to produce well-integrated designs and well understood constructability, with potential cost and management efficiencies and reduced construction risk as a result.

DOE entered into a land lease with SDSTA on May 20, 2016 covering the area on which the DOE funded facilities housing and supporting the LBNF and DUNE detector will be built. The lease provides the framework for DOE and Fermilab to construct federally funded buildings and facilities on non-federal land, and to establish a long-term (multi-decade) arrangement for DOE and Fermilab to use SDSTA space to host the DUNE experiment. Modifications, repairs, replacements, and improvements to SDSTA infrastructure will be funded by the project to ensure safe and reliable operations of the systems required to carry out the DOE mission. Protections for DOE's real property interests in these infrastructure tasks are acquired through the lease with SDSTA, contracts and other agreements such as easements. DOE plans for Fermilab to have responsibility for managing and operating the LBNF and DUNE far detector and facilities for a useful lifetime of 20 years and may contract with SDSTA for day-to-day management and maintenance services. At the end of useful life, federal regulations permit transfer of ownership to SDSTA, which is willing to accept ownership as a condition for the lease. An appropriate decommissioning plan will be developed prior to lease signing.

11-SC-41, Muon to Electron Conversion Experiment (Mu2e),
Fermi National Accelerator Laboratory, Batavia, Illinois
Project is for Design and Construction

1. Significant Changes and Summary

Significant Changes

This Construction Project Data Sheet (CPDS) is an update of the FY 2018 CPDS and does not include a new start for FY 2019.

Summary

The FY 2019 Request for the Muon to Electron Conversion Experiment (Mu2e) is $30,000,000, consistent with the approved baseline funding profile, and is the last year of planned funding for the construction project. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-3 (Approve Start of Construction), concurrent with completion of the final design, approved on July 14, 2016. In FY 2015, CD-2 established the scope, cost, and schedule baseline, and CD-3B initiated civil construction and long-lead procurement of the Transport Solenoid modules. Total Project Cost was approved at $273,677,000. The funding profile supports this TPC. The CD-4 milestone is 1Q FY 2023.

A Federal Project Director with Certification Level 3 has been assigned to this project and has approved this CPDS.

The Mu2e project provides the accelerator beam and experimental apparatus to unambiguously identify neutrinoless muon-to-electron conversion events. The conversion of a muon to an electron in the field of a nucleus would probe new physics for discovery at mass scales far beyond the reach of any existing or proposed experiment.

Construction progressed according to plan in FY 2017. Civil construction of the building and underground housing for the experiment was completed in April 2017. This civil facility has special capabilities required to house the primary beam target and transport systems for producing the muons and stopping them in the detector system. FY 2018 and FY 2019 funding will support procurement and fabrication activities for the accelerator, beamline, superconducting magnets and particle detector technical systems will continue.

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2011	11/24/2009		4Q FY 2010	TBD	4Q FY 2012	TBD	TBD	TBD
FY 2012	11/24/2009		4Q FY 2011	TBD	4Q FY 2013	TBD	TBD	TBD
FY 2013	11/24/2009		4Q FY 2012	4Q FY 2013	4Q FY 2014	4Q FY 2014	N/A	4Q FY 2018
FY 2014	11/24/2009		7/11/2012	2Q FY 2014	2Q FY 2015	4Q FY 2015	N/A	2Q FY 2021
FY 2013 Repro-gramming	11/24/2009		7/11/2012	2Q FY 2014	2Q FY 2015	4Q FY 2015	N/A	2Q FY 2021
FY 2015	11/24/2009		7/11/2012	4Q FY 2014	2Q FY 2015	4Q FY 2014	N/A	2Q FY 2021
FY 2016	11/24/2009	7/11/2012	7/11/2012	2Q FY 2015	3Q FY 2016	3Q FY 2016	N/A	1Q FY 2023
FY 2017 PB	11/24/2009	7/11/2012	7/11/2012	3/4/2015	3Q FY 2016	3Q FY 2016	N/A	1Q FY 2023
FY 2018	11/24/2009	7/11/2012	7/11/2012	3/4/2015	7/14/2016	7/14/2016	N/A	1Q FY 2023
FY 2019	11/24/2009	7/11/2012	7/11/2012	3/4/2015	7/14/2016	7/14/2016	N/A	1Q FY 2023

CD-0 – Approve Mission Need
Conceptual Design Complete – Actual date the conceptual design was completed
CD-1 – Approve Design Scope and Project Cost and Schedule Ranges

CD-2 – Approve Project Performance Baseline
Final Design Complete – Estimated/Actual date the project design will be/was completed
CD-3 – Approve Start of Construction
D&D Complete – Completion of D&D work (see section 9)
CD-4 – Approve Start of Operations or Project Closeout
PB – Indicates the Performance Baseline

	Performance Baseline Validation	CD-3A	CD-3B	CD-3(C)
FY 2014		3Q FY 2013		
FY 2013 Reprogramming		3Q FY 2013		
FY 2015		3Q FY 2014		
FY 2016	2Q FY 2015	7/10/2014	2Q FY 2015	3Q FY 2016
FY 2017 PB	3/4/2015	7/10/2014	3/4/2015	3Q FY 2016
FY 2018	3/4/2015	7/10/2014	3/4/2015	7/14/2016
FY 2019	3/4/2015	7/10/2014	3/4/2015	7/14/2016

CD-3A – Approve Long-Lead Procurement of superconducting wire for the magnet systems.
CD-3B – Approve Long-Lead Procurement for superconducting solenoid magnet modules and for construction of the detector hall.
CD-3(C) – Approve All Construction and Fabrication (same as CD-3)

3. Project Cost History

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC Except D&D	OPC, D&D	OPC, Total	TPC
FY 2011	35,000	TBD	TBD	10,000	TBD	TBD	TBD
FY 2012	36,500	TBD	TBD	18,777	TBD	TBD	TBD
FY 2013	44,000	N/A	N/A	24,177	0	24,177	68,177
FY 2014	61,000	162,000	223,000	26,177	0	26,177	249,177
FY 2013 Reprogramming	49,000	162,000	211,000	23,677	0	23,677	234,677
FY 2015	47,000	162,900	209,900	23,677	0	23,677	233,577
FY 2016	57,000	193,000	250,000	23,677	N/A	23,677	273,677
FY 2017 PB	57,000	193,000	250,000	23,677	N/A	23,677	273,677[a]
FY 2018	60,598[b]	189,402	250,000	23,677	N/A	23,677	273,677
FY 2019	60,598	189,402	250,000	23,677	N/A	23,677	273,677

4. Project Scope and Justification

Scope

The Mu2e project includes accelerator modifications, fabrication of superconducting magnets and particle detector systems, and construction of a civil facility with the special capabilities necessary for the experiment. The scope of work in the Project Data Sheet has not changed. The muon beam for the Mu2e experiment will be produced by an intense 8-GeV proton beam, extracted from the Fermilab Booster accelerator, striking a tungsten target. The Mu2e project is modifying the existing Fermilab accelerator complex (Booster, Recycler, and Debuncher Rings) to deliver the primary proton beam to a muon production target, and will efficiently collect and transport the produced muons to a stopping target. The stopping target is

[a] No construction, other than approved long-lead procurement and detector hall civil construction, was performed prior CD-3 approval.
[b] Increased final design development work in FY 2016 reduced the estimated construction cost with modest delay of final design completion and Critical Decision CD-3.

surrounded by the Mu2e detector system that can identify muon-to-electron conversions and reject background contamination from muon decays, which produce neutrinos, in contrast to muon conversions which are neutrinoless.

The project has designed and is constructing the detector system (consisting of a tracker, calorimeter, cosmic ray veto, and data acquisition subsystem), a new beam line to the detector system from the former Debuncher Ring, and three superconducting solenoid magnets (a Production Solenoid, Transport Solenoid and Detector Solenoid) that will serve as the beam transport channel for collecting the muons and transporting them into the detector system.

The project designed and completed construction of a 25,000 square foot civil facility with the special capabilities required to house the primary beam target and transport systems for producing the muons and stopping them in the detector system. The civil construction consists of an underground detector enclosure and a surface building for containing the necessary equipment and infrastructure that can be accessed while the multikilowatt proton beam is being delivered to the experiment. The building includes radiation shielding and design features for safe operation of the beam line and experimental apparatus.

Justification

The conversion of a muon to an electron in the Coulomb field of an atomic nucleus provides a unique experimental signature for discovery of charged-lepton flavor-symmetry violation (CLFV), which may be accessible to this experiment of unprecedented sensitivity and would allow access to new physics at very high mass scales beyond the reach of the LHC. In 2008, the Particle Physics Project Prioritization Panel (P5), a subpanel of the High Energy Physics Advisory Panel (HEPAP), recommended: "Development of a muon-to-electron conversion experiment should be strongly encouraged under all budget scenarios considered by the panel."[a] Again, in 2014, the most recent P5 Subpanel emphasized the priority of the current "Mu2e" experimental construction project in its new report to HEPAP, saying the Mu2e project is an "immediate target of opportunity in the drive to search for new physics and will help inform future choices of direction." "The scientific case is undiminished relative to its earlier prioritization."[b]

[a] "US Particle Physics: Scientific Opportunities, A Strategic Plan for the Next 10 Years," Report of the Particle Physics Project Prioritization Panel (May 2008).
[b] "Building for Discovery, Strategic Plan for U.S. Particle Physics in the Global Context," Report of the Particle Physics Project Prioritization Panel (May 2014).

Key Performance Parameters

System	Threshold Performance	Objective Performance
Accelerator		
	Accelerator components are acceptance tested at nominal voltages and currents. Components necessary for single-turn extraction installed.	Protons are delivered to the diagnostic absorber in the M4 beamline.
	Shielding designed for 1.5 kW operation delivered to Fermilab and ready for installation.	Shielding designed for 8 kW operation delivered to Fermilab and ready for installation.
	All target station components are complete, delivered to Fermilab and tested. Heat and Radiation Shield is installed in Production Solenoid. Other components are ready to be installed after field mapping.	
Superconducting Solenoid Magnets		
	The Production, Transport and Detector Solenoids have been cooled and powered to the settings necessary to take physics data.	The Production, Transport and Detector Solenoids have been cooled and powered to their nominal field settings.
Detector Components		
	Cosmic Ray Tracks are observed in the Tracker, Calorimeter and a subset of the Cosmic Ray Veto and acquired by the Data Acquisition System after they are installed in the garage position behind the Detector Solenoid. The balance of the Cosmic Ray Veto counters are at Fermilab and ready for installation.	The cosmic ray data in the detectors is acquired by the Data Acquisition System, reconstructed in the online processors, visualized in the event display and stored on disk.

The project is being conducted in accordance with the project management requirements in DOE 413.3B, Program and Project Management for the Acquisition of Capital Assets.

5. Financial Schedule

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Total Estimated Cost (TEC)			
Design			
FY 2013	N/A	N/A	14,653
FY 2014	N/A	N/A	15,404
FY 2015	N/A	N/A	16,892
FY 2016	N/A	N/A	13,649
Total, Design	N/A	N/A	60,598
Construction			
FY 2014	N/A	N/A	0
FY 2015	N/A	N/A	9,907
FY 2016	N/A	N/A	24,300
FY 2017	N/A	N/A	26,868
FY 2018	N/A	N/A	40,000
FY 2019	N/A	N/A	40,000

[a] Costs through FY 2017 reflect actual costs; costs for FY 2018 and the outyears are estimates.

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
FY 2020	N/A	N/A	37,132
FY 2021	N/A	N/A	10,000
FY 2022	N/A	N/A	1,195
Total, Construction	N/A	N/A	189,402
TEC			
FY 2012	24,000	24,000	0
FY 2013	8,000[a]	8,000	14,653
FY 2014	35,000[b]	35,000	15,404
FY 2015	25,000[c]	25,000	26,799
FY 2016	40,100	40,100	37,949
FY 2017	43,500	43,500	26,868
FY 2018	44,400	44,400	40,000
FY 2019	30,000	30,000	40,000
FY 2020	0	0	37,132
FY 2021	0	0	10,000
FY 2022	0	0	1,195
Total, TEC	250,000	250,000	250,000
Other Project Costs (OPC)			
OPC except D&D			
FY 2010	4,777	4,777	3,769
FY 2011	8,400	8,400	8,940
FY 2012	8,000	8,000	6,740
FY 2013	2,500	2,500	1,020
FY 2014	0	0	2,136
FY 2015	0	0	159
FY 2016	0	0	252
FY 2017	0	0	11
FY 2018	0	0	650
Total, OPC	23,677	23,677	23,677

[a] Congress approved a reprogramming that reduced the FY 2013 funding to $8,000,000 from the $22,685,000 that was originally appropriated.
[b] $5,162,907 was for long-lead procurements of superconducting wire for the magnet systems.
[c] $25,000,000 was for long-lead procurements for the superconducting solenoid magnet modules and for civil construction of the detector hall.

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Total Project Cost (TPC)			
FY 2010	4,777	4,777	3,769
FY 2011	8,400	8,400	8,940
FY 2012	32,000	32,000	6,740
FY 2013	10,500	10,500	15,673
FY 2014	35,000	35,000	17,540
FY 2015	25,000	25,000	26,958
FY 2016	40,100	40,100	38,201
FY 2017	43,500	43,500	26,879
FY 2018	44,400	44,400	40,650
FY 2019	30,000	30,000	40,000
FY 2020	0	0	37,132
FY 2021	0	0	10,000
FY 2022	0	0	1,195
Total, TPC	273,677	273,677	273,677

6. Details of Project Cost Estimate

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	60,598	60,598	49,000
Contingency	0	0	8,000
Total, Design	60,598	60,598	57,000
Construction			
Site Work	1,390	2,000	2,000
Construction	18,477	13,000	13,000
Equipment	133,535	129,400	133,000
Contingency	36,000	45,002	45,000
Total, Construction	189,402	189,402	193,000
Total, TEC	250,000	250,000	250,000
Contingency, TEC	36,000	45,002	53,000
Other Project Cost (OPC)			
OPC except D&D			
R&D	8,200	8,200	8,200
Conceptual Planning	2,300	2,300	2,300
Conceptual Design	13,177	13,177	13,177
Total, OPC	23,677	23,677	23,677
Total, TPC	273,677	273,677	273,677
Total, Contingency	36,000	45,002	53,000

7. Schedule of Appropriation Requests

(dollars in thousands)

Request Year		Prior Years	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	Total
FY 2011	TEC	5,000	30,000	0	0	0	0	0	0	0	35,000
	OPC	10,000	0	0	0	0	0	0	0	0	10,000
	TPC	15,000	30,000	0	0	0	0	0	0	0	45,000
FY 2012	TEC	0	24,000	12,500	0	0	0	0	0	0	36,500
	OPC	12,777	6,000	0	0	0	0	0	0	0	18,777
	TPC	12,777	30,000	12,500	0	0	0	0	0	0	55,277
FY 2013	TEC	0	24,000	20,000	0	0	0	0	0	0	44,000
	OPC	13,177	6,000	5,000	0	0	0	0	0	0	24,177
	TPC	13,177	30,000	25,000	0	0	0	0	0	0	68,177
FY 2014	TEC	0	24,000	24,147	35,000	32,000	44,000	45,000	23,000	0	223,000
	OPC	13,177	8,000	8,049	0	0	0	0	0	0	26,177
	TPC	13,177	32,000	32,196[a]	35,000	32,000	44,000	45,000	23,000	0	249,177
FY 2013 Repro-gram-ming	TEC	0	24,000	8,000[b]	35,000	32,000	44,000	45,000	23,000	0	211,000
	OPC	13,177	8,000	2,500	0	0	0	0	0	0	23,677
	TPC	13,177	32,000	10,500	35,000	32,000	44,000	45,000	23,000	0	234,677
FY 2015	TEC	0	24,000	8,000	35,000	25,000	42,000	43,000	32,900	0	209,900
	OPC	13,177	8,000	2,500	0	0	0	0	0	0	23,677
	TPC	13,177	32,000	10,500	35,000	25,000	42,000	43,000	32,900	0	233,577
FY 2016	TEC	0	24,000	8,000	35,000	25,000	40,100	43,500	44,400	30,000	250,000
	OPC	13,177	8,000	2,500	0	0	0	0	0	0	23,677
	TPC	13,177	32,000	10,500	35,000	25,000	40,100	43,500	44,400	30,000	273,677
FY 2017 PB	TEC	0	24,000	8,000	35,000	25,000	40,100	43,500	44,400	30,000	250,000
	OPC	13,177	8,000	2,500	0	0	0	0	0	0	23,677
	TPC	13,177	32,000	10,500	35,000	25,000	40,100	43,500	44,400	30,000	273,677
FY 2018	TEC	0	24,000	8,000	35,000	25,000	40,100	43,500	44,400	30,000	250,000
	OPC	13,177	8,000	2,500	0	0	0	0	0	0	23,677
	TPC	13,177	32,000	10,500	35,000	25,000	40,100	43,500	44,400	30,000	273,677
FY 2019	TEC	0	24,000	8,000	35,000	25,000	40,100	43,500	44,400	30,000	250,000
	OPC	13,177	8,000	2,500	0	0	0	0	0	0	23,677
	TPC	13,177	32,000	10,500	35,000	25,000	40,100	43,500	44,400	30,000	273,677

[a] The FY 2013 amount shown reflected the P.L. 112-175 continuing resolution level annualized to a full year. The TEC, OPC, and TPC total and outyear appropriation assumptions were not adjusted to reflect the final FY 2013 level; the FY 2013 Request level of $25,000,000 ($20,000,000 TEC and $5,000,000 OPC) were assumed instead.

[b] Congress approved a reprogramming that reduced the FY 2013 funding to $8,000,000 from the $22,685,000 that was originally appropriated.

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	FY 2023
Expected Useful Life	10 years
Expected Future Start of D&D of this capital asset	FY 2033

Operations and maintenance of this experiment will become part of the existing Fermilab accelerator facility. Annual related funding estimates are for the incremental cost of five years of full operation, utilities, maintenance and repairs with the accelerator beam on. Five subsequent years are planned for further analysis of the data while the detector and beam line are maintained in a minimal maintenance state (with annual cost of approximately 3% of full operations) to preserve availability for future usage with much smaller annual cost.

(Related Funding Requirements)

(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Current Total Estimate	Previous Total Estimate	Current Total Estimate	Previous Total Estimate
Operations	3,100	3,100	16,000	16,000
Utilities	2,400	2,400	12,400	12,400
Maintenance & Repair	100	100	600	600
Total	5,600	5,600	29,000	29,000

9. Required D&D Information

	Square Feet
Area of new construction	~25,000
Area of existing facility being replaced and D&D'd by this project	0
Area of other D&D outside the project	0
Area of any additional D&D space to meet the "one-for-one" requirement taken from the banked area.	~25,000

The one-for-one replacement has been met through banked space. A waiver from the one-for-one requirement to eliminate excess space at Fermilab to offset the Mu2e project was approved by DOE Headquarters on November 12, 2009. The waiver identified and transferred to Fermilab 575,104 square feet of excess space to accommodate the new Mu2e facilities and other as yet unbuilt facilities from space that was banked at other DOE facilities.

10. Acquisition Approach

The acquisition approach is fully documented in the Acquisition Strategy approved as part of CD-1. This is a high-level summary of material from that document.

DOE awarded the prime contract for the Mu2e project to the Fermi Research Alliance (FRA), the Fermilab Management and Operating (M&O) contractor, rather than have the DOE compete a contract for fabrication to a third party. FRA has a strong relationship with the high energy physics community and its leadership, including many Fermilab scientists and engineers. This arrangement will facilitate close cooperation and coordination between the Mu2e scientific collaboration and an experienced team of project leaders managed by FRA, which will have primary responsibility for oversight of all subcontracts required to execute the project. These subcontracts are expected to include the purchase of components from third party vendors as well as subcontracts with university groups to fabricate detector subsystems.

The largest procurements are the magnet systems and the civil construction. The superconducting solenoid magnets are divided into three systems that could be procured independently but which must ultimately perform as a single integrated magnetic system. Two of the systems are similar to systems that have been successfully built in private industry, so the engineering design and fabrication for two of the solenoids was subcontracted to a third party vendor after a study of industrial vendor capabilities confirmed that the technical risks were acceptable. The third solenoid is unique because of its rather large size and unusual configuration, and no good industrial analog exists. This solenoid was designed at Fermilab and is being fabricated by a third-party vendor in multiple modular components, each of which is well matched to existing industrial capabilities.

There were two major subcontracts for the civil construction. An architectural and engineering contract was placed on a firm-fixed-price basis for Preliminary (Title I) Design, and Final (Title II) Design with an option for construction support (Title III). The general construction subcontract was placed on a firm-fixed-price basis and was completed successfully.

All subcontracts have been competitively bid and awarded based on best value to the government. Fermi Site Office provides contract oversight for FRA's plans and performance. Project performance metrics for FRA are included in the M&O contractor's annual performance evaluation and measurement plan.

Nuclear Physics

Overview

One of the enduring mysteries of the universe is the nature of matter—what are its basic constituents and how do they interact to form the properties we observe? The largest contribution by far to the mass of the visible matter we are familiar with comes from protons and heavier nuclei. The mission of the Nuclear Physics (NP) program is to discover, explore, and understand all forms of nuclear matter. Although the fundamental particles that compose nuclear matter—quarks and gluons—are themselves relatively well understood, exactly how they interact and combine to form the different types of matter observed in the universe today and during its evolution remains largely unknown. Nuclear physicists seek to understand not just the familiar forms of matter we see around us, but also exotic forms such as those that existed in the first moments after the Big Bang and that exist today inside neutron stars, and to understand why matter takes on the specific forms now observed in nature.

Nuclear physics addresses three broad, yet tightly interrelated, scientific thrusts: **Quantum Chromodynamics (QCD)**; **Nuclei and Nuclear Astrophysics**; and **Fundamental Symmetries**:

- **QCD** seeks to develop a complete understanding of how the fundamental particles that compose nuclear matter, the quarks and gluons, assemble themselves into composite nuclear particles such as protons and neutrons, how nuclear forces arise between these composite particles that lead to nuclei, and how novel forms of bulk, strongly interacting matter behave, such as the quark-gluon plasma that formed in the early universe.
- **Nuclei and Nuclear Astrophysics** seeks to understand how protons and neutrons combine to form atomic nuclei, including some now being observed for the first time, and how these nuclei have arisen during the 13.8 billion years since the birth of the cosmos.
- **Fundamental Symmetries** seeks to develop a better understanding of fundamental interactions by studying the properties of neutrons and by performing targeted, single focus experiments using nuclei to study whether the neutrino is its own anti-particle. Neutrinos are very light, nearly undetectable fundamental particles produced during interactions involving the weak force, through which they were first indirectly observed in nuclear beta decay experiments.

The quest to understand the properties of different forms of nuclear matter requires long-term support for both theoretical and experimental research efforts within the NP portfolio. Theoretical approaches are based on calculations of the interactions of quarks and gluons described by the theory of QCD using today's most advanced computers. Quantum computing holds great potential for obtaining solutions to many-body QCD problems that are intractable with today's computers. Other theoretical research that models the forces between nucleons seeks to understand and predict the structure of nuclear matter. Most experimental approaches in nuclear physics use large accelerators that collide particles at nearly the speed of light, producing short-lived forms of matter for investigation. Nuclear physics uses low-energy, precision nuclear experiments, many enabled by new quantum sensors to search for a deeper understanding of fundamental symmetries and nuclear interactions. Comparing experimental observations and theoretical predictions tests the limits of our understanding of nuclear matter and suggests new directions for experimental and theoretical research.

Highly trained scientists who conceive, plan, execute, and interpret transformative experiments are at the heart of the NP program. NP supports these university and national laboratory scientists and U.S. participation in select international collaborations and provides approximately 93 percent of the nuclear science research funding in the U.S., resulting in an average of approximately 90 Ph.D. degrees awarded annually to students for research supported by the program. As documented in the 2015 Nuclear Science Advisory Committee (NSAC) Long Range Plan (LRP) for Nuclear Science, *Reaching for the Horizon*[a], over 40% of the scientists who receive Ph.D.'s in nuclear science find careers in sectors other than academia and DOE research laboratories, serving national needs in defense, government, and industry. DOE's mission and priorities guide NP research, which in turn develop the core competencies and expertise needed to achieve the goals of the NP program and train the next generation of nuclear scientists. National laboratory scientists work and collaborate with academic scientists and other national laboratory experimental and theoretical researchers to collect and analyze data, and to construct, support, and maintain the advanced instrumentation and world-class facilities used in experiments. The

[a] "*Reaching for the Horizon: The 2015 Long Range Plan for Nuclear Science*." Nuclear Science Advisory Committee, October 2015 (https://science.energy.gov/~/media/np/nsac/pdf/2015LRP/2015_LRPNS_091815.pdf).

national laboratories provide state-of-the-art resources for targeted detector and accelerator research and development (R&D) for future upgrades and new facilities. This research develops knowledge, technologies, and trained scientists to design and build next-generation NP accelerator facilities, and is relevant to machines being developed by other domestic and international programs.

The world-class scientific user facilities and associated instrumentation necessary to advance the U.S. nuclear science program are large and complex, and account for a significant portion of the NP budget. NP supports three scientific user facilities: the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL); the Continuous Electron Beam Accelerator Facility (CEBAF) at Thomas Jefferson National Accelerator Facility (TJNAF); and the Argonne Tandem Linac Accelerator System (ATLAS) at Argonne National Laboratory (ANL). Each of these facilities has unique capabilities that advance the scientific thrusts outlined in the LRP. In FY 2019, these facilities will provide particle beams for an international user community of over 2,800 research scientists. In FY 2018, approximately 30 percent of these researchers are from institutions outside of the U.S. and they provide very significant benefits, including leveraging the U.S. program through contributed capital, human capital, and experimental equipment, as well as intellectual contributions. Researchers supported by other SC programs such as High Energy Physics (HEP) and Basic Energy Sciences (BES), DOE Offices such as National Nuclear Security Administration (NNSA) and Nuclear Energy (NE), Federal agencies such as the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), and the Department of Defense (DOD), and industries, use NP scientific user facilities and core competencies to carry out research programs important for their respective missions. The 12 GeV CEBAF Upgrade project, completed in FY 2017 on cost and schedule, offers exciting opportunities to researches to study quark structure. Construction of a world-class nuclear physics scientific user facility with unique capabilities in nuclear structure and astrophysics, the Facility for Rare Isotope Beams (FRIB), continues at Michigan State University (MSU), according to a new baseline cost and schedule. This project is over 82% complete and will provide exciting new capabilities in nuclear structure and astrophysics to better understand the landscape of the periodic table of elements.

The 2015 NSAC LRP for Nuclear Science recommended a high-energy, high-luminosity polarized Electron-Ion Collider (EIC) as the highest priority for new facility construction following the completion of FRIB. Consistent with that vision, in 2016 NP commissioned a National Academy of Sciences (NAS) study by an independent panel of external experts to assess the uniqueness and scientific merit of such a facility; their report is expected in FY 2018. Further, in 2017 NP commissioned the nuclear physics community to convene a panel of technical experts to carry out a peer review to identify critical R&D needed to reduce risk and establish the basic feasibility of various machine concepts for an EIC. The subsequent 2017 report, Report of the Community Review of EIC Accelerator R&D for the Office of Nuclear Physics[a] (the Jones report), was invaluable in aligning R&D efforts to the highest priority efforts.

Involving students in the development and construction of NP facilities and advanced instrumentation, as well as accelerator technology and computational techniques, helps to develop the highly trained workforce needed in the field of nuclear science. In addition to significant advances in discovery science, these facilities and techniques provide collateral benefits such as the creation of new technologies with broad-based applications in industry and society. NP supports short- and mid-term accelerator R&D that is specific to the programmatic needs of its current or planned facilities. In the process, technological advances and core competencies in accelerator science that are developed by NP are also often relevant to other applications and other SC programs. For example, superconducting radio frequency (SRF) particle acceleration developed for NP programmatic missions has provided technological advances for a broad range of applications including materials research, cancer therapy, food safety, bio-threat mitigation, national defense, waste treatment, and commercial fabrication. The Office of Science programs coordinate closely on the different types of accelerator R&D activities to exploit synergies and avoid duplication of efforts.

Highlights of the FY 2019 Budget Request

The FY 2019 Budget Request continues support for the highest priority efforts and capabilities in nuclear science to optimize scientific productivity. Critical infrastructure, scientific user facilities, and R&D efforts are supported to maintain U.S. leadership in nuclear science. The Request will continue support for world-class discovery science research and R&D

[a]https://science.energy.gov/~/media/np/pdf/Reports/Report_of_the_Community_Review_of_EIC_Accelerator_RD_for_the_Office_of_Nuclear_Physics_20170214.pdf

integration to facilitate the development of important new applications for medicine, commerce, and national security. Advances will continue to be enabled by world-class experimental user facilities and Nobel prize-worthy theoretical and experimental nuclear physics research. The Request also provides funding for nascent quantum information science (QIS) efforts, including quantum computing (QC), for NP experiments and modeling in collaboration with the other SC program offices. This effort includes the development of quantum sensors based on atomic-nuclear interactions and quantum control (coherent control) techniques, the production of stable isotopes for next generation quantum information systems, and the development of quantum computing algorithms.

The DOE Isotope Program will continue to introduce new medical isotopes to the community for clinical trials and cancer therapy, and modest support is provided for stable isotope enrichment capabilities in the United States to replenish U.S. inventory and reduce foreign dependence on isotopes of strategic importance for the nation.

The Request for *Research* supports university and laboratory researchers to preserve critical core competencies and enable high priority theoretical and experimental activities to target compelling scientific opportunities at the frontier of nuclear science. The FY 2019 Request supports world-class research in multiple scientific thrusts of nuclear science. These include:

- Experimental and theoretical exploitation of the new capabilities enabled by the 12 GeV CEBAF Upgrade to unravel the mechanism of quark confinement;
- Discovery research at RHIC, the nation’s only remaining collider, to search for a critical point in the phase diagram of QCD matter and further characterize the quark-gluon plasma (QGP) discovered at RHIC that last existed at the beginning of the cosmos;
- Collaboration in the heavy ion program at the CERN LHC to provide U.S. researchers the opportunity to investigate states of matter under substantially different initial conditions than those provided by RHIC, providing complementary information regarding the matter that existed during the infant universe;
- Research in QIS to enable precision nuclear physics measurements, quantum simulations with trapped ions, and quantum computing solutions to otherwise intractable QCD problems;
- Challenging new experiments at ATLAS to study nuclear structure and nuclear reactions occurring under extreme conditions in the cosmos that are conjectured to play a central role in the synthesis of heavy elements;
- High priority, critically needed accelerator R&D to retire potentially “show-stopping” technical challenges to the realization of a possible U.S.-based Electron-Ion Collider (EIC). All current EIC-related R&D efforts within the community funded by NP are now aligned with the priorities identified in the Jones report;
- Pioneering R&D in neutrino-less double beta decay to determine whether the neutrino is its own anti-particle, a discovery that could fundamentally change current understanding of the physical universe;
- Forefront isotope R&D to develop new production methods for critical isotopes in high demand for the nation, including isotopes for medicine that could revolutionize therapy for metastasized cancer, and the development of enriched stable isotope production capabilities to reduce the nation’s dependence on foreign supplies and produce isotopes for quantum computing.

The Request for *Facility Operations* includes funding for the operations of the NP scientific user facilities. Requested funding directs efforts to operations of the facilities to enable world-class science and the optimization of existing capabilities.

- Funding supports RHIC to operate for 2,795 hours (~19 weeks) in FY 2019. The Request allows for the implementation of the Low Energy RHIC e-Cooler (LEReC) project, an accelerator improvement project, which will enable new capability to further increase luminosity in order to carry out a definitive search for a critical point in the phase diagram of QCD matter;
- Funding supports CEBAF to operate for 2,035 hours (~19 weeks) in FY 2019. This continues the highly anticipated science program of the newly constructed 12 GeV machine with associated experimental instrumentation;
- ATLAS operates as the world’s premiere stable ion beam facility for 5,300 hours (~34 weeks) to enable compelling experiments in nuclear structure and astrophysics;
- Operations funding will be provided to FRIB to support the operational optimization of accelerator components as they complete fabrication and commissioning on the project, and the transition of associated operational to a facility operations budget;

- Mission readiness is supported at isotope production facilities. These facilities produce isotopes in short supply that are critical to the nation's federal complex, research enterprise and industry. University isotope production capabilities are networked into the DOE Isotope Program for the eventual coordination of regional production of high priority short-lived isotopes. Operation of the Enriched Stable Isotope Prototype Plant (ESIPP) replenishes U.S. inventory, reduces dependence on foreign suppliers for research quantities of stable isotopes, and produces isotopes for quantum systems.

The request for *Construction and Major Items of Equipment (MIEs)* includes:

- Construction funding for the Facility for Rare Isotope Beams (FRIB), which will provide world-leading capabilities for nuclear structure and nuclear astrophysics, continues; the project has made impressive progress since it started construction in FY 2014 and it is over 82% complete. Construction funding continues according to the currently baselined profile.
- Support for the Gamma-Ray Energy Tracking Array (GRETA) MIE, will enable provision of advanced, high resolution gamma ray detection capabilities for FRIB, and was initiated in FY 2017. GRETA will be funded at a reduced level relative to the planned profile at CD-1.
- Support for the Stable Isotope Production Facility (SIPF) MIE, initiated in FY 2017, will provide increased domestic capability for production of critically needed enriched stable isotopes, and reduce the nation's dependence on foreign supply. This technically driven funding profile will support completion of the facility in FY 2023.
  Funding is provided to initiate the sPHENIX MIE, which will have enhanced capabilities that will further RHIC's scientific mission by studying high rate jet production. This project will be implemented with funding from within the RHIC facility budget.

Nuclear Physics
Funding ($K)

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Medium Energy Nuclear Physics				
Research	35,334	—	33,487	-1,847
Operations	99,990	—	98,541	-1,449
SBIR/STTR and Other	20,783	—	20,347	-436
Total, Medium Energy Nuclear Physics	**156,107**	**—**	**152,375**	**-3,732**
Heavy Ion Nuclear Physics				
Research	38,035	—	34,017	-4,018
Operations	174,538	—	171,598	-2,940
Total, Heavy Ion Nuclear Physics	**212,573**	**—**	**205,615**	**-6,958**
Low Energy Nuclear Physics				
Research	56,669	—	55,060	-1,609
Operations	23,499	—	27,499	+4,000
Total, Low Energy Nuclear Physics	**80,168**	**—**	**82,559**	**+2,391**
Nuclear Theory				
Theory Research	36,725	—	42,075	+5,350
Nuclear Data	7,572	—	7,572	0
Total, Nuclear Theory	**44,297**	**—**	**49,647**	**+5,350**
Isotope Development and Production for Research and Applications				
Research	8,829	—	8,829	0
Operations	20,026	—	25,975	+5,949
Total, Isotopes[b]	**28,855**	**—**	**34,804**	**+5,949**
Subtotal, Nuclear Physics	**522,000**	**520,576**	**525,000**	**+3,000**

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown.

[b] All appropriations for the Isotope Development and Production for Research and Applications subprogram fund a payment into the Isotope Production and Distribution Program Fund as required by P.L. 101–101 and as modified by P.L. 103–316.

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Construction				
14-SC-50, Facility for Rare Isotope Beams	100,000	97,200	75,000	-25,000
Total, Construction	**100,000**	**97,200**	**75,000**	**-25,000**
Total, Nuclear Physics	**622,000**	**617,776**	**600,000**	**-22,000**

SBIR/STTR Funding:

- FY 2017 Enacted: SBIR $15,366,000; and STTR $2,161,000
- FY 2019 Request: SBIR $15,747,000; and STTR $2,300,000

Nuclear Physics
Explanation of Major Changes ($K)

	FY 2019 Request vs FY 2017 Enacted
• **Medium Energy Nuclear Physics**: The Request provides support for the CEBAF accelerator complex, including mission readiness of the four experimental halls, mission readiness of the accelerator, all power and consumables of the site, computing capabilities for data taking and analysis, cryogenics plant, scientific researchers on site and at other laboratories and universities, on site accelerator scientists and technicians, operation of the recently upgraded CEBAF accelerator to support 2,035 operating hours, and experimental activities in some of the newly upgraded experimental halls to pursue the highly anticipated 12 GeV CEBAF physics program. CEBAF facility investments in capital equipment and accelerator improvement projects are deferred. 12 GeV researchers from national laboratories and universities implement, commission, and operate new experiments at CEBAF.	**-3,732**
• **Heavy Ion Nuclear Physics**: The Request supports world-leading research in heavy ion nuclear physics and spin physics. It provides funding for the RHIC accelerator complex including mission readiness and development of the experimental halls and instrumentation, mission readiness of the suite of accelerators, all power and consumables of the site, cryogenics plant, computing capabilities for data taking and analysis, scientific researchers on site and at other laboratories and universities, on site accelerator scientists and technicians, operation of RHIC for a 2,795 hour run, and experimental activities to prepare scientific instrumentation and infrastructure for the scientific program; this includes the initiation of the sPHENIX MIE for studying high rate lets of particles. The FY 2019 run will initiate a high precision scan of the QCD phase diagram and search for the critical point by looking for signs of critical phenomena in event-by-event fluctuations. RHIC facility investments in capital equipment and accelerator improvement projects are deferred. The Request supports U.S. commitments to and U.S. participation in the complementary LHC program, including computing commitments and the implementation of new experimental capabilities for the heavy ion LHC ALICE detector.	**-6,958**
• **Low Energy Nuclear Physics**: The Request supports high priority university and laboratory nuclear structure and nuclear astrophysics efforts to focus on research at the over-subscribed ATLAS facility, which will operate for 5,300 hours. ATLAS facility investments in accelerator and scientific instrumentation capital equipment are deferred. Funding for Fundamental Symmetries research supports ongoing effects in neutrinoless double beta decay domestically and abroad to determine whether the neutrino is its own antiparticle; no funding is requested for R&D towards next-generation experiments. Funding in Fundamental Symmetries also includes a suite of efforts such as the Fundamental Neutron Physics Beamline at the Spallation Neutron Source and its ongoing suite of experiments to study neutron properties. The Request supports operations of the 88-Inch Cyclotron at the Lawrence Berkeley National Lab (LBNL) for an in-house nuclear science program and an electronics irradiation capability for the Department of Defense and NASA. There is an increase planned in FY 2019 for FRIB operations support. Operations of all three experimental University Centers of Excellence, the Texas A&M Cyclotron Facility, the High Intensity Gamma Source (HIGS) at Duke University, and the Center for Experimental Nuclear Physics and Astronomy (CENPA) at the University of Washington are supported. An increase is requested for the GRETA MIE, started in FY 2017, to address certain aspects of engineering design and long-lead procurement; a successful implementation of this detector will represent a major advance in gamma-ray tracking detector technology that will impact nuclear science as well as detection techniques in homeland security and medicine.	**+2,391**

	FY 2019 Request vs FY 2017 Enacted
• **Nuclear Theory**: The Request supports high priority theory research efforts at laboratories and universities, and the U.S. Nuclear Data Program. The Request also provides support for a targeted investment in quantum information science and quantum computing, in coordination with other SC programs, including the enhancement of specialized Lattice Quantum Chromodynamics (LQCD) computing hardware that is oriented towards the research directions in quantum devices and quantum computing supported by the QIS effort. Such efforts will include R&D on quantum sensors to enable precision NP measurements, development of quantum sensors based on atomic-nuclear interactions, and development of quantum computing algorithms applied to quantum mechanical systems and NP topical problems. NP-related QIS and QC efforts have direct relevance for this area of interest in general, and can lead to advances that are important for applications in QIS and QC.	+5,350
• **Isotope Development and Production for Research and Applications**: The Request provides funding for high priority university and laboratory research in new isotope production techniques; efforts continue to develop Ac-225 and other promising cancer therapeutic isotopes for clinical trials. Operations funding increases to restore mission readiness for production activities at national laboratory facilities. The Request provides an increase in university operations for a network of university accelerators and reactors establishes cost-effective, regional production of short-lived isotopes for research and medical applications, and includes the University of Washington and University of Missouri Research Reactor. A modest increase in staff at the National Isotope Development Center aids in addressing the required workforce needed to market the significantly expanded Isotope Program product portfolio. ESIPP is operated to produce research quantities of enriched stable isotopes for next generation quantum information systems, as part of the QIS and QC enhanced efforts. Funding is increased for the Stable Isotope Production Facility (SIPF) MIE, started in FY 2017.	+5,949
• **Construction**: Construction funding continues according to the baselined profile for the Facility for Rare Isotope Beams. Support for the 12 GeV Upgrade at CEBAF completed in 2017.	-25,000
Total, Nuclear Physics	**-22,000**

Basic and Applied R&D Coordination

The NP mission supports the pursuit of unique opportunities for R&D integration and coordination with other DOE Program Offices, Federal Agencies, and non-Federal entities. For example, researchers from the High Energy Physics (HEP), NP, and Advanced Scientific Computing Research (ASCR) programs coordinate and leverage forefront computing resources and technical expertise through the Lattice Quantum Chromodynamics (LQCD) and SciDAC projects to determine the properties of as-yet unobserved exotic particles predicted by the theory of QCD, advance progress towards a model of nuclear structure with predictive capability, and dramatically improve modeling of neutrino interactions during core collapse supernovae. The U.S. Nuclear Data Program, which recently stood up an Inter-Agency working group including NNSA, the Department of Homeland Security (DHS), and DOE's Office of Nuclear Energy (NE), provides evaluated cross-section and decay data relevant to a broad suite of Federal missions and topics such as reactor design (e.g., of interest to the NE and Fusion Energy Sciences [FES] programs), materials under extreme conditions (of interest to the BES and FES programs), and nuclear forensics (NNSA, DHS, and Federal Bureau of Investigations [FBI]). NP research develops technological advances relevant to the development of advanced fuel cycles for next generation nuclear reactors (NE); advanced cost-effective accelerator technology and particle detection techniques for medical diagnostics and treatment (National Institutes of Health [NIH], HEP); and research in developing neutron, gamma, and particle beam sources with applications in cargo screening and nuclear forensics (NNSA, DHS, and FBI).

R&D coordination and integration are hallmarks of the NP Isotope Development and Production for Research and Applications subprogram (DOE Isotope Program), which produces commercial and research isotopes in short supply that are critical for basic research and applications. It also supports research on the development of new or improved production and separation techniques for stable and radioactive isotopes. NP continues to further align the Federal, industrial, and research stakeholders of the DOE Isotope Program and has strong communication between the various communities. To ascertain current and future demands of the research and applied communities, NP organizes working groups, workshops, symposia, and discussions with Federal agencies and community and industrial stakeholders on a continuous basis. It also works collaboratively with other DOE Offices (NNSA and NE) to help ensure adequate supplies of isotopes needed for their missions, such as lithium-7, which is used by nuclear power plants as a coolant reagent. The DOE Isotope Program conducts biennial Federal workshops to identify isotope demand and supply across a broad range of Federal agencies (including NIH, NASA, FBI, DOD, DHS, DOT, NSF, NIST, ONDI, DOS, and DOE) to ensure that isotopes are available for the federal complex to accomplish its missions.

Program Accomplishments

RHIC Collisions Create a Vortex of Quark-Gluon Plasma. The Quark-Gluon Plasma (QGP), a hot soup of unbound quarks and gluons discovered in high energy collisions of gold (Au) ions at the RHIC at Brookhaven National Laboratory, is thought to also have existed a few microseconds after the Big Bang. Previous measurements have demonstrated that the QGP is one of the hottest, densest, and least viscous fluids known. New measurements at RHIC have demonstrated that this hot soup of particles is also rapidly swirling, much faster than any other known fluid. The measurements promise to illuminate detailed properties of the hot dense fluid and more precise data in the future may provide a direct measurement of what is predicted to be the strongest magnetic field in the universe.

The 12 GeV Continuous Electron Beam Accelerator Facility (CEBAF) Upgrade Project is completed. The 12 GeV CEBAF Upgrade project has received final approval (CD-4) to start operations. This project, ongoing since March 2004, was completed within its approved cost, schedule, and scope baseline. This formal start of operations promises a watershed in new scientific knowledge on how protons and neutrons collectively act together to yield the properties of nuclei observed in the lab; whether new, predicted, but as-yet unobserved exotic particles, can be found which further elucidate the theory of the strong nuclear force; and whether small violations of nature's fundamental symmetries will be observed which reveal new physics beyond our present understanding.

Facility for Rare Isotope Beams (FRIB) Construction continues. The construction of FRIB to provide unprecedented capability for research on neutron-rich nuclei is NP's highest priority construction project. Even though ground breaking of this state-of-the-art, highly complex facility started a little over three years ago in March 2014, FRIB construction has already surpassed the ~80% completion mark as of July 31, 2017. A notable accomplishment is that beneficial occupancy of the facilities completed as part of the civil construction was achieved in March 2017, ahead of schedule. These facilities can now be used for their intended purposes. That includes early commissioning of the ion source that will "feed" FRIB with the highly charged atoms it will accelerate to create rare isotope beams. Final completion efforts will continue in parallel, including the installation of technical components such as the beamlines, cryogenics systems, and superconducting cryomodules used for particle acceleration. Over 1,400 scientists eagerly await the physics opportunities that FRIB will provide, and new collaborations to deepen theoretical understanding of FRIB science and develop new detector instrumentation are actively underway.

Building a National University Isotope Production Network for Regional and Unique Isotope Needs. The DOE Isotope Program has recently established a partnership agreement with the University of Missouri Research Reactor (MURR) to enable MURR to supply selenium-75, a biological tracer and research isotope. Addressing a recommendation in the NSAC-Isotope 2015 Long Range Plan for the DOE Isotope Program, the partnership with MURR marks the second agreement (first reactor-based production agreement) established to create a network of university-based isotope production capabilities to promote availability of high priority isotopes. Consideration of additional university sites to the network is underway.

Pioneering the Development of a Novel Isotope for Positron Emission Tomography. Positron Emission Tomography (PET) scans provide physicians with the capability to not only obtain internal images of patients, such as cancer metastases, but also to study organ functionality, such as cardiac blood flow. The variety of studies that can be performed increases with the development of radioactive isotopes with different physical properties (e.g., chemistry, radioactive half-life). Isotope production research at the Brookhaven and Los Alamos National Laboratories has led to the availability of a novel PET isotope, scandium-44, for researchers to develop new PET diagnostics. The research involved developing methods of production of titanium-44, the long half-life parent of scandium-44, and a chemical “generator” from which clinical researchers can extract scandium-44 from the titanium-44. Scandium-44 can be used with existing tumor targeting agents to provide high resolution imaging results over its short half-life, which are crucial to metabolic tracking and therapeutic treatment planning. The generator also offers a convenience in distribution and application as other PET isotopes are typically cyclotron-produced.

Important Milestones Reached Deep Under Ground: First Data From Recently Commissioned Detectors. One of the most urgent Grand Challenge questions of modern physics is why the neutrino mass is so small, and whether the neutrino is its own anti-particle. Several first-generation experiments are attempting to demonstrate their capability to answer these questions by detecting rare decays predicted to happen for a single nucleus only once every 10^{28} years or, for example, for 10^{28} nuclei, once per year. A prototype detector named the Majorana Demonstrator (MJD), an experiment jointly funded by NP and NSF, was recently commissioned at the Sanford Underground Research Facility in Lead, South Dakota to study the feasibility of that technology. The MJD detector demonstrated the best energy resolution of any experiment looking for these rare decays and published its first results on physics beyond the Standard Model. Another experiment, the Cryogenic Underground Observatory for Rare Events detector was also commissioned deep underground at the Laboratori Nazionalie del Gran Sasso in Italy as part of this international scientific quest that could help illuminate the reason for the relatively small amount of anti-matter in our present-day universe. The data these projects will provide is a crucial first step in understanding the deeper nature of the neutrino and its role in the evolution of the cosmos.

A New Measurement of the Neutron Lifetime with Unprecedented Precision. While protons remain stable for at least 10^{34} years, if not bound inside a nucleus, a neutron survives just 15 minutes before it decays into a proton, electron, and an antineutrino. Astrophysicists need to know the precise value of the free neutron lifetime to calculate the rate of nucleosynthesis during the "Big Bang”, and nuclear and particle physicists can use the lifetime to constrain fundamental parameters of the Standard Model. To do so, the lifetime of the neutron needs to be known to better than half a second. Given discrepancies in the world’s data however, the current uncertainty is larger than 8 seconds. NP researchers at Los Alamos National Laboratory used an array of magnets to trap ultra-slow neutrons and count how many survive with time. The experiment determined the lifetime to within one second uncertainty and showed that its ultimate sensitivity would be smaller than half a second. This result adds excitement to the world-wide effort to finally determine with sufficient accuracy how long the neutron lives.

FIONA to take on the periodic table’s heavyweights. A new tool at the DOE’s LBNL will be taking on some of the periodic table’s latest heavyweight champions (a.k.a. “super-heavy nuclei”) to see how their masses measure up to predictions. Nuclear physicists have used the known masses of radioactive decay “daughter atoms” as a framework for determining the masses for these heavier “parent” elements. But determining the mass number of some of the heaviest elements has remained out of reach because it is challenging to produce isolated atoms and to measure them before they rapidly decay. The new "For the Identification of Nuclide A" (FIONA) detector provides an opportunity to measure both the mass numbers, A and the charges, Z of the new super heavy elements at the same time. Commissioning is complete and FIONA will now be used to study decay processes associated with element 115, which was recently named Moscovium by the International Union of Pure and Applied Science along with Nihonium, Oganesson, and Tennesine in honor of important contributions to the discovery of these new elements.

Creating Heavy Nuclei in Mergers of Massive Stellar Objects. Working with an international team, scientists at the LBNL have developed new computer models to explore what happens when a black hole joins with a neutron star – the super-dense remnant of an exploded star. The simulations are intended to help detectors home in on the gravitational-wave signals. One of these studies models the first milliseconds (thousandths of a second) in the merger of a black hole and neutron star, and another details separate simulations that model the formation of a disk of material formed within seconds of the merger, and of the evolution of matter that is ejected in the merger. The studies provide insight into the astrophysical conditions of the possible site where nucleosynthesis happens, and provide predictions for observable consequence of gravitational wave sources.

Nuclear Physics
Medium Energy Nuclear Physics

Description
The Medium Energy Nuclear Physics subprogram focuses primarily on experimental tests of the theory of the strong interaction, known as Quantum Chromodynamics (QCD). According to QCD, all observed nuclear particles, collectively known as hadrons, arise from the strong interaction of quarks, antiquarks, and gluons. The protons and neutrons inside nuclei are the best known examples of hadrons. QCD, although difficult to solve computationally, predicts what hadrons exist in nature, and how they interact and decay. Specific questions addressed within this subprogram include:

- What is the internal landscape of the protons and neutrons (collectively known as nucleons)?
- What does QCD predict for the properties of strongly interacting matter?
- What is the role of gluons and gluon self-interactions in nucleons and nuclei?

Various experimental approaches are used to determine the distribution of up, down, and strange quarks, their antiquarks, and gluons within protons and neutrons, as well as clarifying the role of gluons in confining the quarks and antiquarks within hadrons. Experiments that scatter electrons off of protons, neutrons and nuclei are used to clarify the effects of the quark and gluon spins within nucleons, and the effect of the nuclear medium on the quarks and gluons. The subprogram also supports experimental searches for higher-mass "excited states" and exotic hadrons predicted by QCD, as well as studies of their various production mechanisms and decay properties.

The Medium Energy Nuclear Physics subprogram supports research at and operation of the subprogram's primary research facility, CEBAF at TJNAF, as well as the spin physics research that is carried out using RHIC at BNL. The subprogram has provided support for spin physics research at RHIC, the only collider in the world that can provide polarized proton beams.

CEBAF provides high quality beams of polarized electrons that allow scientists to extract information on the quark and gluon structure of protons and neutrons from measurements of how the electrons scatter when they collide with nuclei. CEBAF also uses polarized electrons to make precision measurements to search for processes that violate a fundamental symmetry of nature, called parity, in order to search for physics beyond what is currently described by the Standard Model. These capabilities are unique in the world. The increase in beam energy provided by the 12 GeV CEBAF Upgrade continues to open up exciting new scientific opportunities and will secure continued U.S. world leadership in this area of physics. The upgrade construction project was successfully completed on cost and schedule in 2017, and the highly anticipated science program is will be launched in FY 2018. Some of the science goals of the 12 GeV experimental program include the search for exotic new quark anti-quark particles to advance our understanding of the strong force, evidence of new physics from sensitive searches for violations of nature's fundamental symmetries, and a microscopic understanding in the 12 GeV energy regime of the internal structure of the proton, including the origin of its spin, and how this structure is modified when the proton is inside a nucleus. Research at RHIC using colliding beams of spin-polarized protons, a capability unique to RHIC, will provide information on the origin of the spin of the proton in a kinematic range complementary to that at CEBAF to extend present knowledge beyond the kinematic boundaries accessible at CEBAF alone. Research support for CEBAF and RHIC includes laboratory and university scientific and technical staff needed to conduct high priority data analysis to extract scientific results. Complementary special focus experiments that require different capabilities are also supported at the High Intensity Gamma Source (HIGS) at Triangle Universities Nuclear Laboratory, Europe, and elsewhere. Efforts are supported at the Research and Engineering Center of the Massachusetts Institute of Technology (MIT), which has specialized infrastructure used to develop and fabricate advanced instrumentation and accelerator equipment.

The "SBIR/STTR and Other" category provides funding in accordance with the Small Business Innovation Development Act and related legislation, resulting in commercialization opportunities in medicine, homeland security, defense, and industry, as well as products and services that benefit NP. This category includes funding to meet other obligations, such as the annual Lawrence Awards and Fermi Awards.

<u>Research</u>
The Medium Energy Research subprogram supports a focused effort of medium energy research groups at TJNAF, BNL, ANL, the Los Alamos National Laboratory (LANL), and the LBNL to carry out the highest priority research programs and conduct

experiments at CEBAF, RHIC, and elsewhere. Scientists participate in the development and implementation of select advanced instrumentation, including state-of-the-art detectors for experiments that may also have application in areas such as medical imaging instrumentation and homeland security. TJNAF staff research efforts will focus on continuing the 12 GeV experimental program, including the implementation of select experiments, acquiring data, and performing data analysis at select CEBAF experimental halls (Halls A, B, C, and D) and RHIC. Scientists conduct targeted research to advance knowledge and to identify and develop the science opportunities and goals for next generation instrumentation and facilities. The subprogram also supports a visiting scientist program at TJNAF and bridge positions with regional universities as a cost-effective approach to augmenting scientific expertise at the laboratory and boosting research experience opportunities.

ANL scientists play a leadership role in new experiments in the 12 GeV scientific program, and are engaged in commissioning experiments, instrumentation development, and data taking. ANL scientists continue precise measurements of the electric dipole moments of laser-trapped atoms as part of an intensive world-wide effort to set limits on QCD parameters and contribute to the search for possible explanations of the excess of matter over antimatter in the universe. Research groups at BNL and LBNL play leading roles in RHIC data analysis critical for determining the spin structure of the proton. Researchers at MIT and at TJNAF are developing high current, polarized electron sources for next generation NP facilities.

Accelerator R&D research proposals for short and mid-term accelerator R&D from universities and laboratories specific to improving operations of current NP facilities or developing new NP facilities are evaluated by peer review through a single competition for funding that is included under the Heavy Ion and Medium Energy subprograms. Limited accelerator R&D funding in Medium Energy and Heavy Ion accelerator R&D supports the most critical pre-conceptual Electron Ion Collider (EIC) accelerator R&D based on the priorities identified by the NP community's EIC R&D review. The focus is on the most significant technical challenges and risk reduction activities required toward the possible realization of a U.S. based EIC.

Operations

The science user community, including a strong international component, uses CEBAF's polarized electron beam capabilities to study the contributions of quarks and gluons to the properties of hadrons. The subprogram provides Accelerator Operations funding for a focused team of accelerator physicists at TJNAF that operate CEBAF, as well as for maintenance and power costs in the second year of operations following the completion of the 12 GeV CEBAF Upgrade project in 2017. The Request defers investments in accelerator improvements aimed at addressing CEBAF reliability, GPP investments for infrastructure, and capital equipment for research and facility instrumentation. Support is provided for the most important efforts in developing advances in superconducting radiofrequency (SRF) technology relevant to improving operations of the existing machine. The core competency in SRF technology plays a crucial role in many DOE projects and facilities outside of nuclear physics (such as the Basic Energy Sciences project LCLS II) and has broad applications in medicine and homeland security. For example, SRF R&D at TJNAF has led to improved land-mine detection techniques and carbon nanotube and nano-structure manufacturing techniques for constructing super-lightweight composites such as aircraft fuselages. TJNAF also has a core competency in cryogenics and has developed award-winning techniques that have led to more cost-effective operations at TJNAF and several other SC facilities; their cryogenics expertise is being applied to the FRIB project and LCLS-II. TJNAF accelerator physicists help train the next generation of accelerator physicists, enabled in part by a close partnership with nearby universities and other institutions with accelerator physics expertise. The subprogram provides focused Experimental Support for scientific and technical staff, as well as for critical materials and supplies needed for the implementation, integration, assembly, and operation of the large and complex CEBAF experiments. Four experimental halls, increased from three prior to the 12 GeV upgrade, are now capable of providing new and enhanced capabilities for scientists world-wide.

Nuclear Physics
Medium Energy Nuclear Physics

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Medium Energy Nuclear Physics $156,107,000	**$152,375,000**	**-$3,732,000**
Research $35,334,000	**$33,487,000**	**-$1,847,000**
Researchers participated in the early 12 GeV physics program at TJNAF and continued to implement and develop experimental instrumentation. Researchers published in FY 2017 the first 12 GeV GlueX physics result showing that polarization provides powerful new information on meson production. Researchers participated in the high luminosity RHIC spin run to test and confirm the QCD structure of color spin interactions. Analysis of prior RHIC polarized proton beam data to learn more about the origin of the proton's spin, and support for short and mid-term accelerator R&D, continued.	The Request continues the 12 GeV experimental program at CEBAF, with high priority experiments taking data in experimental halls. Science goals include the search for exotic new quark/anti-quark particles, sensitive searches for violations of nature's fundamental symmetries, and a detailed microscopic understanding of the internal structure of the proton. This includes support for scientific workforce resident at TJNAF and outside universities and national laboratories that plan the scientific program; develop, implement and maintain scientific instrumentation; participate in the experimental runs to acquire data; analyze data and publish experimental results; and train students in nuclear science. Analysis of prior RHIC polarized proton beam data to learn more about the origin of the proton's spin, and support for short and mid-term accelerator R&D, continues.	Funding supports a focused group of 12 GeV researchers from national laboratories and universities to mount, implement, and operate the highest priority experiments at CEBAF. The Request prioritizes the implementation of the scientific experimental program at TJNAF.
Operations $99,990,000	**$98,541,000**	**-$1,449,000**
Funding supported the required machine development, and its associated incremental power costs, the completion of the 12 GeV CEBAF project on cost and schedule, and beam time for the early physics program in select Halls. Funding was provided for Other Project Costs (within project TPC), as part of the 12 GeV CEBAF Upgrade project profile. CEBAF operated for 2,191 hours or 17 weeks in FY 2017.	Operations of the newly upgraded CEBAF facility will support the continuation of the high priority 12 GeV science program, following the successful completion of the project in 2017. Funding will support 2,035 operational hours of running for research, tuning, and beam studies. Experiments in multiple halls will be operated for data taking.	Accelerator operations and experimental support funding supports ~19 weeks of operations. Funding is not requested for facility capital equipment, accelerator improvement funding, and General Plant Projects. Funding supports a more focused operations staff, power costs, materials, and supplies.

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
SBIR/STTR and Other $20,783,000	**$20,347,000**	**-$436,000**
Funding was provided in accordance with the Small Business Innovation Development Act and subsequent related legislation, as well as for other DOE and Office of Science obligations.	Funding will be provided in accordance with the Small Business Innovation Development Act and subsequent related legislation, as well as for other DOE and Office of Science obligations.	The decrease reflects the mandated set-aside for SBIR/STTR.

Nuclear Physics
Heavy Ion Nuclear Physics

Description

The Heavy Ion Nuclear Physics subprogram focuses on studies of nuclear matter at extremely high densities and temperatures, directed primarily at answering overarching questions in Nuclear Physics, including:

- What are the phases of strongly interacting matter, and what roles do they play in the cosmos?
- What governs the transition of quarks and gluons into pions and nucleons?
- What determines the key features of QCD and their relation to the nature of gravity and space-time?

At the Relativistic Heavy Ion Collider (RHIC) facility, scientists continue to pioneer the study of condensed quark-gluon matter at the extreme temperatures characteristic of the infant universe. The goal is to explore and understand unique manifestations of QCD in this many-body environment and their influence on the universe's evolution. In the aftermath of collisions at RHIC and at the Large Hadron Collider (LHC) at CERN, researchers have seen signs of the same quark-gluon plasma that is believed to have existed shortly after the Big Bang. With careful measurements, scientists are accumulating data that offer insights into the processes early in the creation of the universe, and how protons, neutrons, and other bits of normal matter developed from that plasma. Important avenues of investigation are directed at learning more about the physical characteristics of the quark-gluon plasma including exploring the energy loss mechanism for quarks and gluons traversing the plasma, determining the speed of sound in the plasma, establishing the threshold conditions (minimum nucleus mass and energy) under which the plasma can be formed, and discovering whether a the critical point exists where there is a phase transition between normal nuclear matter and the quark-gluon plasma.

The RHIC facility places heavy ion research at the frontier of discovery in nuclear physics. The RHIC facility is uniquely flexible, providing a full range of colliding nuclei at variable energies spanning the transition to the quark gluon plasma discovered at RHIC. The facility continues to set new records in performance for both integrated Au-Au luminosity at full energy and a number of other beam settings. This flexibility and performance enables a groundbreaking science program extending into the next decade to answer outstanding questions about this exotic form of matter. The FY 2017 run tested the present understanding of QCD as applied to the spin structure of the proton and will further clarify the scientific interpretation of recent heavy ion measurements. In FY 2019, researchers at RHIC will utilize significant accelerator improvements developed over the past couple of years to increase luminosity, enabling a campaign to search for a critical point in the phase diagram of nuclear matter the following year. The Request will continue to support efforts, within available, existing resources, to enhance the capabilities of the STAR detector, and initiate an upgrade of the PHENIX detector to sPHENIX with funds previously used to operate the PHENIX detector. In addition, the Request will support modest short and mid-term accelerator R&D at RHIC in critical areas that may include the cooling of high-energy hadron beams, high intensity polarized electron sources, and high-energy, high-current energy recovery linear (ERL) accelerators. The RHIC facility is typically used by about 1,200 DOE, NSF, and foreign agency-supported researchers annually.

Collaboration in the heavy ion program at the LHC at CERN provides U.S. researchers the opportunity to investigate states of matter under substantially different initial conditions than those provided by RHIC, providing complementary information regarding the matter that existed during the infant universe. Data collected by the ALICE, CMS, and ATLAS detectors confirm that the quark-gluon plasma discovered at RHIC is also seen at the higher energy, and comparing these results to the results at RHIC has led to important new insights. U.S. researchers have been making important scientific contributions to the emerging results from all three LHC experiments. In ALICE and CMS, U.S. researchers have been participating in developing and upgrading instrumentation for future heavy ion campaigns at the LHC.

<u>Research</u>

The subprogram will support heavy ion research groups at BNL, LBNL, LANL, and the Oak Ridge National Laboratory (ORNL) to participate in experiments at RHIC and the LHC. In FY 2019, laboratory and university workforce will be focused on the highest priority efforts at RHIC; research commitments to the LHC program are fully met.

The university and national laboratory research groups provide focused personnel and graduate students for taking data within the RHIC heavy ion program; analyzing data; publishing results; conducting R&D of next-generation detectors;

developing and implementing scientific equipment; and planning for future experiments. BNL and LBNL provide computing infrastructure for petabyte-scale data analysis and state-of-the-art facilities for detector and instrument development. At LBNL, a large-scale computational system, the NP-supported Parallel Distributed Systems Facility (PDSF), is a major shared resource used for the analysis of RHIC data in alliance with the National Energy Research Scientific Computing Center (NERSC), which is supported by SC's Advanced Scientific Computing Research (ASCR) program.

Accelerator R&D research proposals for short and mid-term accelerator R&D from universities and laboratories specific to improving operations of current NP facilities or developing new NP facilities are evaluated by peer review through a single competition for funding that is included under the Heavy Ion and Medium Energy subprograms. Accelerator R&D funding in Medium Energy and Heavy Ion accelerator R&D supports the most critical pre-conceptual EIC accelerator R&D based on the priorities identified by the NP community's EIC R&D review. The focus is on the most significant technical challenges and risk reduction activities required toward the possible realization of a U.S. based EIC.

Operations

The Heavy Ion subprogram provides support for the operations and power costs of the RHIC accelerator complex at BNL. In FY 2019, the subprogram focuses support on RHIC operations and does not request support for capital equipment and accelerator improvement projects. The accelerator complex includes the Electron Beam Ion Source (EBIS), Booster, and the Alternating Gradient Synchrotron (AGS) accelerators that together serve as the injector for RHIC. Staff provide experimental support to the facility, including the development, implementation, and commissioning of scientific equipment associated with the RHIC program. In FY 2019, the only detector operating at RHIC is STAR; the remaining available funding will be used to initiate the proposed upgrade of PHENIX to "super PHENIX" (sPHENIX). sPHENIX will enable scientists to study how the near-perfect QGP liquid, which has the lowest shear viscosity ever observed arises from the strongly interacting quarks and gluons from which it is formed.

Through operations of the RHIC complex, important core competencies have been nurtured in accelerator physics techniques to improve RHIC performance and support the NP mission. These core competencies provide collateral benefits to applications in industry, medicine, homeland security, and other scientific projects outside of NP. Accelerator Improvement Projects in prior years have focused on cooling of low energy heavy ion beams with bunched electron beam, which is projected to increase the luminosity by up to another factor of 10; the full system is planned to be implemented in FY 2018. RHIC accelerator physicists are providing leadership to the effort to address technical feasibility issues of relevance to a possible next-generation collider, including beam cooling techniques and energy recovery linacs. Accelerator physicists also play an important role in the training of next generation accelerator physicists, with support of graduate students and post-doctoral associates.

RHIC operations allow for parallel and cost-effective operations of the Brookhaven Linac Isotope Producer Facility (BLIP), supported by the DOE Isotope Program for the production of research and commercial isotopes critically needed by the Nation, and of the NASA Space Radiation Laboratory Program for the study of space radiation effects applicable to human space flight as well as electronics.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Heavy Ion Nuclear Physics $212,573,000	**$205,615,000**	**-$6,958,000**
Research $38,035,000	**$34,017,000**	**-$4,018,000**
Researchers completed the heavy flavor measurements at RHIC, enabled by the STAR Heavy Flavor Tracker MIE, and continued to analyze data. Researchers completed taking data with the PHENIX detector and performed R&D and conceptual design of the sPHENIX detector. NP provided scientific leadership to the heavy ion efforts at the international ALICE, CMS, and ATLAS LHC experiments, as well as the required funding to the LHC for U.S. commitments for management and operating costs and an upgrade to the ALICE instrumentation. Competitive accelerator R&D relevant to NP programmatic needs was also supported.	Researchers will participate in the analysis and collection of data from RHIC to explore new phenomena in quark-gluon plasma formation, with a particular search for signs of critical phenomena in event-by-event fluctuations that could reveal the critical point in the QCD Phase Diagram. Modest scientific efforts will initiate the sPHENIX MIE for the study of high rate particle jets. This includes support for scientific workforce resident at RHIC and outside universities and national laboratories that plan the scientific program; develop, fabricate, implement and maintain scientific instrumentation; participate in the experimental runs to acquire data; analyze data and publish experimental results; and train students in nuclear science. U.S. scientists play a leadership role in the heavy ion efforts at the international ALICE, CMS, and ATLAS LHC experiments, and provide the required funding to the LHC for U.S. commitments for management and operating costs, computing, and contributions towards upgrades of the ALICE detector. Mid- and short-term accelerator R&D relevant to NP programmatic needs will also be supported.	The Request will support a narrowed focus of university and national laboratory RHIC research. U.S. scientists participate in the Nuclear Physics program at the LHC.

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Operations $174,538,000	**$171,598,000**	**-$2,940,000**
RHIC operations provided for 2,631 beam hours, which was approximately 21 weeks in support of the planned RHIC research program that is taking advantage of dramatic improvements in collider performance and versatility made possible by recent RHIC upgrades. The facility is now operating at 44 times its design luminosity.	RHIC will operate for 2,795 hours and will focus on the beam energy scan with the newly implemented Low Energy electron Cooling to increase luminosity of low energy beams. Funding supports the RHIC accelerator complex (four different particle accelerators not including the RHIC collider rings that are 2.4 miles in circumference), including mission readiness and development of the experimental halls and instrumentation, mission readiness of the suite of accelerators, all power and consumables of the site, cryogenics plant, computing capabilities for data taking and analysis, accelerator scientists, engineers, and technicians, and RHIC operations staff. High priority facility specific accelerator R&D will continue.	Funding will provide for ~19 weeks of operation. The Request does not include support for capital equipment and Accelerator Improvement Projects.

Description

The Low Energy Nuclear Physics subprogram focuses on answering the overarching questions associated with Nuclei and Nuclear Astrophysics and Fundamental Symmetries that can be probed by studying neutrons and nuclei.
Questions associated with Nuclei and Nuclear Astrophysics include:

- What is the nature of the nuclear force that binds protons and neutrons into stable nuclei and rare isotopes?
- What is the origin of simple patterns in complex nuclei?
- What is the nature of neutron stars and dense nuclear matter?
- What is the origin of the elements in the cosmos?
- What are the nuclear reactions that drive stars and stellar explosions?

This subprogram addresses these questions through support of research to develop a comprehensive description of nuclei using beams of stable and rare isotopes to yield new insights and reveal new nuclear phenomena. The subprogram also measures the cross sections of the nuclear reactions that power stars and lead to spectacular stellar explosions, which are responsible for the synthesis of the elements.

Questions addressed in the area of Fundamental Symmetries that can be probed by studying neutrons and nuclei include:

- What is the nature of the neutrinos, what are their masses, and how have they shaped the evolution of the cosmos? What experimental approach for a next generation, ton-scale neutrino-less double beta day detector is capable of achieving the sensitivity necessary to determine if the neutrino is its own anti-particle?
- Why is there now more matter than antimatter in the universe? Is there evidence from the electric-dipole moments of atomic nuclei and the neutron that indicate our current understanding of the fundamental laws governing nuclear physics is incomplete?
- Will evidence for time-reversal violation in electron scattering and possible lepton number violation in the decay of nuclei indicate forces present at the dawn of the universe that disappeared from view as the universe evolved?

The Fundamental Symmetries portfolio currently addresses these questions through precision studies using neutron beams and decays of nuclei, including neutrinoless double-beta decay. U.S. scientists are world leaders in the global research effort aimed at neutrino science and NP is the steward of neutrinoless double beta decay in the Office of Science. In partnership with the NSF, NP has invested in past, current and future neutrino experiments both domestically and overseas, playing critical roles in international experiments which depend on U.S. leadership for their ultimate success (CUORE, KATRIN). Beams of cold and ultracold neutrons at the Spallation Neutron Source are used to study fundamental properties of neutrons, and R&D towards an experiment for this beamline to measure the electric dipole moment of the neutron, which could shed light on the asymmetry of matter versus antimatter in the universe, is addressing technical feasibility and on the path towards becoming the flagship experiment at this beamline. Precision studies to observe or set a limit on violation of time-reversal invariance—the principle that the physical laws should not change if the direction of time is reversed—in nucleonic, nuclear, and atomic systems investigate fundamental questions in nuclear physics, astrophysics, and cosmology. The ATLAS scientific user facility at ANL is the DOE-supported facility providing research opportunities in Nuclear Structure and Nuclear Astrophysics, serving a combined international community of about 400 scientists. ATLAS is the world's premiere facility for stable beams and provides high-quality beams of all the stable elements up to uranium as well as selected beams of short-lived nuclei for experimental studies of nuclear properties under extreme conditions and reactions of interest to nuclear astrophysics. ATLAS also provides some capabilities in radioactive or rare isotope beams with the Californium Rare Ion Breeder Upgrade (CARIBU) ion source. The facility continues to provide increasingly higher intensity stable beams and improved quality radioactive beams with modest accelerator improvements. Technologically cutting-edge and unique instrumentation are a hallmark at the facility, and the ATLAS Facility continues to be significantly oversubscribed by the user community. In addition to its world-class, standalone scientific program, ATLAS is also an essential training ground for scientists and students as they prepare for the FRIB research program. The ATLAS facility nurtures a core competency in accelerator science with superconducting radio frequency cavities for heavy ions that are relevant to the next generation of high-performance proton and heavy ion linacs. This competency is important to the SC mission and international stable and radioactive ion beam facilities. ANL maintains a target development laboratory in direct support of ongoing low energy research undertaken at ATLAS. In FY 2017, this core competency was strengthened to establish the National Center for Accelerator Target Science, a national asset for the low energy community, including FRIB.

Disposition activities of the ORNL Holifield Radioactive Ion Beam Facility, which ceased operations in FY 2012, are completed in FY 2017.

Accelerator operations are supported at two university Centers of Excellence with specific goals and unique physics programs: the Cyclotron Institute at Texas A&M University (TAMU) and accelerator facilities at the Triangle Universities Nuclear Laboratory (TUNL) at Duke University. A third university center, the Center for Experimental Nuclear Physics and Astrophysics (CENPA) at the University of Washington, provides unique expertise and capabilities for instrumentation development. NP also supports operations of the LBNL 88-Inch Cyclotron to provide beams for a small in-house nuclear science program focused on studying the properties of newly discovered elements on the periodic table, and unique testing capabilities in materials irradiation important for external users and other critical missions, such as the Department of Defense and NASA.

The Facility for Rare Isotope Beams (FRIB), under construction at Michigan State University (MSU), will advance understanding of rare nuclear isotopes and the evolution of the cosmos by providing beams of rare isotopes with neutron and proton numbers far from those of stable nuclei in order to test the limits of nuclear existence. The Request includes funds to support FRIB operations and retain critical operations staff as accelerator components on the project are completed and efforts transition to operations. The Gamma-Ray Energy Tracking Array (GRETA) MIE, initiated in FY 2017, is continued in the FY 2019 Request. This advanced instrumentation is one of the primary tools that the nuclear science community has identified to leverage the capabilities of FRIB. GRETA will have ten times the gamma-ray resolving power of current generation detectors for the vast majority of experiments, and up to a factor of 100 for those requiring multiple gamma-ray correlations. GRETA's unprecedented combination of full coverage with high efficiency, and excellent energy and position resolution, will extend the reach of FRIB's ability to study the nuclear landscape, provide new opportunities to discover and characterize key nuclei for electric dipole moment (EDM) searches, and open new areas of study in nuclear astrophysics.

<u>Research</u>
The subprogram will support focused efforts of Low Energy research groups at ANL, BNL, LBNL, LANL, LLNL, ORNL, and PNNL. About half of the scientists conduct nuclear structure and astrophysics research primarily using specialized instrumentation at the ATLAS scientific user facility, as well as the smaller accelerator facilities at university-based Centers of Excellence. The GRETA MIE continues at a pace slower than planned to provide unprecedented gamma-ray tracking capabilities for the future FRIB facility. GRETA will revolutionize gamma-ray spectroscopy providing more than an order of magnitude increased sensitivity for gamma ray coincidence measurements. The remaining groups primarily conduct research in fundamental symmetries, including experiments at the Fundamental Neutron Physics Beamline (FNPB) at the Spallation Neutron Source; double beta-decay experiments such as the Cryogenic Underground Observatory for Rare Events (CUORE) experiment at Gran Sasso Laboratory in Italy and the Majorana Demonstrator R&D effort at the Sanford Underground Research Facility in Lead, South Dakota; a measurement of the neutrino mass with the Karlsruhe Tritium Neutrino (KATRIN) experiment at the Karlsruhe Institute of Technology in Karlsruhe, Germany; and R&D to measure the neutron electric dipole moment. Support is not requested for next-generation R&D aimed at a ton-scale neutrinoless double beta decay experiment. Support is also provided to the university Centers of Excellence to maintain and nurture their unique capabilities.

<u>Operations</u>
ATLAS provides highly reliable and cost-effective stable and selected radioactive beams and specialized instrumentation for scientists to conduct research on nuclear structure and nuclear astrophysics. The subprogram provides support for operations, power costs, accelerator improvement projects and experimental support of ATLAS. In FY 2019, efforts will be focused on operating the machine, and the Program does not request support for accelerator and scientific instrumentation capital equipment. Recent or to be completed in 2018 accelerator and scientific instrumentation include the Electron Beam Ion Source (EBIS), the cutting edge CARIBU radioactive beam system for accelerated radioactive ion beams, the in-flight radioactive ion separator to increase the intensity of radioactive beams, and a new gas filled analyzer completed in FY 2017.

The ATLAS facility nurtures a core competency in accelerator science with superconducting radio frequency cavities for heavy ions that are relevant to the next generation of high-performance proton and heavy ion linacs. This competency is important to the Office of Science mission and international stable and radioactive ion beam facilities. Efforts continue in developing technology that could reduce the backlog of experiments and increase available beam time, such as the capability to operate stable and radioactive ion beams simultaneously.

Support is provided to maintain operations support of the 88-Inch Cyclotron. Modest funds are provided to support FRIB operations, which will be initiated in FY 2018. These funds retain critical operations staff as accelerator components are completed on the project and efforts transition to operations.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Low Energy Nuclear Physics $80,168,000	**$82,559,000**	**+$2,391,000**
Research $56,669,000	**$55,060,000**	**-$1,609,000**
University and laboratory nuclear structure and nuclear astrophysics efforts continued to focus on research at ATLAS, university-based Centers of Excellence, as well as the highest priority instrumentation development efforts to realize unique scientific opportunities afforded by stopped, slow, and fast beams at FRIB. Efforts continued with the Majorana Demonstrator and EXO to demonstrate technical feasibility of a next generation detector in double beta decay. Support is continued for operations of the GRETINA detector, operations of the KATRIN experiment, operations of the FNPB, operations of CUORE and R&D on setting a world leading limit on the electric dipole moment of the neutron and R&D on the lifetime of the neutron.	The Request supports high priority university and laboratory nuclear structure and nuclear astrophysics efforts to focus on research at ATLAS, the world's premiere stable beam facility, as well as development of the FRIB scientific program. Research and operations continue at the unique university-based Centers of Excellence. Research will continue with the Majorana Demonstrator and EXO to consider performance of different technologies in neutrinoless double beta decay experiments. U.S. participation in the operations of the international KATRIN and CUORE experiments will continue, as does ongoing R&D at the FNPB on the feasibility of setting a world leading limit on the electric dipole moment of the neutron. The Request continues to support the GRETA MIE.	No funding is requested for the R&D effort aimed at developing technology for the next generation neutrinoless double beta decay (0vbb) experiment in partnership with NSF. The GRETA MIE will continue, as will research on the neutron electric dipole moment experiment.
Operations $23,499,000	**$27,499,000**	**+$4,000,000**
Continued operation of ATLAS was a high priority as demand for ATLAS beam time continues to far exceed availability. In FY 2017, ATLAS cost-effectively delivered 5,468 hours or ~34 weeks. The AGFA gas filled analyzer was completed on cost and schedule, and the AIRIS spectrometer is on track for completing as planned in FY 2018. The National Center for Accelerator Target Science, an asset for the entire Low Energy community and leveraged by ATLAS staff, was launched in FY 2017.	The Request supports the operation of ATLAS to address the high demand for ATLAS beam time, which continues to far exceed availability. ATLAS funding at this cost-effective facility will support 5,300 hours of beam time. Funding is also provided to ramp up the operations activities for FRIB.	Funding supports operations of ATLAS for ~34 weeks. Funding supports an increase in FRIB operations and maintenance of operations at the 88-Inch Cyclotron.

Description

The Nuclear Theory subprogram provides the theoretical support needed to interpret the wide range of data obtained from the experimental nuclear science subprograms and to advance new ideas and hypotheses that identify potential areas for future experimental investigations. Currently, Nuclear Theory addresses all three of NP's scientific thrusts and in FY 2019, it will focus on the two remaining thrusts, that of QCD and Nuclear Structure and Astrophysics. One major theme of theoretical research is the development of an understanding of the mechanisms and effects of quark confinement and deconfinement. A quantitative description of these phenomena through QCD is one of this subprogram's greatest intellectual challenges. New theoretical and computational tools are also being developed to describe nuclear many-body phenomena; these approaches will likely also see important applications in condensed matter physics and in other areas of the physical sciences. Another major research area is nuclear astrophysics, which includes efforts to understand the origins of the elements and the consequences that neutrino masses have for nuclear astrophysics.

This subprogram supports the Institute for Nuclear Theory (INT) at the University of Washington. The fourth year of five-year topical collaborations within the university and national laboratory communities will be supported in FY 2019 within available funds to address only the highest priority topics in nuclear theory that merit a concentrated theoretical effort.

The U.S. Nuclear Data Program (USNDP) provides current, accurate, and authoritative data for workers in pure and applied areas of nuclear science and engineering. It addresses this goal primarily through maintaining and providing public access to extensive nuclear physics databases, which summarize and cross-correlate the results of over 100 years of research on nuclear science. These databases are an important national and international resource, and they currently serve approximately three million retrievals of nuclear data annually. The USNDP also addresses important gaps in nuclear data through targeted experiments and the development and use of theoretical models. The program involves the combined efforts of approximately 50 nuclear scientists at 10 national laboratories and universities, and is managed by the National Nuclear Data Center (NNDC) at BNL. The USNDP recently established two university efforts, one at Michigan State University, in association with FRIB, and the other at the University of California at Berkeley, in association with the existing Bay Area Nuclear Data groups at LBNL and LLNL. The U.S. Nuclear Data Program also recently stood up an Inter-Agency working group including NNSA, DHS, NE, and other Federal Agencies to provide evaluated cross-section and decay data relevant to a broad suite of Federal missions and topics. Plans have been underway for the USNDP to support efforts on opportunistic measurements to address serious gaps and uncertainties in existing nuclear data archives.

Much of the research supported by the Nuclear Theory subprogram requires extensive access to leading-edge supercomputers. One area that has a particularly pressing demand for large, dedicated computational resources is Lattice QCD (LQCD). LQCD calculations are critical for understanding and interpreting many of the experimental results from RHIC, LHC, and CEBAF. A five-year computer hardware project "LQCD-ext II" started in FY 2015 and has been carried out jointly with HEP to ensure effective coordination through FY 2017. It follows the previous joint efforts that address the computational requirements of LQCD research by continuing to provide specialized computing resources for LQCD research. NP requires this type of computing capability in order to conduct simulations that address its science program. In FY 2019, NP will support LQCD computing needs for dedicated computational resources with investments at JLab, and support is augmented from the new SC quantum information science (QIS) initiative to accommodate new developments in quantum devices and quantum computing algorithms.

The Request provides support for NP activities related to QIS and quantum computing (QC), in collaboration with efforts by the other SC research program offices. NP-specific efforts could include R&D on quantum sensors to enable precision NP measurements, development of quantum sensors based on atomic-nuclear interactions, and development of quantum computing algorithms applied to quantum mechanical systems and NP topical problems. NP-related QIS and QC efforts have direct relevance for this area of interest in general, and can lead to advances that are important for applications in QIS and QC in many fields.

The Nuclear Theory subprogram also supports SciDAC, a collaborative program with ASCR that partners scientists and computer experts in research teams to address major scientific challenges that require supercomputer facilities performing at current technological limits. The NP SciDAC program operates on a five year cycle, and supports computationally intensive research projects jointly with other SC and DOE offices in areas of mutual interest. SciDAC-3 awards were made in FY 2012 and continued through FY 2016. A new group of SciDAC-4 awards were selected in FY 2017 and continue in FY 2019.

Theory Research

The Nuclear Theory subprogram supports the highest priority research programs of nuclear theory groups at seven national laboratories (ANL, BNL, LANL, LBNL, LLNL, ORNL, and TJNAF). This research has the goals of improving our fundamental understanding of nuclear physics, interpreting the results of experiments carried out under the auspices of the experimental nuclear physics program, and identifying and exploring important new areas of research. Based on mission need, the success of the initial cohort of topical collaborations, and community support of this program, the subprogram will continue to support the 5-year topical collaborations initiated in FY 2016/FY 2017 within available funds to bring together theorists to address specific high-priority theoretical challenges. The ongoing topical collaborations will receive continued support in FY 2019: the Beam Energy Scan Theory (BEST) Collaboration, the Coordinated Theoretical Approach to Transverse Momentum Dependent Hadron Structure in QCD (TMD) Collaboration, the Nuclear Theory for Double Beta Decay and Fundamental Symmetries Collaboration and the Fission in R-process Elements (FIRE) Collaboration. The BEST and TMD proposals are intimately related to LQCD, one of nuclear theory's greatest intellectual challenges. BEST addresses "hot" QCD and the RHIC beam-energy scan, while TMD deals with "cold" QCD, three-dimensional hadron structure and spin physics, and looks forward in the direction of a future EIC. FIRE is jointly funded by NP and the NNSA to advance the theory of nuclear fission and explore the role of fission recycling in the creation of atomic nuclei in astrophysical environments. The subprogram will continue efforts on FRIB theory initiated in FY 2017, which is critical to theory efforts associated with the planned FRIB scientific program in order to optimize the interpretation of the experimental results. Efforts related to QIS and QC are initiated to address the needs of the NP program and provide technological and computational advances relevant to other fields.

Nuclear Data

Funding is requested to support the USNDP to collect, evaluate, and disseminate nuclear physics data for basic nuclear research and for applied nuclear technologies and their development.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Nuclear Theory $44,297,000	**$49,647,000**	**+$5,350,000**
Theory Research $36,725,000	**$42,075,000**	**+$5,350,000**
Funding continued to support the highest priority theoretical research at universities and national laboratories for the interpretation of experimental results obtained at NP facilities. Theorists concentrated on applying QCD to nucleon structure and hadron spectroscopy, to the force between nucleons, and to the structure of light nuclei. Advanced dynamic calculations to describe relativistic nuclear collisions, nuclear structure and reactions, and topics related to fundamental symmetries focused on activities in preparation for the research program at the upgraded CEBAF 12 GeV facility, the research program at the planned FRIB facility, and ongoing and planned fundamental symmetries experiments. Funding continued to support ongoing SciDAC-3 grants and the LQCD ext-II computing project. Support was provided to initiate the second round of theory topical collaborations.	Funding will provide for QIS efforts, including support for QIS research and LQCD computing. Funding will support high priority theoretical research at universities and national laboratories for the interpretation of experimental results obtained at NP facilities, and the exploration of new ideas and hypotheses that identify potential areas for future experimental investigations. Theorists will focus on applying QCD to a wide range of problems from nucleon structure and hadron spectroscopy, through the force between nucleons, to the structure of light nuclei. Advanced dynamic calculations to describe relativistic nuclear collisions and nuclear structure and reactions will continue to focus on activities related to the research program at the upgraded 12 GeV CEBAF facility, the research program at the planned FRIB, and ongoing and planned RHIC experiments. Funding will also support the third year of support for SciDAC-4 grants and the fourth year for the theory topical collaborations initiated in FY 2016.	Increased funding will be provided for QIS research and LQCD computing aimed at QIS and QC activities. Funding supports the highest priority theoretical research efforts across the Nuclear Physics program, and supports a theoretical collaboration focused on the science at FRIB.

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Nuclear Data $7,572,000	**$7,572,000**	**$0**
Nuclear data evaluation was the prime nuclear data product, combining experiment with theory and linking basic science with applications. The emphasis in FY 2017 was on the compilation and evaluation of nuclear reaction and nuclear structure data which included advanced nuclear reaction modeling and uncertainty quantification; maintaining and developing nuclear data formats and data verification codes; and archiving nuclear physics data and disseminating it using up to date technology.	Funding is requested to support the USNDP to collect, evaluate, and disseminate nuclear physics data for basic nuclear research and for applied nuclear technologies and their development. A modest experimental component to address gaps in the existing nuclear data will be considered.	The Request supports the highest priority USNDP efforts at universities and national laboratories.

Nuclear Physics
Isotope Development and Production for Research and Applications[a]

Description

The Isotope Development and Production for Research and Applications subprogram (DOE Isotope Program) supports the production, distribution, and development of production techniques for radioactive and stable isotopes in short supply and critical to the Nation. Isotopes are commodities of strategic importance for the Nation that are essential for energy exploration and innovation, medical applications, national security, and basic research. The goal of the program is to make key isotopes more readily available to meet U.S. needs. To achieve this goal, the program incorporates all isotope related R&D and production capabilities, including facilities and technical staff, required for supply chain management of critically important isotopes. The subprogram also supports R&D efforts associated with developing new and more cost-effective and efficient production and processing techniques, and on the production of isotopes needed for research purposes. The R&D activities also provide collateral benefits for training, contributing to workforce development, and helping to ensure a future U.S.-based expertise in the fields of nuclear chemistry and radiochemistry. These disciplines are foundational not only to radioisotope production, but to many other critical aspects of basic and applied nuclear science as well.

All funding from the Isotope Development and Production for Research Applications subprogram is executed through the Isotope Production and Distribution Program revolving fund. The isotope revolving fund maintains its financial viability by utilizing the appropriations from this subprogram along with revenues from the sale of isotopes and services. These resources are used to maintain the staff, facilities, and capabilities at user-ready levels and to support peer-reviewed R&D activities related to the production of isotopes. Isotopes sold to commercial customers are priced to recover the full cost of production, or the market price (whichever is higher). Research isotopes are sold at a reduced price to ensure high priority research requiring them does not become cost prohibitive. Investments in new capabilities are made to meet the growing demands of the Nation and foster future research in applications that will support national security and the health and welfare of the public.

Isotopes are critical national resources used to improve the accuracy and effectiveness of medical diagnoses and therapy, to enhance national security, and to improve the efficiency of industrial processes, and provide precise measurement and investigative tools for materials, biomedical, archeological, and other research. Some examples are:

- strontium-82 for cardiac imaging;
- californium-252 for well logging, homeland security, and energy security;
- germanium-68 for the development of gallium-68 radiopharmaceuticals for cancer imaging;
- berkelium-249, californium-251, and curium-248 for use as targets for discovery of new superheavy elements;
- selenium-75 for industrial radiography;
- actinium-225, bismuth-213, lead-212, astatine-211, copper-67, thorium-227, and radium-223 for cancer and infectious disease therapy research;
- nickel-63 for molecular sensing devices, and lithium-6 and helium-3 for neutron detectors for homeland security applications;
- lithium-7 as a coolant reagent for pressurized water nuclear power plants;
- actinium-227, tungsten-188, lutetium-177, strontium-90, and cobalt-60 for cancer therapy; and
- arsenic-73, iron-52, and zinc-65 as tracers in metabolic studies.

Stable and radioactive isotopes are vital to the missions of many Federal agencies including the NIH, the National Institute of Standards and Technology, the Department of Agriculture, DHS, NNSA, and DOE SC programs. NP continues to work in close collaboration with all federal organizations to develop strategic plans for isotope production and to establish effective communication to better forecast isotope needs and leverage resources. NP conducts biennial workshops, attended by representatives of all Federal agencies that require stable and radioactive isotopes, to provide a comprehensive assessment of national needs for isotope products and services, to inform priorities for investments in research for developing new isotope production and processing techniques, to communicate advances in isotope production research and availability,

[a] All appropriations for the Isotope Development and Production for Research and Applications subprogram fund a payment into the Isotope Production and Distribution Program Fund as required by P.L. 101–101 and as modified by P.L. 103–316.

and to communicate concerns about potential constrained supplies of important isotopes to the federal complex. The Isotope Program participates in a number of federal Working Groups and Interagency groups to promote communication, including the White House Office of Science and Technology Policy (OSTP) working group on molybdenum-99 (Mo-99), the National Science and Technology Committee (NSTC) Subcommittee on Critical and Strategic Mineral Supply Chains, the Interagency Group on Helium-3, which it leads, that reports to the White House National Security Staff, and the OSTP Interagency Working Group on Alternatives to High-Activity Radioactive Sources (whose activities completed in FY 2017). NP participates in the Certified Reference Material Working Group which assures material availability for nuclear forensics applications that support national security missions and also the Nuclear Regulatory Commission Committee on Alternatives to Sealed Sources. As a service, the Isotope Program collects demand and usage information on helium-4 from the federal complex and provides it to the Bureau of Land Management (BLM) so that BLM can optimize their plans for the helium-4 federal reserve.

The DOE Isotope Program also invests in the nation's future nuclear chemistry and biomedical researchers through support for the Nuclear Chemistry Summer School (NCSS) program. The NCSS consists of an intensive six-week program of formal accredited lectures on the fundamentals of nuclear science, radiochemistry, and their applications in related fields, as well as laboratory practicums focusing on state-of-the-art instrumentation and technology used routinely in basic and applied nuclear science.

While the Isotope Program is not responsible for the production of Mo-99, which is the most widely used isotope in diagnostic medical imaging in the Nation, it works closely with NNSA, the lead entity responsible for domestic Mo-99 production, offering technical and management support. Consistent with the National Defense Authorization Act for Fiscal Year 2013, NP also oversees proceedings of the Nuclear Science Advisory Committee in response to a charge to annually assess progress by NNSA toward ensuring a domestic supply of Mo-99. Additionally, NP participates in the international High-Level Group on the Security of Supply of Medical Isotopes lead by the Organisation for Economic Co-operation and Development.

The mission of the Isotope Program is facilitated by the National Isotope Development Center (NIDC), which is a virtual center that interfaces with the user community and manages the coordination of isotope production across the facilities and business operations involved in the production, sale, and distribution of isotopes. The NIDC includes the Isotope Business Office, which is located at ORNL.

Research

The subprogram supports research to develop new or improved production or separation techniques for high priority isotopes in short supply. Research investments tackle challenges in the efficiency of producing critical isotopes, and develop production methods for isotopes of interest to federal agencies and other stakeholders, when no production route is in existence, enabling new applications and research. The research activity has two primary components. One is support of R&D via competitive funding opportunity announcements open to both universities and laboratories. The other is provision of core R&D funding to national laboratories that possess unique facilities and technical expertise that directly support the mission of the DOE Isotope Program. In both components, peer review is used to assess the quality of the research being performed and its relevance for assuring availability of isotopes that are in short supply and needed for research and applications important to the Nation's science and industry. There is also an emphasis in the R&D program on providing training opportunities to students and post-docs to help assure a vibrant work-force essential to the technologies associated with isotope production. Priorities in research isotope production are informed by guidance from NSAC as described in the 2015 Long Range Plan for the DOE-NP Isotope Program published in July 2015 under the title "Meeting Isotope Needs and Capturing Opportunities for the Future." The Isotope Program has also funded research to demonstrate technical feasibility of modern stable isotope enrichment devices to provide the Nation with small-scale enrichment capabilities that have been absent since the DOE calutrons ceased operation in 1998. The U.S. is currently dependent on foreign sources for supplies of stable isotopes; the U.S. inventory has been depleted in the cases of some specific isotopes. The R&D program also develops domestic production capabilities for important radioisotopes for which the U.S. is dependent on foreign sources. Recent research results have also demonstrated technical feasibility of a potential new production route for lithium-7, an isotope used as a coolant reagent in pressurized water nuclear power plants. Currently, the U.S. is dependent upon foreign supplies of lithium-7 which are not always reliable; this successful research could provide a path for re-establishing domestic production of lithium-7. Also, in anticipation of the opportunity FRIB will provide as a unique source of many important isotopes for research and applications, scientists are exploring technologies to potentially harvest some of the isotopes that will be produced during physics research experiments.

A high priority is a dedicated research effort to produce actinium-225, an isotope that shows great promise in the treatment of diffuse cancers and infections if it can be produced in sufficient quantity and quality. Research efforts have demonstrated that the accelerator produced actinium-225 functions equivalently to the material derived from the decay of thorium-229 which is presently the only viable source of small quantities of actinium-225. In coordination with NIH, samples of the isotope produced by the accelerator production approach were evaluated by several different researchers involved in medical applications research to confirm these results. The accelerator route of production has the potential to provide quantities sufficient to support both research trials and ultimately clinical applications in the future.

Research supported for the past couple of years has culminated in the demonstration of reactor-produced actinium-227, representing the world's first source of new material. Actinium-227 decays to radium-223, which is used in new radiopharmaceutical drugs to treat prostate cancer. The provision of actinium-227 by the Isotope Program ensures that prostate cancer patients can have a reliable supply of palliative care drugs.

Operations

The Isotope Program is the steward of the Isotope Production Facility (IPF) at LANL and the Brookhaven Linac Isotope Producer (BLIP) facility at BNL, and provides support for hot cell facilities for processing and handling irradiated materials and purified products at ORNL, BNL, and LANL. Facilities at other sites are used as needed, such as the Idaho National Laboratory reactor for the production of cobalt-60, the Pacific Northwest National Laboratory (PNNL) for processing and packaging strontium-90, the Y-12 National Security Complex for processing and packaging lithium-6 and lithium-7, the LANL Plutonium Facility for extracting americium-241 from NNSA plutonium processes, the Low Energy Accelerator Facility (LEAF) at Argonne National Laboratory for the production of the medical isotope copper-67, and the Savannah River Site for the extraction and distribution of helium-3. In addition to isotope production at DOE facilities, the Isotope Program is funding production at universities with capabilities beyond those available at the stewarded facilities, such as an alpha-particle cyclotron at the University of Washington where full-scale production of astatine-211 was developed to support research into the use of the isotope in cancer therapy, and the recently added University of Missouri Research Reactor (MURR) where the Isotope Program supported the development of reactor production of selenium-75 for industrial gamma radiography. The establishment of a coordinated network of university-based isotope production was a recommendation in the 2015 NSAC-Isotope Long Range Plan. The network is designed to leverage the unique and often underutilized facilities available at academic institutions which are generally more suited to low-energy production reactions and can support nationwide availability of short-lived radioisotopes. Investments in FY 2019 increase the size of the University Network to more efficiently meet domestic isotope production needs. The suite of facilities that the Isotope Program supports continues to expand, with the above mentioned LANL Plutonium Facility, ANL LEAF, MURR and the University of Washington being the most recent additions.

The DOE Isotope Program has invested funds to develop stable isotope separation technology, first identified as a high priority by the NSAC Subcommittee on Isotopes in 2009. The R&D effort has resulted in an Enriched Stable Isotope Prototype Plant (ESIPP) to produce research quantities of enriched stable isotopes through the use of electromagnetic separation and centrifuge technology. The SIPF MIE was initiated in FY 2017 to establish kilogram production capability to help meet the nation's demand for enriched stable isotopes for basic research, medical, national security and industrial applications as recommended by the NSAC Subcommittee on Isotopes in 2015. The FY 2019 Request supports the SIPF MIE with a technically-driven profile for completion in FY 2023, reducing the nation's dependence for these critical isotopes on a foreign source. Examples of discovery research efforts that could benefit from the facility are foreign neutrinoless double beta decay experiments and dark matter experiments in high energy physics that are interested in kilogram quantities of enriched stable isotopes, which are not presently available in the U.S. Similarly, the accelerator-production route for Mo-99, a critical medical isotope for cardiac imaging, relies on a feedstock of enriched Mo isotopes, which are also unavailable domestically. Stable isotopic nuclides of heavier elements used for agricultural, nutritional, industrial, ecological, and computing applications can also be produced. ESIPP focuses on ruthenium-96 production in FY 2017 and FY 2018 to provide the otherwise unavailable target material to RHIC for its planned physics program. In FY 2019, funding is provided to produce specialty enriched stable isotopes for future QIS-drive technologies.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Isotope Development and Production for Research and Applications $28,855,000	**$34,804,000**	**+$5,949,000**
Research $8,829,000	**$8,829,000**	**$0**
Funding continued to support competitive R&D awards to universities and laboratories, as well as laboratory research groups at LANL, BNL, and ORNL. Development of production techniques for alpha-emitting radionuclides for medical therapy continued to be a priority, and was implemented through a concerted collaborative R&D effort by experts at the national laboratories, particularly at BNL, LANL, and ORNL. Research at universities and national laboratories also lead to new isotope production technologies and effectively engaging and training students and post-docs in nuclear chemistry and radiochemistry.	Funding will continue for high priority competitive R&D activities at universities and national laboratories leading to new isotope production technologies. Core support will continue to be provided to national laboratories for the highest priority R&D that enhances isotope production capabilities specifically relevant to the physical resources and expertise available at the laboratories.	Funding for national laboratory and university research will support the highest priority efforts.

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Operations $20,026,000	**$25,975,000**	**+$5,949,000**
Support was provided for infrastructure and maintenance of facilities, core competencies in isotope production and development, and for the NIDC. The maintenance of aging facilities continued to be a funding priority to maintain isotope production capabilities. Funding for program investments and production of particular isotopes was informed by the NSAC's updated long-range plan for the Isotope Program (completed in FY 2015) and the Federal workshop held in the fall of 2016.	Funding supports mission readiness of the isotope production facilities and the most critical core competencies in isotope production and development, ensuring that isotope orders for cancer therapy and other commitments are reliably met. NIDC activities will support the effective interfaces with the growing stakeholder community. Funding will provide mission readiness of the newly commissioned ESIPP for the production of important enriched stable isotopes for the nation. In FY 2019, funding will also provide to produce stable isotopes for next generation QIS-driven technologies. The SIPF MIE will be supported for completion in FY 2023. Funding will support the addition of several new universities into the National University Isotope Production Network, which will emphasize production of astatine-211 for cancer therapy.	Funding is increased for the SIPF MIE with planned completion in FY 2023. Support for the mission readiness of isotope production facilities will be modestly increased to account for additional production capabilities and competencies needed to meet customer commitments. NIDC workforce is modestly increased to address the growing isotope program portfolio. Funding will provide for production of isotopes critical for QIS research and next-generation quantum computing technologies. Funding will be provided to grow the university production network for production of unique isotopes.

Nuclear Physics
Construction

Description

Consistent with the 2015 NSAC Long-Range Plan's highest priority, the FY 2019 Request includes funding to capitalize on NP's prior scientific facilities investments. Funding in this subprogram provides for design and construction of scientific research facilities needed to meet overall objectives of the Nuclear Physics program. NP currently has two ongoing projects, for which only one will be receiving construction line item funding in FY 2019.

The Facility for Rare Isotope Beams (FRIB) at Michigan State University (MSU) will continue construction activities in FY 2019, with a funding request aligned to the current baseline. The project is proceeding on track within the established project baseline and working towards an "early finish," FRIB will provide intense beams of rare isotopes for world-leading research opportunities in nuclear structure, nuclear astrophysics, and fundamental symmetry studies that will advance knowledge of the origin of the elements and the evolution of the cosmos. It offers a facility for exploring the limits of nuclear existence and identifying new phenomena, with the possibility that a broadly applicable theory of the structure of nuclei will emerge. FRIB will provide an essential scientific tool for over 1,400 scientists each year from across academic, industrial and government institutions. The project is funded through a cooperative agreement with MSU and was established as a control point in the FY 2014 appropriation. Prior to that time, funding was provided within the Low Energy subprogram.

The 12 GeV CEBAF Upgrade at TJNAF will enable scientists to address one of the mysteries of modern physics—the mechanism of quark confinement. The project was completed in 2017, on cost and schedule.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Construction $100,000,000	**$75,000,000**	**-$25,000,000**
14-SC-50, Facility for Rare Isotope Beams (FRIB) $100,000,000	**$75,000,000**	**-$25,000,000**
The FY 2017 funding supported conventional construction which resulted in the project achieving Beneficial Occupancy of its buildings in March 2017, approximately ten weeks ahead of schedule. The funds also supported fabrication, assembly, installation and testing of the technical systems including the Front End system, cryomodules, and experimental systems. A technically related achievement in FY 2017 regarding the front end system was that the FRIB project successfully produced its first ion beam from its ARTEMIS electron-cyclotron-resonance (ECR) ion source.	The FY 2019 funding will support the ongoing fabrication, assembly and testing of cryomodules that will also be installed and tested in the newly constructed tunnel. Other technical systems, such as the experimental related systems will also be fabricated, assembled, installed and tested. As the various systems near completion, the linear accelerator commissioning effort will occur to validate their performance according to project requirements.	Funding decreases, as planned, relative to FY 2017. FRIB will proceed on track within the established project baseline.

Nuclear Physics
Performance Measure

In accordance with the GPRA Modernization Act of 2010, the Department sets targets for, and tracks progress toward, achieving performance goals for each program.

	FY 2017	FY 2018	FY 2019
Performance Goal (Measure)	**NP Construction/MIE Cost & Schedule - Cost-weighted mean percentage variance from established cost and schedule baselines for major construction, upgrade, or equipment procurement projects**		
Target	< 10 %	N/A	< 10 %
Result	Met	N/A	TBD
Endpoint Target	Adhering to the cost and schedule baselines for a complex, large scale, science project is critical to meeting the scientific requirements for the project and for being good stewards of the taxpayers' investment in the project.		
Performance Goal (Measure)	**NP Facility Operations - Average achieved operation time of NP user facilities as a percentage of total scheduled annual operation time**		
Target	≥ 80 %	≥ 80 %	≥ 80 %
Result	Met	TBD	TBD
Endpoint Target	Many of the research projects that are undertaken at the Office of Science's scientific user facilities take a great deal of time, money, and effort to prepare and regularly have a very short window of opportunity to run. If the facility is not operating as expected the experiment could be ruined or critically setback. In addition, taxpayers have invested millions or even hundreds of millions of dollars in these facilities. The greater the period of reliable operations, the greater the return on the taxpayers' investment.		
Performance Goal (Measure)	**NP Nuclear Structure - Conduct fundamental research to discover, explore, and understand all forms of nuclear matter.**		
Target	Demonstrate the capability to extend the sensitivity of searches for neutrinoless double-beta decay by at least a factor of 5.	Perform measurements in experimental halls with CEBAF to enhance our understanding of the QCD structure of nuclei and hadronic matter.	Initiate a search for a Critical Point in the Phase Diagram of Nuclear Matter.
Result	Met	TBD	TBD
Endpoint Target	Increase the understanding of the existence and properties of nuclear matter under extreme conditions, including that which existed at the beginning of the universe		

Nuclear Physics
Capital Summary ($K)

	Total	Prior Years	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Capital Operating Expenses Summary						
Capital equipment	n/a	n/a	13,400	—	9,887	-3,513
General plant projects (GPP)	n/a	n/a	1,000	—	0	-1,000
Accelerator improvement projects (AIP)	n/a	n/a	4,608	—	1,504	-3,104
Total, Capital Operating Expenses	**n/a**	**n/a**	**19,008**	**—**	**11,391**	**-7,617**
Capital Equipment						
Gamma-Ray Energy Tracking Array (GRETA) MIE	52,000–67,000[b]	n/a	500	—	2,500	+2,000
Stable Isotope Production Facility (SIPF) MIE	9,500–10,500	n/a	2,500	—	5,000	+2,500
Super-PHENIX (sPHENIX) MIE[c]	29,000-35,000	n/a	—	—	1,200	+1,200
Total Non-MIE Capital Equipment	n/a	n/a	10,400	—	1,187	-9,213
Total, Capital Equipment	**n/a**	**n/a**	**13,400**	**—**	**9,887**	**-3,513**
General Plant Projects						
General plant projects under $5 million TEC	n/a	2,200	1,000	—	0	-1,000
Accelerator Improvement Projects (AIP)						
RHIC Low Energy Electron Cooling	8,300	7,000	1,300	—	0	-1,300
Other projects under $5 million TEC	n/a	3,652	3,308	—	1,504	-1,804
Total, Accelerator Improvement Projects	**n/a**	**10,652**	**4,608**	**—**	**1,504**	**-3,104**

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown.

[b] Total Project Cost range

[c] sPHENIX MIE will be funded through existing operations funding which would typically be used to operate the previous version of the detector, PHENIX; no new funds are required.

Major Items of Equipment Descriptions

Low Energy Nuclear Physics

The *Gamma-Ray Energy Tracking Array (GRETA) detector* directly supports the NP mission by addressing the goal to understand the structure of nuclear matter, the processes of nuclear astrophysics, and the nature of the cosmos. A successful implementation of this detector will represent a major advance in gamma-ray tracking detector technology that will impact nuclear science, as well as detection techniques in homeland security and medicine. GRETA will provide unprecedented gains in sensitivity, addressing several high priority scientific topics, including how weak binding and extreme proton-to-neutron asymmetries affect nuclear properties and how the properties of nuclei evolve with changes in excitation energy and angular momentum. GRETA will provide transformational improvements in efficiency, peak-to-total ratio and higher position resolution than the current generation of detector arrays. In particular, the capability of reconstructing the position of the interaction with millimeter resolution is needed to fully exploit the physics opportunities of FRIB. Without GRETA, FRIB will rely on existing instrumentation. In that event, beam-times necessary for the proposed experiments will be expanded significantly, and some proposed experiments will not be feasible at all. CD-0 for GRETA was approved in September 2015 with an estimated Total Project Cost of $52,000,000–$67,000,000. CD-1 was obtained in September FY 2017. The FY 2019 Request for GRETA of $2,500,000 is the third year of Total Estimated Cost (TEC) funding. The Total Project Cost Range will be re-evaluated in FY 2019 to consider changes in the planned funding profile.

Isotope Development and Production for Research and Applications

The *Stable Isotope Production Facility (SIPF).* The DOE Isotope Program has invested funds since 2009 to develop stable isotope separation technology at ORNL, first identified as a high priority by the NSAC Subcommittee on Isotopes in 2009. NP completed an R&D effort in 2017, which has resulted in a prototype capability to produce small research quantities of enriched stable isotopes. The prototype demonstration has been established in a facility that can be expanded and the resulting capability is completely scalable to produce kilogram quantities of enriched stable isotopes in a cost-effective manner. There is a high demand for a domestic capability to produce enriched stable isotopes for basic research, medical and industrial applications. For example, foreign neutrinoless double beta decay experiments in nuclear physics and dark matter experiments in high-energy physics are interested in kg quantities of enriched stable isotopes, which are not available in the U.S. The accelerator production route for Mo-99, a critical medical isotope for cardiac imaging, which is being supported by NNSA, relies on a feedstock of enriched Mo isotopes, which are also not available domestically. Stable isotopic nuclides of heavier elements are used for agricultural, nutritional, industrial, ecological and computing applications could also be produced. The FY 2017 appropriation initiated this Major Item of Equipment to initiate fabrication of a domestic production facility for full-scale production of stable enriched isotopes to help mitigate the dependence of the U.S. on foreign suppliers and meet the high demands for enriched stable isotopes for the Nation. MIE funding provides infrastructure, and optimizes the design of centrifuges to isotopes of interest. CD-0 was approved September 2015 with an estimated Total Project Cost of $9,500,000–$10,500,000. CD-1 is planned for 2018. The FY 2019 Request of $5,000,000 represents a technically-driven project implementation.

Heavy Ion Nuclear Physics

The *Super Pioneering High Energy Nuclear Interaction Experiment (sPHENIX)* directly supports the Nuclear Physics mission by using precision, high rate jet measurements to further characterize the quark-gluon plasma (QGP) discovered at RHIC in order to understand the anomalous energy loss observed in the QGP. sPHENIX will enable scientists to study how the near perfect QGP liquid with the lowest shear viscosity ever observed arises from the strongly interacting quarks and gluons from which it is formed. CD-0 was approved September 2016 with an estimated Total Project Cost of $29,000,000 to $35,000,000. CD-1 is planned for 2018. This MIE is funded within the existing funds for RHIC operations. Operating funds that are typically used to maintain and operate the PHENIX detector will be used to upgrade the detector. No new funding is required. sPHENIX adds electron and hadron calorimeters to the existing silicon tracking capabilities and makes use of a recycled solenoid magnet for a cost effective upgrade. The FY 2019 Request for sPHENIX of $1,200,000 is the first year of Total Estimated Cost (TEC) funding.

Nuclear Physics
Construction Projects Summary ($K)

	Total	Prior Years	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
14-SC-50, Facility for Rare Isotope Beams						
DOE TPC	635,500[b]	318,000[c]	100,000	97,200	75,000	-25,000
Total, Construction (TPC) All Construction Projects	**n/a**	**n/a**	**100,000**	**97,200**	**75,000**	**-25,000**

Funding Summary ($K)

	FY 2017 Enacted	FY 2018 Annualized CR[i]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Research	200,015	—	196,587	-3,428
Scientific User Facilities Operations	292,727	—	292,138	-589
Other Facility Operations	21,826	—	25,275	+3,449
Projects				
Major Items of Equipment	4,176	—	8,700	+4,524
Facility for Rare Isotope Beams	100,000	—	75,000	-25,000
Total Projects	104,176	—	83,700	-20,476
Other[d]	3,256	—	2,300	-956
Total Nuclear Physics	**622,000**	**617,776**	**600,000**	**-22,000**

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown.
[b] This is the DOE TPC; MSU's cost share is $94,500,000 bringing the total project cost to $730,000,000. FRIB is funded with operating dollars through a Cooperative Agreement financial assistance award with a work breakdown structure (WBS) that is slightly different from typical federal capital assets. The WBS totals $730,000,000 including MSU's cost share. Because the WBS scope is not pre-assigned to DOE or MSU funds, DOE's baseline of $635,500,000 cannot be broken down between TEC and OPC.
[c] A portion of the PY funding was provided within the Low Energy subprogram. The FY 2014 appropriation established FRIB as a control point.
[d] Includes SBIR/STTR funding.

Scientific User Facility Operations ($K)

The treatment of user facilities is distinguished between two types: TYPE A facilities that offer users resources dependent on a single, large-scale machine; TYPE B facilities that offer users a suite of resources that is not dependent on a single, large-scale machine.

Definitions:
Achieved Operating Hours – The amount of time (in hours) the facility was available for users.

Planned Operating Hours –
- For Past Fiscal Year (PY), the amount of time (in hours) the facility was planned to be available for users.
- For Current Fiscal Year (CY), the amount of time (in hours) the facility is planned to be available for users.
- For the Budget Fiscal Year (BY), based on the proposed budget request the amount of time (in hours) the facility is anticipated to be available for users.

Optimal Hours – The amount of time (in hours) a facility would be available to satisfy the needs of the user community if unconstrained by funding levels.

Percent of Optimal Hours – An indication of utilization effectiveness in the context of available funding; it is not a direct indication of scientific or facility productivity.
- For BY and CY, Planned Operating Hours divided by Optimal Hours (OH) expressed as a percentage
- For PY, Achieved Operating Hours divided by Optimal Hours.

Unscheduled Downtime Hours – The amount of time (in hours) the facility was unavailable to users due to unscheduled events. NOTE: For type "A" facilities, zero Unscheduled Downtime Hours indicates Achieved Operating Hours equals Planned Operating Hours.

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
TYPE A FACILITIES				
CEBAF (TJNAF)[b]	**$111,076**	**—**	**$108,767**	**-$2,309**
Number of Users	1,597	—	1,600	+3
Achieved operating hours	2,191	—	N/A	N/A
Planned operating hours	2,190	—	2,035	-155

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown.
[b] During FY 2017, the planned operating hours and optimal hours include 330 hours of operations (commissioning) that are supported from 12 GeV CEBAF Upgrade OPC funding, or pre-ops, that are part of the project TPC. FY 2018 is the first year of operations after project completion; optimal hours increase in FY 2018 and FY 2019 as operational experience is gained.

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
TYPE A FACILITIES				
Optimal hours	3,330	—	3,940	+610
Percent optimal hours	65.8%	—	51.6%	-14.2%
Unscheduled downtime hours			N/A	
RHIC (BNL)	**$181,921**	**—**	**$178,162**	**-$3,659**
Number of Users	985	—	985	0
Achieved operating hours	2,631	—	N/A	N/A
Planned operating hours	2,640	—	2,795	+155
Optimal hours	4,100	—	4,100	0
Percent optimal hours	64.2%	—	68.2%	+4.0%
Unscheduled downtime hours			N/A	
ATLAS (ANL)	**$23,946**	**—**	**$17,695**	**-$6,251**
Number of Users	231	—	272	+41
Achieved operating hours	5,468	—	N/A	N/A
Planned operating hours	5,300	—	5,300	0
Optimal hours	6,600	—	6,600	0
Percent optimal hours	82.8%	—	80.3%	-2.5%
Unscheduled downtime hours			N/A	
FRIB (MSU)	**$0**	**—**	**$4,000**	**+$4,000**
Number of Users	—	—	N/A	N/A
Achieved operating hours	—	—	N/A	N/A
Planned operating hours	—	—	N/A	N/A
Optimal hours[a]	—	—	N/A	N/A
Percent optimal hours	—	—	N/A	N/A
Unscheduled downtime hours	—	—	N/A	N/A
Total Scientific User Facility Operations	**$316,943**	**—**	**$291,834**	**-$25,109**

[a] ATLAS was able to achieve 103.2% of the planned operating hours in FY 2017 as a result of very high reliability.

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
TYPE A FACILITIES				
Number of Users	2,813	—	2,857	+44
Achieved operating hours	10,290	—	N/A	N/A
Planned operating hours	10,130	—	10,130	0
Optimal hours	14,030	—	14,640	+610
Percent of optimal hours[a]	66.2%	—	63.3%	-2.9%
Unscheduled downtime hours				

Scientific Employment

	FY 2017 Enacted	FY 2018 Annualized CR[b]	FY 2019 Request	FY 2019 vs FY 2017
Number of permanent Ph.D.'s (FTEs)	802	—	757	-45
Number of postdoctoral associates (FTEs)	355	—	335	-20
Number of graduate students (FTEs)	507	—	481	-26
Other[c]	1,056	—	979	-77

[a] For total facilities only, this is a "funding weighted" calculation FOR ONLY TYPE A facilities: $\frac{\sum_1^n[(\%OH\ for\ facility\ n)\times(funding\ for\ facility\ n\ operations)]}{Total\ funding\ for\ all\ Type\ A\ facility\ operations}$

[b] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown.

[c] Includes technicians, engineers, computer professionals, and other support staff.

14-SC-50, Facility for Rare Isotope Beams (FRIB)
Michigan State University (MSU), East Lansing, MI
Project is for a Cooperative Agreement

1. Significant Changes and Summary

Significant Changes
This Project Data Sheet (PDS) is an update of the FY 2018 PDS and does not include a new start for FY 2019.

Summary
The most recent approved Critical Decision (CD) for the Facility for Rare Isotope Beams (FRIB) project is CD-3B, Approve Start of Construction of the Accelerator and Experimental Systems, which was approved on August 26, 2014, with a DOE Total Project Cost (TPC) of $635,500,000, and a scheduled CD-4 by 3Q FY 2022. Michigan State University (MSU) is providing an additional cost share of $94,500,000, bringing the total project cost to $730,000,000. Start of civil construction officially began in March 2014, and technical construction began in August 2014. Since the start of the civil and technical construction, multiple independent project assessments have determined the project is proceeding on track within the established project baseline. There are no changes in the project's scope since the establishment of the project's baseline.

FRIB is funded through a cooperative agreement financial assistance award with MSU per 10 CFR 600, and the project is required by this agreement to follow the principles of the DOE Order 413.3B. Funding tables contained in sections 3, 5, and 6 of this PDS differ slightly in how the baseline is presented from a traditional PDS for a federal capital asset construction project in that they include the MSU cost share. The table in section 7, Schedule of Appropriation Requests, displays only DOE funding.

A Federal Project Director with certification level 4 has been assigned to this project and approves this PDS.

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3A	CD-3B	D&D Complete	CD-4
FY 2011	2/9/2004		4Q FY 2010	TBD	TBD	TBD	TBD	N/A	FY 2017–2019
FY 2012	2/9/2004		9/1/2010	4Q FY 2012	TBD	TBD	TBD	N/A	FY 2018–2020
FY 2013	2/9/2004		9/1/2010	TBD	TBD	TBD	TBD	N/A	TBD
FY 2014	2/9/2004		9/1/2010	3Q FY 2013	TBD	3Q FY 2013	TBD	N/A	TBD
FY 2015	2/9/2004		9/1/2010	8/1/2013	4Q FY 2014	8/1/2013	4Q FY 2014	N/A	3Q FY 2022
FY 2016	2/9/2004	9/1/2010	9/1/2010	8/1/2013	8/26/2014[a]	8/1/2013	8/26/2014	N/A	3Q FY 2022
FY 2017	2/9/2004	9/1/2010	9/1/2010	8/1/2013	8/26/2014[a]	8/1/2013	8/26/2014	N/A	3Q FY 2022
FY 2018	2/9/2004	9/1/2010	9/1/2010	8/1/2013	8/26/2014	8/1/2013	8/26/2014	N/A	3Q FY 2022
FY 2019	2/9/2004	9/1/2010	9/1/2010	8/1/2013	8/26/2014	8/1/2013	8/26/2014	N/A	3Q FY 2022

CD-0 – Approve Mission Need
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline

[a] This date represents when the design was substantially complete to allow the start of technical construction (CD-3B). A limited amount of design effort continued through 4Q FY 2017.

CD-3A – Approve Start of Civil Construction
CD-3B – Approve Start of Technical Construction
CD-4 – Approve Start of Operations or Project Closeout
D&D Complete – Completion Demolition & Decontamination

3. Project Cost History[a]

(dollars in thousands)

	Design/ Construction	R&D/Conceptual Design/NEPA	Pre-Operations	Total TPC	Less MSU Cost Share	DOE TPC
FY 2015	655,700	24,600	49,700	730,000	-94,500	635,500
FY 2016	655,700	24,600	49,700	730,000	-94,500	635,500
FY 2017	655,700	24,600	49,700	730,000	-94,500	635,500
FY 2018	655,700	24,600	49,700	730,000	-94,500	635,500
FY 2019	655,700	24,600	49,700	730,000	-94,500	635,500

4. Project Scope and Justification

Scope
FRIB scope includes the design, construction, fabrication, assembly, testing, and commissioning of the civil and technical scope that will enable high intensity primary beams of stable isotopes to be accelerated up to a minimum energy of 200 MeV per nucleon by a superconducting linear accelerator (linac) capable of delivering 400 kW of beam power at full energy. The scope also includes the capability for secondary beams of rare isotopes to be produced "in-flight" and separated from unwanted fragments by magnetic analysis. In support of these capabilities, the civil construction portion includes a structure of approximately 220,000 square feet that will house the linac tunnel, target high bay area, linac support area, and cryoplant area. The technical scope includes a 2K/4.5K cryogenics plant, linac front end, cryomodules, and experimental systems.

As contractually required under the financial assistance award agreement, FRIB is being constructed in accordance with the project management principles in DOE Order 413.3B, Program and Project Management for the Acquisition of Capital Assets, and all appropriate project management requirements have been met.

Justification
The science which underlies the FRIB mission is a core competency of nuclear physics: understanding how protons and neutrons combine to form various nuclear species; understanding how long chains of different nuclear species survive; and understanding how one nuclear species decays into another and what is emitted when that happens. Forefront knowledge and capability in this competency is essential, both for U.S. leadership in this scientific discipline and to provide the knowledge and workforce needed for numerous activities and applications relevant to national security and economic competitiveness.

FRIB will provide intense beams of rare isotopes for a wide variety of studies in nuclear structure, nuclear astrophysics, and other topics in nuclear physics. This facility will enable the study of the origin of the elements and the evolution of the cosmos, and offers an opportunity for exploring the limits of nuclear existence and identifying new phenomena, with the possibility that a more broadly applicable theory of nuclei will emerge. The facility will offer new glimpses into the origin of the elements, leading to a better understanding of key issues by creating exotic nuclei that, until now, have existed only in nature's most spectacular explosion, the supernova.

[a] Because this project is funded with operating dollars through a financial assistance award, its baseline is categorized through a work breakdown structure (WBS), which is slightly different from typical federal capital assets. Note that the project's WBS totals $730,000,000 including MSU's cost share. The WBS scope is not pre-assigned to DOE or MSU funds.

FRIB is optimized to produce large quantities of a wide variety of rare isotopes by breaking stable nuclei into rare isotopes. High intensity primary beams of stable isotopes are produced in Electron Cyclotron Resonator ion sources and accelerated up to a minimum energy of 200 MeV per nucleon by a superconducting linear accelerator capable of delivering 400 kW of beam power at full energy. Secondary beams of rare isotopes are produced "in-flight" and separated from unwanted fragments by magnetic analysis. These rare isotope beams are delivered to experimental areas or stopped in a suite of ion-stopping stations where they can be extracted and used for experiments at low energy, or reaccelerated for astrophysical experiments or for nuclear structure experiments. The project includes the necessary infrastructure and support facilities for operations and the 1,000-person user community.

Key Performance Parameters

System	Parameter	Performance Criteria
Accelerator System	Accelerate heavy-ion beam	Measure FRIB driver linac Argon-36 beam with energy larger than 200 MeV per nucleon and a beam current larger than 20 pico nano amps (pnA)
Experimental Systems	Produce a fast rare isotope beam of Selenium-84	Detect and identify Selenium-84 isotopes in FRIB fragment separator focal plane
	Stop a fast rare isotope beam in gas and reaccelerate a rare isotope beam	Measure reaccelerated rare isotope beam energy larger than 3 MeV per nucleon
Conventional Facilities	Linac tunnel	Beneficial occupancy of subterranean tunnel structure of approximately 500 feet path length (minimum) to house FRIB driver linear accelerator
	Cryogenic helium liquefier plant—building and equipment	Beneficial occupancy of the cryogenic helium liquefier plant building and installation of the helium liquefier plant complete
	Target area	Beneficial occupancy of target area and one beam line installed and ready for commissioning

5. Financial Schedule[a]

	(dollars in thousands)		
	Appropriations	Obligations	Costs[b]
DOE Total Project Cost (TPC)			
FY 2009	7,000	7,000	4,164
FY 2010	12,000	12,000	13,283
FY 2011	10,000	10,000	11,553
FY 2012	22,000	22,000	18,919
FY 2013	22,000	22,000	20,677
FY 2014[c]	55,000	55,000	48,369
FY 2015	90,000	90,000	79,266
FY 2016	100,000	100,000	121,769
FY 2017	100,000	100,000	100,000
FY 2018	80,000	80,000	80,000
FY 2019	75,000	75,000	75,000

[a] The funding profile represents DOE's requested portion, which is less than the current baselined TPC. This will be updated once a re-baseline effort is complete.
[b] Costs through FY 2017 reflect actual costs; costs for FY 2018 and the outyears are estimates.
[c] The first project data sheet submitted for FRIB was in the FY 2015 Congressional Budget Request. It was established as a control point in the FY 2014 appropriation. Funding for the project in FY 2013 and prior years was provided within the Low Energy subprogram.

	Appropriations	Obligations	Costs[b]
	(dollars in thousands)		
FY 2020	57,200	57,200	47,200
FY 2021	5,300	5,300	10,300
FY 2022	0	0	5,000
Total, DOE TPC	635,500	635,500	635,500

6. Details of Project Cost Estimate[a]

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
	(dollars in thousands)		
Design & Construction			
Management and Support	37,153	39,268	35,400
Conventional Facilities	208,100	208,201	165,300
Accelerator Systems	289,726	282,974	241,400
Experimental Systems	74,207	67,175	55,000
Contingency (DOE Held)	46,564	58,132	158,650
Total, Design & Construction	655,750	655,750	655,750
Other Costs			
Conceptual Design/Tech R&D/NEPA	24,641	24,640	24,600
Pre-ops/Commissioning/Spares	34,659	34,658	35,500
Contingency (DOE Held)	14,950	14,952	14,150
Total, Other Costs	74,250	74,250	74,250
Total, TPC	TBD	730,000	730,000
Less MSU Cost Share	-94,500	-94,500	-94,500
Total, DOE TPC	635,500	635,500	635,500
Total, Contingency (DOE Held)	61,514	73,084	172,800

7. Schedule of Appropriation Requests[b]

(Dollars in Thousands)

		Prior Years	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	Outyears	Total
FY 2011	TPC	29,000	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
FY 2012	TPC	59,000	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
FY 2013	TPC	73,000	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
FY 2014	TPC	128,000	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
FY 2015 PB[c]	TPC	218,000	100,000	100,000	97,200	75,000	40,000	5,300	0	635,500
FY 2016	TPC	218,000	100,000	100,000	97,200	75,000	40,000	5,300	0	635,500

[a] This section shows a breakdown of the total project cost of $730,000,000 as of 11/30/2017, which includes MSU's cost share. The scope of work is not pre-assigned to DOE or MSU funds.
[b] The funding profile represents DOE's portion of the baselined TPC to be provided through federal appropriations.
[c] The Performance Baseline was approved August 1, 2013. The first project data sheet submitted for FRIB was in the FY 2015 Congressional Budget Request. It was established as a control point in the FY 2014 appropriation. Funding for the project prior to that time was provided within the Low Energy subprogram.

(Dollars in Thousands)

		Prior Years	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	Outyears	Total
FY 2017	TPC	218,000	100,000	100,000	97,200	75,000	40,000	5,300	0	635,500
FY 2018	TPC	218,000	100,000	100,000	80,000	75,000	57,200	5,300	0	635,500
FY 2019	TPC	218,000	100,000	100,000	80,000	75,000	57,200	5,300	0	635,500

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	3Q FY 2022
Expected Useful Life (number of years)	20
Expected Future Start of D&D of this capital asset	NA[a]

(Related Funding requirements)

(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Current Total Estimate	Previous Total Estimate	Current Total Estimate	Previous Total Estimate
Operations[b]	90,000	90,000	1,800,000[c]	1,800,000

9. D&D Information

The FRIB project is being constructed at MSU under a cooperative agreement financial assistance award. The one-for-one requirement, which requires the demolition of a square foot of space for every square foot added, is not applicable, since this is not a federal capital acquisition.

10. Acquisition Approach

FRIB project activities will be accomplished following all procurement requirements, which include using fixed-priced competitive contracts with selection based on best value. MSU has contracted for the services of an architect-engineer firm for the design of the conventional facilities. The Driver Linac and Experimental System components will be self-performed by the MSU design staff with assistance from outside vendors and from DOE national laboratories that possess specific areas of unique expertise unavailable from commercial sources. Integration of the conventional facilities with the Driver Linac and Experimental Systems will be accomplished by the MSU FRIB Project Team.

[a] Per the financial assistance award agreement, MSU is responsible for D&D.
[b] Utilities, maintenance, and repair costs are included within the Operations amounts.
[c] The total operations and maintenance (O&M) is estimated at an average annual cost of approximately $90,000,000 (including escalation) over 20 years.

Workforce Development for Teachers and Scientists

Overview

The Workforce Development for Teachers and Scientists (WDTS) program mission is to help ensure that DOE has a sustained pipeline of science, technology, engineering, and mathematics (STEM) workforce. Accomplishing this mission depends on continued support for undergraduate internships and graduate thesis research; administration of the Albert Einstein Distinguished Educator Fellowship for K–12 STEM teachers for federal agencies; and annual, nationwide, middle- and high-school science competitions culminating in the National Science Bowl® in Washington, D.C. These investment activities support the development of the next generation of scientists and engineers to address the DOE mission, administer programs, and conduct research.

WDTS activities rely significantly on DOE's 17 national laboratories and scientific facilities, which employ more than 30,000 individuals with STEM backgrounds. The DOE laboratory system provides access to leading scientists; world-class scientific user facilities and instrumentation; and large-scale, multidisciplinary research programs unavailable in universities or industry. WDTS leverages these assets to develop and train post-secondary students and educators in support of the DOE mission. WDTS experience-based STEM learning opportunity programs enable highly qualified applicants to conduct research at DOE laboratories and facilities in support of the workforce mission.

Highlights of the FY 2019 Request

The FY 2019 Request prioritizes funding for programs that place highly qualified applicants in authentic STEM learning and training experience opportunities at DOE laboratories. It also prioritizes support for the DOE National Science Bowl® (NSB), a signature STEM competition testing middle and high school students' knowledge in science and mathematics. By encouraging students to pursue STEM careers, these programs address the DOE's STEM mission critical workforce pipeline needs required to advance national security and promote American competitiveness.

Description

Activities at the DOE Laboratories

WDTS supports activities such as the Science Undergraduate Laboratory Internships program, the Community College Internships program, the Office of Science (SC) Graduate Student Research Program, and the Visiting Faculty Program. One of the primary goals of these programs is to prepare students to enter STEM careers that are especially relevant to the DOE mission. By providing research experiences at DOE laboratories under the direction of scientific and technical laboratory staff who serve as research advisors and mentors, these activities provide opportunities for participants to engage in research requiring specialized instrumentation; large-scale, multidisciplinary efforts; and/or scientific user facilities. WDTS activities are aligned with the STEM workforce training recommendations of the Federal advisory committees of SC's six research program offices, the strategic objectives of the National Science and Technology Council Committee on STEM Education (CoSTEM) Federal STEM Education 5-Year Strategic Plan,[a] and the Administration's goals for developing a future-focused workforce.[b]

The Science Undergraduate Laboratory Internships (SULI) program places students from two- and four year undergraduate institutions as paid interns in science and engineering research activities at DOE laboratories, working with laboratory staff scientists and engineers on projects related to ongoing research programs. Appointments are for 10 weeks during the summer term and 16 weeks during the fall and spring terms.

The Community College Internships (CCI) program places community college students as paid interns in technological activities at DOE laboratories, working under the supervision of a laboratory technician or researcher. Appointments are for 10 weeks during the summer, fall, and spring terms.

[a] https://www.whitehouse.gov/sites/whitehouse.gov/files/ostp/Federal_STEM_Strategic_Plan.pdf
[b] https://www.whitehouse.gov/sites/whitehouse.gov/files/omb/memoranda/2017/m-17-30.pdf

The Office of Science Graduate Student Research (SCGSR) program goal is to prepare graduate students for STEM careers critically important to the SC mission by providing graduate thesis research opportunities at DOE laboratories. The SCGSR program provides supplemental awards for graduate students to pursue part of their graduate thesis research at a DOE laboratory or facility in areas that address scientific challenges central to the SC mission. U.S. graduate students pursuing Ph.D. degrees in physics, chemistry, materials sciences, non-medical biology, mathematics, computer or computational sciences, or specific areas of environmental sciences aligned with the SC mission are eligible for research awards to conduct part of their graduate thesis research at a DOE laboratory or facility in collaboration with a DOE laboratory scientist. Research award terms range from three months to one year.

The Visiting Faculty Program (VFP) goal is to increase the research competitiveness of faculty members and students at institutions of higher education historically underrepresented in the research community. Through direct collaboration with research staff at DOE host laboratories, VFP appointments provide an opportunity for faculty and their students to develop skills applicable to programs at their home institutions; this helps increase the STEM workforce in DOE science mission areas at institutions historically under-represented within the DOE enterprise. Appointments are in the summer term for 10 weeks.

Albert Einstein Distinguished Educator Fellowship

The Albert Einstein Distinguished Educator Fellowship Act of 1994 charges the Department of Energy (DOE) with administering a fellowship program for elementary and secondary school mathematics and science teachers that focuses on bringing teachers' real-world expertise to government to help inform federal STEM education programs. Selected teachers spend eleven months in a Federal agency or a Congressional office. WDTS manages the Albert Einstein Distinguished Educator Fellowship (AEF) Program for the Federal government. Fellows are supported by DOE and other Federal agencies. Typically, SC supports six Fellows each year; five are placed in Congressional offices and one is placed in SC. Participating agencies have included the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), and the National Oceanic and Atmospheric Administration (NOAA), as well as other DOE offices. The Fellows provide educational expertise, years of teaching experience, and personal insights to these offices to advance science, mathematics, and technology education programs.

National Science Bowl®

The DOE National Science Bowl® is a nationwide academic competition testing students' knowledge in all areas of mathematics and science, including energy. High school and middle school students are quizzed in a fast-paced, question-and-answer format. Approximately 275,000 students have participated in the National Science Bowl® throughout its 27-year history, and it is one of the nation's largest science competitions. The U.S. Department of Energy Office of Science manages the National Science Bowl®, and sponsors the NSB finals competition. Regional competitions rely upon volunteers and are supported by numerous local organizations, both public and private.

The National Science Bowl® regional winning teams receive expenses-paid trips to Washington, D.C. to compete at the National Finals in late April. Competing teams are composed of four students, one alternate, and a teacher who serves as an advisor and coach. SC manages the National Science Bowl®, provides central management of 116 regional events, and sponsors the NSB Finals competition.

In FY 2017, more than 5,100 middle school students from 651 schools, and approximately 9,000 high school students from 1,191 schools, participated in the regional competitions, with 48 middle school and 63 high school teams (552 students) participating in the National Finals in Washington, D.C. All 50 U.S. States, the District of Columbia, and Puerto Rico were represented at regionals. More than 5,000 volunteers also participate in the local and national competitions.

The National Science Bowl® championship finals are held at the Lisner Auditorium, located on the campus of The George Washington University, and features a live web-streaming broadcast of the event.

The DOE National Science Bowl® is aligned with the CoSTEM Federal STEM Education 5-Year Strategic Plan priority investment area for STEM engagement.

Technology Development and On-Line Application
This activity modernizes on-line systems used to manage applications and review, data collection, and evaluation for WDTS programs. A project to develop, build, and launch new online application and program support systems is progressing to improve program management, execution, and evaluation by WDTS program staff and by DOE laboratory staff. An important component of the systems is the ability to support regular evidence-based evaluation of program performance and impact. A phased approach is being used to develop and build these systems. The final phase involves the development of an analytics and visualization portal, using a data-dictionary and data warehouse of participant information, with an embedded commercially available business intelligence software tool as its analysis and visualization engine. Using this toolset, a scheduled portfolio of reports will be made available to DOE host laboratories to inform them of participant trends and program outcomes. WDTS will use this toolset as part of a data-driven programmatic impact evaluation process, providing means to measure progress and optimize program management.

Evaluation Studies
The Evaluation Studies activity supports work to assess whether WDTS programs meet established goals. This is accomplished through the use of triannual reviews of its program performers, and of WDTS itself. These reviews are either subject matter program peer reviews, or Federal Advisory Committee commissioned Committee of Visitors reviews, respectively. Additional supported activities that measure and assess program performance involve the collection and analysis of data and other materials, including pre- and post-participation questionnaires, participant deliverables, notable outcomes (publications, presentations, patents, *etc*.), and longitudinal participant tracking. In FY 2014, evaluation plans for each WDTS activity were completed. In FY 2015, a data management and analysis plan was completed and a set of technical requirements developed, which were used to define a project plan in FY 2016 and begin its execution to develop and implement a data-driven analysis, visualization, and reporting toolset. In FY 2017, development of this toolset was completed. In FY 2018, a pilot longitudinal study of program outcomes has commenced.

In FY 2014, SC completed a study to identify disciplines in which significantly greater emphasis in workforce training at the graduate student or postdoc levels is necessary to address gaps in current and future SC mission needs. In this study, each Office of Science Federal Advisory Committee, each Associate Director, and each Laboratory Director were asked to provide expert assessment on the following: (i) STEM disciplines not well represented in academic curricula; (ii) STEM disciplines in high demand, nationally and/or internationally, resulting in difficulties in recruitment and retention at U.S. universities and at DOE laboratories; (iii) STEM disciplines for which the DOE laboratories may play a role in providing needed workforce development; and (iv) recommendations for programs at the graduate student or postdoc levels that can address discipline-specific workforce development needs. The outcomes of this study now guide prioritization of eligible SCGSR programmatic research areas and inform WDTS strategic planning. More broadly, the outcomes of this study have identified for SC both program-specific workforce development needs and crosscutting workforce development needs in areas such as computing and computational sciences. Based upon the guiding principles, the availability of relevant research areas for SCGSR is reviewed and updated to address emerging mission workforce area needs.

The Evaluation Studies activity is aligned with the GPRA Modernization Act of 2010, which emphasizes the need for federal programs (including STEM education programs) to demonstrate their effectiveness through rigorous evidence-based evaluation. WDTS works cooperatively with SC programs, other DOE programs, and other federal agencies through CoSTEM to share best practices for STEM program evaluation to ensure the implementation of evaluation processes appropriate to the nature and scale of the program effort.

Outreach
WDTS engages in outreach activities, some in cooperation with other DOE program offices and select federal agencies, to widely publicize its opportunities. The WDTS website[a] is the most widely used tool for prospective program participants to obtain information about WDTS and is the gateway to accessing the online applications for the WDTS programs. To help diversify the applicant pool, outreach is conducted via presentations to targeted key stakeholder groups, and via the web using virtual webinar meetings that highlight the programs, their opportunities, and the WDTS internship experience. A portfolio of recorded webinars is available on the WDTS website.

[a] https://science.energy.gov/wdts

In FY 2016, DOE host laboratories and facilities issued a pilot proposal solicitation to develop and execute outreach activities aimed at recruiting a more diverse spectrum of applicants to WDTS laboratory-based programs. Eligible laboratories and facilities are those that hosted FY 2016 participants in the SULI, CCI, VFP, and/or SCGSR programs. Based upon this pilot and its reported deliverables, a more programmatically focused solicitation was issued in FY 2017 for outreach activities commencing in FY 2018.

The Laboratory Equipment Donation Program has been consolidated under Outreach, and it continues to provide excess laboratory equipment to faculty at non-profit research institutions and post-secondary educational institutions. Through the Energy Asset Disposal System, DOE sites identify excess equipment and colleges and universities can then search for equipment of interest and apply via the website. The equipment is free, but the receiving institution pays for shipping costs. This consolidation does not alter the scope of this activity.

Workforce Development for Teachers and Scientists
Funding ($K)

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Activities at the DOE Laboratories				
Science Undergraduate Laboratory Internships	8,300	—	8,300	0
Community College Internships	1,000	—	1,000	0
Office of Science Graduate Student Research Program	2,500	—	2,500	0
Visiting Faculty Program	1,700	—	1,700	0
Total, Activities at the DOE Laboratories	**13,500**	**—**	**13,500**	**0**
Albert Einstein Distinguished Educator Fellowship	**1,200**	**—**	**1,200**	**0**
National Science Bowl®	**2,900**	**—**	**2,900**	**0**
Technology Development and On-Line Application	**750**	**—**	**550**	**-200**
Evaluation Studies	**600**	**—**	**350**	**-250**
Outreach	**500**	**—**	**500**	**0**
Laboratory Equipment Donation Program	**50**	**—**	**0**	**-50**
Total, Workforce Development for Teachers and Scientists	**19,500**	**19,368**	**19,000**	**-500**

[a]A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

Program Accomplishments

Science Undergraduate Laboratory Internships (SULI) — In FY 2017, approximately 50% of the 780 participants worked on SC supported research projects, which is by far the largest DOE program office-funded research project representation. While all participants work on DOE mission relevant activities, this outcome supports SC research mission relevancy, and illustrates willingness of SC principal investigators to serve as mentors. More than 50 of the FY 2017 participants were from Minority Serving Institutions (MSIs).

Community College Internships (CCI) — In FY 2017, approximately 35% of the participants were from Minority Serving Institutions (MSIs).

Office of Science Graduate Student Research Program (SCGSR) — In FY 2017, with the addition of a placement at the National Energy Technology Laboratory, SCGSR had participants at all 17 DOE national laboratories. To date, there has been about 260 awardees from 102 graduate institutions across the U.S.

WDTS coordinated with SC's Office of Fusion Energy Sciences to support the DIII-D tokomak user facility to host SCGSR awardees. As an outcome, beginning in FY 2017 DIII-D is a new host site for SCGSR applicants. General Atomics, where DIII-D is sited, has a 20+ year record of hosting undergraduate and graduate students performing research and using DIII-D to train students in plasma and fusion sciences.

Visiting Faculty Program (VFP) — In FY 2017, approximately 50% of the faculty participants were from MSIs.

Albert Einstein Distinguished Educator Fellowship (AEF) — In FY 2017, two of six WDTS sponsored AEF participants held WDTS office appointments. In addition to engaging in WDTS programmatic activities, one of these participants, as a nationally recognized STEM educator, also collaborated with Brookhaven National Laboratory and the Savannah River National Laboratory to apply their expertise to portions of their STEM education outreach activities.

The National Science Bowl® (NSB) — The National Finals of the 27th DOE National Science Bowl® took place in the Washington, DC, area from April 27 – May 1, 2017. The White House Deputy Chief Technology Officer and Senior Advisor, delivered congratulatory remarks to the 63 high schools and 48 middle schools at the finals, and conferred awards to the winning teams.

The NSB's Science Day is a cornerstone event, opening the finals competition with a tradition of attracting prominent speakers, including outstanding researchers from DOE laboratories, who are able to connect workplace experience and relevancy to these students' STEM area studies. Having Science Day speakers from across the DOE laboratory complex is particularly relevant from a workforce mission perspective, as this is often the first time that these students become aware of DOE mission research, and the its national laboratory complex. The 2017 NSB Science Day for high-school finalists had as its theme Quantum Information Sciences (QIS), a rapidly-developing interdisciplinary field, with substantial intersections with the program offices within SC and significant implications for the Nation as a whole.

A new Cyber-Challenge middle school activity successfully replaced the middle school electric car competition. This Cyber-Challenge activity leverages NNSA's *Cybersecurity Workforce Pipeline Consortium* investments, and is based upon activities developed at Lawrence Livermore National Laboratory. The NSB provided an opportunity to develop and test these cybersecurity outreach and training activities at large concurrent participant scales.

Technology Development and On-Line Application — WDTS completed an initial phase of a project to develop and implement a data-dictionary/data-warehouse based analytics and visualization toolset supporting data-driven program evaluation. Completed activities include the development of a participant relational database and data dictionary, selection and implementation of a business intelligence server-side solution using a commercial software package, QlikSense (QlikTech Inc., Radnor, PA) for efficient data analyses, and the development and implementation of a related evaluation toolset and reporting portal.

Evaluation — An external peer review of DOE host labs was completed resulting in updated guidance for the SULI, CCI, and VFP Core Requirements and Model Practices, which will be used by host labs in their updated program Implementation Plans. These plans establish an execution roadmap for host labs to follow as means to achieve the Core Requirements, thereby helping ensure that participants receive a substantially equivalent internship experience regardless of host lab placement, as well as providing a measurement framework for future program reviews and process improvement cycles. A Committee of Visitors (COV) review of WDTS activities implemented at DOE laboratories (*i.e*. SULI, CCI, VFP, and SCGSR) was held in FY 2017, with its final report presented and approved by the Basic Energy Sciences Advisory Committee. The COV report and WDTS responses to the report's recommendations are posted on appropriate SC webpages. The COV found that all programs reviewed as either very good or excellent, and noted that the developed suite of online system tools used to manage applications and their reviews, data collection and archiving, and data evaluation and reporting for WDTS programs greatly enhances program management and oversight efficacy and increases program execution efficiencies at host labs.

Outreach — DOE host laboratories and facilities executed pilot projects aimed at recruiting a more diverse applicant pool to WDTS laboratory-based programs. These projects all targeted recruitment of individuals traditionally underrepresented in STEM and address needs to increase the applicant pool diversity for one or more of the WDTS programs currently implemented at DOE host laboratories and facilities. Based upon outcomes, this pilot is being used to establish a baseline for ongoing outreach activities and future solicitations.

Workforce Development for Teachers and Scientists

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Activities at the DOE Laboratories $13,500,000	**$13,500,000**	**$0**
Science Undergraduate Laboratory Internships ($8,300,000) SULI supported approximately 800 students.	*Science Undergraduate Laboratory Internships ($8,300,000)* SULI will support approximately 800 students.	*Science Undergraduate Laboratory Internships ($0)* No change.
Community College Internships ($1,000,000) CCI supported approximately 100 students.	*Community College Internships ($1,000,000)* CCI will support approximately 100 students.	*Community College Internships ($0)* No change.
Graduate Student Research Program ($2,500,000) The SCGSR program supported approximately 110 graduate students for periods of 3 months to 1 year to conduct a part of their thesis research at DOE laboratories. Targeted priority research areas were informed by SC's workforce training needs studies.	*Graduate Student Research Program ($2,500,000)* The SCGSR program will support approximately 110 graduate students for periods of 3 months to 1 year to conduct a part of their thesis research at DOE laboratories. Targeted priority research areas will be informed by SC's workforce training needs studies.	*Graduate Student Research Program ($0)* No change.
Visiting Faculty Program ($1,700,000) VFP supported approximately 65 faculty and 40 students.	*Visiting Faculty Program ($1,700,000)* VFP will support approximately 65 faculty and 40 students.	*Visiting Faculty Program ($0)* No change.
Albert Einstein Distinguished Educator Fellowship $1,200,000	**$1,200,000**	**$0**
FY 2017 funding supported 6 Fellows.	FY 2019 funding will support 6 Fellows.	No change.
National Science Bowl $2,900,000	**$2,900,000**	**$0**
WDTS sponsored the finals competition and provided central management of 116 regional events, involving 14,300 students from all fifty states, the District of Columbia, Puerto Rico, and the U.S. Virgin Islands.	WDTS will sponsor the finals competition and provide central management of 116 regional events, involving 14,300 students from all fifty states, the District of Columbia, Puerto Rico, and the U.S. Virgin Islands.	No change.

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Technology Development and On-line Application Systems $750,000	**$550,000**	**$-200,000**
Funding continued development and operation of the on-line systems.	Funding will continue development and operation of the on-line systems.	The requested funding prioritizes programmatically required on-line system operations.
Evaluation $600,000	**$350,000**	**$-250,000**
Funding continued support for evaluation activities, including data archiving, curation, and analyses.	Funding will continue support for evaluation activities, including data archiving, curation, and analyses.	The requested funding prioritizes programmatically required evaluation activities.
Outreach $500,000	**$500,000**	**$0**
Funding supported outreach activities to the scientific community targeting Office of Science mission-driven disciplinary workforce needs in the next 5 to 10 years, including additional outreach activity proposal solicitations from DOE host labs and facilities.	Funding will support outreach activities to the scientific community targeting Office of Science mission-driven disciplinary workforce needs in the next 5 to 10 years, including additional outreach activity proposal solicitations from DOE host labs and facilities.	No change. The requested funding prioritizes critical outreach activities at DOE host labs and facilities.
Laboratory Equipment Donation Program $50,000	**$0**	**$-50,000**
Funding supported Laboratory Education Equipment Donation Program (LEDP) activities.	Program is funded in FY 2019 under the Outreach program.	No impact.

Science Laboratories Infrastructure

Overview

The Science Laboratories Infrastructure (SLI) program mission is to support scientific and technological innovation at the Office of Science (SC) laboratories by funding and sustaining general purpose infrastructure and fostering safe and environmentally responsible operations. The main priorities of the SLI program are improving SC's existing physical assets and funding new cutting-edge facilities that enable emerging science opportunities. The SLI program also funds Payments in Lieu of Taxes (PILT) to local communities around the Argonne, Brookhaven, and Oak Ridge National Laboratories.

SC laboratories conduct rigorous and consistent analyses of the condition, utilization, and functionality of the facilities and infrastructure that are the most critical to mission accomplishment. SC works with each of its laboratories to use these assessments in developing comprehensive Campus Strategies, which are integrated into the SC Annual Laboratory Planning process. Each laboratory's Campus Strategy identifies activities and infrastructure investments (e.g., Line-Item Construction, General Plant Projects [GPPs]) required to achieve the core capabilities and scientific vision for the laboratory. SC leadership uses these Campus Strategies to establish the corporate facilities and infrastructure priorities, which form the basis for SLI Budget Requests.

A thorough analysis of SC's physical assets reveals the continued need to focus on our deferred maintenance backlog as well as the inadequacies of SC facilities, including the core infrastructure across its laboratory campuses. In FY 2016, SC invested over $475 million dollars in needed maintenance, repair, and upgrades of general purpose infrastructure. These investment activities were from a variety of funding sources, including federal appropriations for line-item construction projects and GPPs, as well as overhead-funded investments in institutional GPP work and routine maintenance and repair. The SLI program provides two important pieces of this overall strategy—line-item construction projects and a suite of infrastructure support investments that focus on laboratory core infrastructure and operations.

Highlights of the FY 2019 Request

The SLI program continues to focus on improving infrastructure across the SC national laboratory complex. The FY 2019 Request includes funding for two new construction starts, the Electrical Capacity and Distribution Capability project at the Argonne National Laboratory (ANL) and the Science User Support Center at the Brookhaven National Laboratory (BNL). The Electrical Capacity and Distribution Capability project at ANL will retire major risks associated with capacity limitations and single points of failure, and will support the anticipated FY 2021 electrical demands of the exascale computing program, as well as current mission critical operations in multiple facilities across the laboratory complex. The Science User Support Center at BNL will collocate support organization into a single facility, and provide modern, efficient, and collaborative space to support world-class research.

The Request supports five on-going construction projects: the Materials Design Laboratory project at ANL, the Integrative Genomics Building project at Lawrence Berkeley National Laboratory (LBNL), the Core Facility Revitalization project at BNL, the Integrated Engineering Research Center at Fermi National Accelerator Laboratory (FNAL), and the Energy Sciences Capability project at Pacific Northwest National Laboratory (PNNL). These ongoing projects will provide new laboratory buildings, renovated facilities, and upgraded utilities and are proceeding towards on-time completion within budget. The FY 2019 Request includes funding for general purpose infrastructure projects that will address critical core infrastructure issues across SC laboratories and facilities. Funding requested in FY 2019 supports modernizing water and sewer utilities at ANL, removing excess facilities at FNAL, and enhancing and updating ALS Support HVAC systems and utiltiies at LBNL. Lastly, the Request provides funding to continue de-inventory, removal, and transfer of nuclear material at Building 350, formerly the site of the New Brunswick Laboratory (NBL) on the ANL campus.

Science Laboratories Infrastructure
Funding ($K)

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Infrastructure Support	**66,549**	**66,097**	**48,671**	**-17,878**
Construction				
19-SC-71, Science User Support Center, BNL	–	–	2,000	+2,000
19-SC-72, Electrical Capacity and Distribution Capability, ANL	–	–	20,000	+20,000
18-SC-71, Energy Sciences Capability, PNNL	–	–	4,000	+4,000
17-SC-71, Integrated Engineering Research Center, FNAL	2,500	2,483	5,000	+2,500
17-SC-73, Core Facility Revitalization, BNL	1,800	1,788	13,632	+11,832
15-SC-76, Materials Design Laboratory, ANL	19,590	19,457	20,000	+410
15-SC-77, Photon Science Laboratory Building, SLAC	20,000	19,864[b]	–	-20,000
15-SC-78, Integrative Genomics Building, LBNL	19,561	19,428	13,549	-6,012
Total, Construction	**63,451**	**63,020**	**78,181**	**+14,730**
Total, Science Laboratories Infrastructure	**130,000**	**129,117**	**126,852**	**-3,148**

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).
[b] Photon Science Laboratory Building at SLAC received final year of funding in FY 2017.

Science Laboratories Infrastructure
Explanation of Major Changes ($K)

	FY 2019 Request vs FY 2017 Enacted
Science Laboratories Infrastructure	
Infrastructure Support: Funding continues to support PILT, nuclear facilities at Oak Ridge National Laboratory (ORNL) and landlord responsibilities at the Oak Ridge Reservation. Support continues for critical core infrastructure at SC laboratories, the Oak Ridge Institute for Science and Education (ORISE), and the Office of Scientific and Technical Information (OSTI). The Request includes funding for the de-inventory, removal, and transfer of nuclear material at Building 350, formerly the site of NBL on the ANL campus.	-17,878
Construction: Funding supports five on-going line-item projects at Argonne National Laboratory (ANL), Lawrence Berkeley National Laboratory, Fermi National Accelerator Laboratory, Brookhaven National Laboratory (BNL), and Pacific Northwest National Laboratory and two new line-item projects at BNL and ANL.	+14,730
Total, Science Laboratories Infrastructure	**-3,148**

Program Accomplishments

Since FY 2006, the SLI program has invested over $770 million in infrastructure and has successfully completed 11 line- item projects while garnering eight DOE Secretary's Achievement Awards. These investments occurred following an FY 2006 SC decision to initiate a major effort to modernize infrastructure across the SC-stewarded laboratory complex. With these investments, the SLI program constructed more than 900,000 gross square feet (gsf) of new space and modernized nearly 400,000 gsf of existing space. As a result, an estimated 2,300 laboratory users and researchers now occupy newly constructed and/or modernized buildings that better support scientific and technological innovation in a collaborative environment.

The *Materials Design Laboratory project at ANL* and the *Integrative Genomics Building project at LBNL*. Construction has started and foundation work has been completed for both of these projects.

Removal of Hazard Category 3 Materials from the New Brunswick Laboratory (NBL). The SLI program successfully transferred nuclear material from NBL at the ANL to bring the facility to a state below Hazard Category 3. The SLI program continues to transfer the remaining nuclear materials from NBL so the building can eventually be renovated and re-purposed.

The *Photon Science Laboratory Building (SLAC).* This project represents a partnership between Stanford University and the Department of Energy to mutually benefit and reduce the capital investment by both parties. In November 2016, Stanford University completed the construction of the building shell and officially turned over the building to DOE. In March 2016, DOE began constructing the fit-out of a portion of the building shell for SLAC use, which will provide a combination of modernized office and laboratory space to enhance science collaboration, productivity, efficiency, and functionality to support simulation, theory and modeling, and materials synthesis and characterization at SLAC.

Core General Plant Project upgrades across SC Laboratories. The SLI program funded a suite of investments in core infrastructure whose efficiency and reliability are critical to the success of SC missions. To date, SLI funded the replacement of nine 12kV -480 V substations (K-subs) serving the SLAC Linac, upgraded approximately 1.5 miles of high voltage electrical cable and associated substation equipment at ANL, and upgraded electrical distribution systems at Ames National Laboratory. At FNAL, SLI funded renovations to Wilson Hall that will provide for increased collaboration space on two of the 15 floors in the lab's largest building and correct deficiencies on the building exterior. At LBNL, SLI funded the enhancement of HVAC systems by adding capacity to provide more cooling for approximately 130,000 square feet and updating controls to approximately 140,000 square feet. Lastly, at the Thomas Jefferson National Accelerator Facility, SLI funded the replacement of the 27 year old SC1 cold box in the Central Helium Liquifier plant serving the accelerator.

Science Laboratories Infrastructure
Infrastructure Support

Description
This subprogram funds infrastructure support investments that focus on laboratory core infrastructure and operations. Continuing Investments in core infrastructure (e.g., utility systems, site-wide services, and general-purpose facilities) ensure facilities and utilities are upgraded when they approach end-of-life, systems are improved to increase reliability and performance, and excess space is removed so that it no longer requires operation and maintenance funding. Without this type of investment, SC laboratories would not be able to keep up with the pace of needed upgrades and repairs. Activities include GPP upgrades at various laboratories, general infrastructure support, de-inventory of nuclear material in Building 350 (formerly NBL) at ANL, and support for the nuclear facilities at ORNL.

This subprogram also funds PILT to local communities around ANL, BNL, and ORNL, as well as stewardship-type needs (e.g., roads and grounds maintenance) across the Oak Ridge Reservation.

Funding ($K)

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Infrastructure Support				
Facilities and Infrastructure	32,603	32,382	30,724	-1,879
Nuclear Operations	26,000	25,823	10,000	-16,000
Oak Ridge Landlord	6,182	6,140	6,434	+252
Payments in Lieu of Taxes	1,764	1,752	1,513	-251
Total, Infrastructure Support	**66,549**	**66,097**	**48,671**	**-17,878**

Facilities and Infrastructure
This activity funds infrastructure support investments that focus on laboratory core infrastructure and operations. SC laboratories conduct rigorous condition assessments of their core infrastructure which validate the need for investments in these basic systems that form the backbone of their campuses. Each year, the SLI program continues this focus and collaborates with the SC research programs to review investment needs. This activity also supports general facilities and infrastructure support, as well as operations and maintenance, de-inventory, removal, and transfer of nuclear material in the former NBL building on the site of ANL. SC is working to transfer the DOE Certified Reference Material (CRM) program, formerly operated out of the NBL building, to NNSA.

Nuclear Operations
To support critical DOE nuclear operations, this Request includes funding to manage ORNL's nuclear facilities (i.e., Buildings 7920, 7930, 3525, and 3025E) to current expectations, in accordance with federal regulations and DOE Directives. This funding supports critical nuclear complex equipment and infrastructure to support compliance with safety standards.

Oak Ridge Landlord
This funding supports landlord responsibilities, including infrastructure for the 24,000 acre Oak Ridge Reservation and DOE facilities in the city of Oak Ridge, Tennessee. Activities include maintenance of roads, grounds, and other infrastructure; support and improvement of environmental protection, safety, and health; and PILT to Oak Ridge communities.

Payments in Lieu of Taxes
Funding within this activity supports SC stewardship responsibilities for PILT. The Department is authorized to provide discretionary payments to state and local government authorities for real property that is not subject to taxation because it

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

is owned by the United States Federal Government and operated by the Department. Under this authorization, PILT is provided to communities around the ANL and BNL to compensate for lost tax revenues for land removed from local tax rolls. PILT payments are negotiated between the Department and local governments based on land values and tax rates.

Science Laboratories Infrastructure
Infrastructure Support

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Infrastructure Support $66,549,000	**$48,671,000**	**-$17,878,000**
Facilities and Infrastructure $32,603,000	**$30,724,000**	**-$1,879,000**
Funding supported investments in critical core infrastructure at SLAC, ANL, FNAL, general infrastructure support at OSTI and ORISE, and supported operations, de-inventory and removal of nuclear material at the former NBL Building at ANL.	The FY 2019 Request will continue to support de-inventory and removal of nuclear material at the former NBL Building at ANL, and critical core infrastructure at SC laboratories, ORISE, and OSTI.	Funding decreases overall as a result of completed core infrastructure projects at SLAC, ANL, and FNAL. Funding increases in FY 2019 to support de-inventory, removal, and transfer of nuclear material at Building 350, formerly the site of NBL on the ANL campus. Funding for general purpose infrastructure at OSTI and ORISE is no longer provided on an annual basis as funding for infrastructure at these sites is now included as part of the core infrastructure planning process.
Nuclear Operations $26,000,000	**$10,000,000**	**-$16,000,000**
Funding supported critical nuclear operations and provides funding to manage ORNL's nuclear facilities.	The FY 2019 Request will continue to support critical nuclear operations and provides funding to manage ORNL's nuclear facilities.	Funding supports the most critical nuclear operations efforts at ORNL.
Oak Ridge Landlord $6,182,000	**$6,434,000**	**+$252,000**
Funding supported landlord responsibilities across the Oak Ridge Reservation. Activities include maintenance of roads, grounds, and other infrastructure; support and improvement of environmental protection, safety, and health; and PILT to Oak Ridge communities.	The FY 2019 Request will provide funding to support landlord responsibilities across the Oak Ridge Reservation. Activities include maintenance of roads, grounds, and other infrastructure; support and improvement of environmental protection, safety, and health; and PILT to Oak Ridge communities.	Funding supports increased PILT requirements at Oak Ridge communities.
Payment in Lieu of Taxes $1,764,000	**$1,513,000**	**-$251,000**
Funding supported PILT payments to communities around ANL and BNL.	The FY 2019 Request will provide funding for PILT payments to communities around ANL and BNL.	Funding reflects anticipated PILT payments in FY 2019.

Science Laboratories Infrastructure
Construction

Description

The SLI Construction program funds line-item projects to maintain and enhance the general purpose infrastructure at SC laboratories. SLI's infrastructure modernization construction projects are focused on the accomplishment of long-term science goals and strategies at each SC laboratory.

The FY 2019 Request includes funding for:

- two new line-item construction projects:
  - Science User Support Center at BNL
  - Electrical Capacity and Distribution Capability project at ANL
- and five ongoing line-item construction projects:
  - Energy Sciences Capability project at PNNL.
  - Integrated Engineering Research Center at FNAL
  - Core Facility Revitalization project at BNL
  - Materials Design Laboratory project at ANL
  - Integrative Genomics Building project at LBNL

<u>Science User Support Center, BNL</u>

BNL user facilities and capabilities supported by DOE and partnering agencies attract over 40,000 visiting scientists, guests, users, and contractors annually to conduct research in a broad range of basic and applied sciences. However, the ability to efficiently process and support the needs of this growing community of researchers is limited by the age, condition, and dispersed nature of BNL's current facilities. The scientific impact of BNL can be expanded by an improved user support building that facilitates improved administrative functions and the availability of accessible conferencing and collaboration facilities. BNL also has many World War II-era structures dispersed around the site that house research support organizations in deteriorated facilities that are no longer sustainable and contribute to operational inefficiencies. Construction of the Science User Support Center will provide convenient and efficient facilities for processing and supporting the users of BNL's premier research facilities by replacing the current substandard, dispersed and inefficient facilities. It will also provide conference facilities to support the collaborative science and research agenda for the user community and BNL scientists.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, *Approve Mission Need,* approved on December 12, 2016. This project has a preliminary total project cost range of $72,000,000 to $96,000,000. The preliminary total project cost is estimated to be $85,000,000.

<u>Electrical Capacity and Distribution Capability, ANL</u>

Mission critical improvements to ANL's high voltage electrical distribution systems are needed to address the anticipated 2021 electrical demands of the exascale computing program as well as current mission critical operations in multiple facilities across the laboratory complex. Elements of ANL's high voltage electrical distribution systems are rated in poor condition due to age, limiting the ability to support the electricity requirements of new and expanding facilities and scientific programs. Much of the main electrical supply infrastructure was constructed in the 1960's and is now beyond its useful life. The Electrical Capacity and Distribution Capability project will improve and expand critical electrical distribution systems to support the electrical capacity growth needed to support the Advanced Scientific Computing Research investments in an exascale-capable supercomputer, as part of the DOE Exascale Computing Initiative. Other SC facilities will also be positively impacted by these critical high voltage electrical and distribution upgrades, including the Advanced Photon Source and the Center for Nanoscale Materials, among others.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, *Approve Mission Need,* approved on September 11, 2017. This project has a preliminary total project cost range of $53,000,000 to $96,000,000. The preliminary total project cost is estimated to be $61,000,000.

Energy Sciences Capability, PNNL

The Chemical and Molecular Sciences capability forms the basis for PNNL's fundamental science programs in catalysis science, condensed phase and interfacial molecular science, computational and theoretical chemistry, geosciences, and separations and analysis. This core capability also has strong ties to the Condensed Matter Physics and Materials Science, Computational Science, and the Applied Mathematics core capabilities. Exercise of this core capability is hampered by many infrastructure capability gaps, including insufficient hood space for catalysis synthesis and collaboration; lack of proper environmental controls for state-of-the-art in situ characterization; limited space to integrate experimental capabilities for visualization supporting research in data analytics, modeling, and simulation, and performance modeling (for the Center for Advanced Technology Evaluation/ASCR related capability); and limited collaboration space for users and strategic partners. Closing these gaps will provide for mission-appropriate utility and infrastructure support systems for PNNL research. It will also significantly improve collaboration among researchers, both on-site and remotely.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, *Approve Mission Need,* approved on December 12, 2016. This project has a preliminary total project cost range of $73,000,000 to $99,000,000. The preliminary total project cost is estimated to be $93,000,000.

Integrated Engineering Research Center, FNAL

The Integrated Engineering Research Center project will construct a scientific user support facility to accommodate increased collaboration and interactions among staff at FNAL, who will in turn be working with scientific collaborators and international partners in the design, construction, and operation of physics experiments.

In May 2014, the Particle Physics Project Prioritization Panel (P5) issued a report that included recommendations to "develop a coherent short- and long-baseline neutrino program hosted at Fermilab" and to "reformulate the long-baseline neutrino program as an internationally designed, coordinated, and funded program with [FNAL] as host." SC and the High Energy Physics (HEP) program accepted the recommendations in the P5 report and are committed to implementing a successful program based on this vision.

Implementing these recommendations will require significantly increased collaboration and interactions among FNAL staff, who will in turn be working with scientific collaborators and international partners in the design, construction, and operation of physics experiments. Currently, staff and their associated manufacturing, assembly, engineering, and technical facilities are scattered among three parts of the campus—the Silicon Detector Complex, the Village, and Wilson Hall. As a result, they are unable to efficiently collaborate on ongoing and planned projects in support of the mission of the laboratory. The Integrated Engineering Research Center will provide FNAL with a collaborative, multi-divisional and interdisciplinary research center. This research center will close existing capability and infrastructure gaps by reducing the overall footprint of outdated facilities, and collocating engineering and associated research staff in a new or renovated facility near the central campus. This approach will complement the ongoing and planned renovations of Wilson Hall by establishing the main campus as the anchor point of the site. It will improve operational efficiency and collaboration because groups working on key projects would be in close proximity. Such a facility will provide technical and engineering staff the necessary environment for interdisciplinary collaboration necessary to establish an international neutrino program and support other HEP science opportunities described in the P5 report.

The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-1, *Approve Alternative Selection and Cost Range*, which was approved on April 18, 2017. The preliminary total project cost is estimated to be $86,000,000.

Core Facility Revitalization, BNL

A significant amount of computation and data storage is currently conducted within the Relativistic Heavy Ion Collider (RHIC) ATLAS Computing Facility (RACF) that is located on the BNL campus. The RACF directly supports RHIC research operations funded by Nuclear Physics (NP) and the US-ATLAS research operations funded by HEP. The RACF also provides mid-scale computing support to other research programs funded by SC, research efforts funded by strategic partners, and computationally-intensive research that indirectly supports the broader SC mission.

The data volume generated by the RHIC experiments and ATLAS is expected to increase three to six times over the next ten years and will require proportional increases in computation and data storage capacities. Almost half of the current RACF computing and data storage facility is expected become functionally obsolete and unable to accommodate future generations of computation and data storage technologies over the next five to ten years. Therefore, the projected capability gaps in computing infrastructure are due to a combination of decreases due to degrading capacities and increases in future requirements of mid-scale computing performed by RACF. Increases in computation and data storage will drive increased requirements for space, power, and cooling of computing facilities. A mission need therefore exists to provide sufficient mid-range computation and data storage capabilities to support to current and planned experiments using RHIC and the ATLAS detectors, and potentially other programs.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-1, *Approve Alternative Selection and Cost Range,* was approved on April 18, 2017. This project has a total project cost range of $68,500,000 to $84,500,000. The preliminary total project cost is estimated to be $74,850,000

Materials Design Laboratory, ANL

The Materials Design Laboratory will support research in materials science in energy and a range of other fields. It will entail constructing a new laboratory office building of approximately 100,000 gsf in size and located adjacent to the recently completed Energy Sciences Building. The existing research buildings at ANL dedicated to this SC research mission are all more than 40 years old, some as old as 55 years. These structures require frequent repair, resulting in interruptions to research activities, and they are unable to meet modern standards for instruments requiring vibration, electromagnetic, and/or thermal stability.

This project is currently in construction and will receive final year of funding in FY 2019. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-3, Approve Start of Construction, on August 12, 2016. The Total Project Cost (TPC) for this project is $96,000,000.

Integrative Genomics Building, LBNL

The Integrative Genomics Building will allow the laboratory to relocate a significant fraction of the research and operations currently located in commercially leased space onto the main LBNL campus. Portions of the biosciences program at LBNL are located off-site, away from the main laboratory, and dispersed across multiple locations up to 20 miles apart. Collocation of these programs will increase the synergy and efficiency of biosciences and other research at LBNL and will provide a state-of-the-art facility for biosciences research in a collaborative environment close to other key LBNL facilities and programs.

This project is currently in construction and will receive final year of funding in FY 2019. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-3, Approve Start of Construction, which was approved on October 7, 2016. The TPC for this project is $91,500,000.

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Construction $63,451,000	**$78,181,000**	**+$14,730,000**
19-SC-71, Science User Support Center, BNL $0	**$2,000,000**	**+$2,000,000**
	Funding will support Project Engineering and Design (PED) activities.	Funding will initiate PED for this new construction project.
19-SC-72, Electrical Capacity and Distribution Capability, ANL $0	**$20,000,000**	**+$20,000,000**
	Funding will support PED and construction activities.	Funding will initiate PED as well as construction for this new project.
18-SC-71, Energy Sciences Capability, PNNL $0	**$4,000,000**	**+$4,000,000**
	Funding will support PED activities.	Funding will support continued PED activities.
17-SC-71, Integrated Engineering Research Center, FNAL $2,500,000	**$5,000,000**	**+$2,500,000**
Funding supported PED activities.	Funding will support PED activities as well as construction activities.	Funding will support PED and construction activities.
17-SC-73, Core Facility Revitalization, BNL $1,800,000	**$13,632,000**	**+$11,832,000**
Funding supported Project Engineering and Design activities.	Funding will support PED activities as well as construction activities.	Funding will support PED and construction activities.
15-SC-76, Materials Design Laboratory, ANL $19,590,000	**$20,000,000**	**+$410,000**
Funding supported on-going construction of the project.	Funding will support completion of construction of this project.	Funding supports on-going construction activities.
15-SC-77, Photon Science Laboratory Building, SLAC $20,000,000	**$0**	**-$20,000,000**
Funding supported completion of construction of the project.	Final year of funding was received in FY 2017.	Final year of funding was received in FY 2017.
15-SC-78, Integrative Genomics Building, LBNL $19,561,000	**$13,549,000**	**-$6,012,000**
Funding supported on-going construction of the project.	Funding will support completion of construction of the project.	The decrease in funding is consistent with the project's baseline funding profile.

Science Laboratories Infrastructure
Capital Summary ($K)

	Total	Prior Years	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Capital Operating Expense Summary						
General Plants Projects						
ALS HVAC System Upgrade at LBNL (TEC $9.0M)	9,000	–	9,000	–	–	-9,000
Electrical Distribution Upgrades at SLAC (TEC $10.0M)	10,000	–	10,000	–	–	-10,000
Cryogenics Upgrades at TJNAF (TEC $8.0M)	8,000	–	8,000	–	–	-8,000
Linac K-sub Remediation at SLAC (TEC $9.8M)	9,800	9,800	–	–	–	–
Wilson Hall Renovations at FNAL (TEC $9.0M)	9,000	9,000	–	–	–	–
Water and Sewer Utilities Modernization at ANL (TEC $8.5M)	–	–	–	–	8,500	+8,500
ALS Support HVAC System and Utility Upgrade at LBNL ($8.5M)	–	–	–	–	8,500	+8,500
Other GPP (TEC <$5M)	n/a	n/a	3,200	–	3,000	-200
Total, Capital Operating Expenses	**n/a**	**n/a**	**30,200**	**–**	**20,000**	**-10,200**

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

Construction Projects Summary ($K)

	Total Project Cost (TPC)	Prior Years	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
19-SC-71, Science User Support Center, BNL						
TEC	85,000[b]	0	0	0	2,000	+2,000
OPC[c]	1,000	0	800	–	0	-800
TPC	86,000[b]	0	800	–	2,000	+1,200
19-SC-72, Electrical Capacity and Distribution Capability, ANL						
TEC	60,000[b]	0	0	0	20,000	+20,000
OPC[c]	1,000	0	0	–	0	0
TPC	61,000[b]	0	0	–	20,000	+20,000
18-SC-71, Energy Sciences Capability, PNNL						
TEC	90,000[b]	0	0	1,000	4,000	+4,000
OPC[c]	3,000	0	1,100	–	0	-1,100
TPC	93,000[b]	0	1,100	–	4,000	+2,900
17-SC-71, Integrated Engineering Research Center, FNAL						
TEC	85,000[b]	0	2,500	2,483	5,000	+2,500
OPC[c]	2,000	630	300	–	0	-300
TPC	87,000[b]	630	2,800	–	5,000	+2,200
17-SC-73, Core Facility Revitalization, BNL						
TEC	74,000[b]	0	1,800	1,788	13,632	+11,832
OPC[c]	850	850	0	–	0	0
TPC	74,850[b]	850	1,800	–	13,632	+11,832

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).
[b] This project has not received CD-2 approval; therefore, preliminary cost estimates are shown for TEC and TPC.
[c] Other Project Costs (OPC) are funded through laboratory overhead.

	Total Project Cost (TPC)	Prior Years	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
15-SC-76, Materials Design Laboratory, ANL						
TEC	95,000	30,910	19,590	19,457	20,000	+410
OPC[b]	1,000	1,000	0	–	0	0
TPC	96,000	31,910	19,590	–	20,000	+410
15-SC-77, Photon Sciences Laboratory Building, SLAC						
TEC	55,000	35,000	20,000	19,864[c]	0	-20,000
OPC[b]	2,000	1,541	459	–	0	-459
TPC	57,000	36,541	20,459	–	0	-20,459
15-SC-78, Integrative Genomics Building, LBNL						
TEC	90,000	32,090	19,561	19,428	13,549	-6,012
OPC[b]	1,500	1,500	0	–	0	0
TPC	91,500	33,590	19,561	–	13,549	-6,012
Total, Construction						
TEC	n/a	n/a	63,451	63,020	78,181	+14,730
OPC[b]	n/a	n/a	2,659	–	0	-2,659
TPC	n/a	n/a	66,110	–	78,181	+12,071

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

[b] Other Project Costs (OPC) are funded through laboratory overhead.

[c] Photon Science Laboratory Building at SLAC received final year of funding in FY 2017.

19-SC-71, Science and User Support Center
Brookhaven National Laboratory (BNL), Upton, NY
Project is for Design and Construction

1. Significant Changes and Summary

Significant Changes
This Construction Project Data Sheet (CPDS) includes a new start for FY 2019.

Summary
The FY 2019 Request for the Science and User Support Center is $2,000,000. The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on December 12, 2016.

This project has a preliminary Total Estimated Cost (TEC) range of $71,000,000 to $95,000,000 and a preliminary Total Project Cost (TPC) range of $72,000,000 to $96,000,000. These cost ranges encompass the most feasible preliminary alternatives. This preliminary information reflects funding for a project that will provide a facility to serve the research community and improve scientific and operational productivity by consolidating visitor and support services.

A Federal Project Director with the appropriate certification level will be assigned to this project prior to CD-1 approval.

FY 2019 funds will initiate Project Engineering and Design activities.

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2019	12/12/2016	4Q FY 2018	2Q FY 2019[a]	4Q FY 2020[a]	3Q FY 2021	4Q FY 2021[a]	N/A	4Q FY 2025[a]

CD-0 – Approve Mission Need
Conceptual Design Complete – Actual date the conceptual design was completed
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
Final Design Complete – Actual date the final design was completed
CD-3 – Approve Start of Construction
D&D Complete – Completion of D&D Work
CD-4 – Approve Project Completion

3. Preliminary Project Cost History

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC[b] Except D&D	OPC, D&D	OPC, Total	TPC
FY 2019	9,400	75,600[a]	85,000[a]	1,000	N/A	1,000	86,000[a]

[a] This project is pre-CD-2; schedule and funding estimates are preliminary.
[b] Other project costs (OPC) are funded through laboratory overhead.

4. Preliminary Project Scope and Justification

Scope

The Science and User Support Center (SUSC) project is in the pre-conceptual stage of development and several alternatives will be considered in preparation for CD-1. It is currently conceived as a project to construct a multi-story office building of approximately 70,000 – 120,000 gross square feet (gsf) to consolidate and provide space for visitor processing, offices for approximately 200-350 occupants, space for conferences, extension of utilities to the building, and related roadway modifications and parking lot development.

Key Performance Parameters (Preliminary)

The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve.

Description	Threshold Value (Minimum)	Objective Value (Maximum)
Multi-story Building	70,000 gsf	120,000 gsf

Justification

Brookhaven National Laboratory (BNL) has nine user facilities that attract over 40,000 visiting scientists, guests, users, and contractors annually to conduct research in a broad range of basic and applied sciences, however the ability to efficiently process and support the needs of this growing community of researchers is limited by the age, condition and dispersed nature of BNL's current facilities. The Laboratory's scientific impact can be improved by a facility that centralizes the administrative support functions and provides easier visitor access to conferencing and collaboration space to support the Office of Science research agenda. BNL also has many World War II era facilities dispersed around the site that house research support organizations in deteriorated facilities that are no longer sustainable and contribute to operational inefficiencies. Construction of the SUSC will provide convenient and efficient facilities for processing and supporting the users of BNL's premier research facilities, which would enable for the demolition of the current substandard, dispersed, and inefficient facilities. It will also provide conference facilities to support the collaborative science and research agenda for the user community and BNL scientists.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets.*

5. Financial Schedule

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Total Estimated Cost (TEC)			
Design			
FY 2019	2,000	2,000	2,000
FY 2020	7,400	7,400	7,400
Total, Design	9,400	9,400	9,400
Construction			
FY 2021	20,039	20,039	15,000
FY 2022	30,311	30,311	30,000
FY 2023	25,250	25,250	25,000
FY 2024	0	0	5,600
Total, Construction	75,600	75,600	75,600

[a] Costs for FY 2018 and the outyears are estimates.

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
TEC			
FY 2019	2,000	2,000	2,000
FY 2020	7,400	7,400	7,400
FY 2021	20,039	20,039	15,000
FY 2022	30,311	30,311	30,000
FY 2023	25,250	25,250	25,000
FY 2024	0	0	5,600
Total, TEC	85,000	85,000	85,000
Other Project Cost (OPC)[b]			
OPC except D&D			
FY 2018	1,000	1,000	1,000
Total, OPC	1,000	1,000	1,000
Total Project Cost (TPC)			
FY 2018	1,000	1,000	1,000
FY 2019	2,000	2,000	2,000
FY 2020	7,400	7,400	7,400
FY 2021	20,039	20,039	15,000
FY 2022	30,311	30,311	30,000
FY 2023	25,250	25,250	25,000
FY 2024	0	0	5,600
Total, TPC	86,000	86,000	86,000

6. Details of Project Cost Estimate

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	7,800	N/A	N/A
Contingency	1,600	N/A	N/A
Total, Design	9,400	N/A	N/A
Construction			
Construction	63,000	N/A	N/A
Contingency	12,600	N/A	N/A
Total, Construction	75,600	N/A	N/A
Total, TEC	85,000	N/A	N/A
Contingency, TEC	14,200	N/A	N/A

[a] Costs for FY 2018 and the outyears are estimates.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Other Project Cost (OPC)[a]			
OPC except D&D			
Conceptual Planning	400	N/A	N/A
Conceptual Design	400	N/A	N/A
Contingency	200	N/A	N/A
Total, OPC	1,000	N/A	N/A
Contingency, OPC	200	N/A	N/A
Total, TPC	86,000	N/A	N/A
Total, Contingency	14,400	N/A	N/A

7. Schedule of Appropriation Requests

(dollars in thousands)

Request Year		FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023	Total
FY 2019	TEC	0	2,000	7,400	20,039	30,311	25,250	85,000
	OPC[a]	1,000	0	0	0	0	0	1,000
	TPC	1,000	2,000	7,400	20,039	30,311	25,250	86,000

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy Expected ....4Q FY 2025
Useful Life ....50 years
Expected Future Start of D&D of this capital asset ....N/A

(Related Funding Requirements)

(dollars in thousands)

	Annual Costs		Life-Cycle Costs	
	Current Total Estimates	Previous Total Estimates	Current Total Estimates	Previous Total Estimates
Operations	166	N/A	8,307	N/A
Utilities	78	N/A	3,879	N/A
Maintenance and Repair	384	N/A	19,200	N/A
Total – Operations and Maintenance	628	N/A	31,386	N/A

[a] Other Project Costs (OPC) are funded through laboratory overhead.

9. D&D Information

The new area being constructed in this project is not replacing existing facilities.

	Square Feet
New area being constructed by this project at *Brookhaven National Laboratory*	70,000 – 120,000
Area of D&D in this project at *Brookhaven National Laboratory*	None
Area at *Brookhaven National Laboratory* to be transferred, sold, and/or D&D outside the project including area previously banked"	None[a]
Area of D&D in this project at other sites	None
Area at other sites to be transferred, sold, and/or D&D outside the project including area previously "banked"	None
Total area eliminated	70,000 – 120,000

10. Preliminary Acquisition Approach

Acquisition for this project will be performed by the BNL Management and Operating (M&O) Contractor, Brookhaven Science Associates. The M&O Contractor will be responsible for awarding and managing all subcontracts related to the project. The Brookhaven Site Office will be responsible for overseeing the performance of the M&O Contractor. Various acquisition and project delivery methods will be evaluated prior to achieving CD-1. The M&O Contractor will evaluate potential benefits of using a single or multiple contracts to procure materials, equipment, construction, commissioning and other project scope elements. Project performance metrics will be included in the M&O Contractor's annual performance and evaluation measurement plan.

[a] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

19-SC-72, Electrical Capacity and Distribution Capability
Argonne National Laboratory (ANL), Argonne, IL
Project is for Construction

1. Significant Changes and Summary

Significant Changes
This Construction Project Data Sheet (CPDS) includes a new start for FY 2019.

Summary
The FY 2019 Request for the Electrical Capacity and Distribution Capability project is $20,000,000.The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on September 22, 2017.

This project has a Total Estimated Cost (TEC) of $60,000,000 and a Total Project Cost (TPC) of $61,000,000. This preliminary information reflects funding for a project to improve high voltage electrical distribution systems to support the anticipated electrical demands of the exascale computing program as well as current mission critical operations in multiple facilities across Argonne National Laboratory (ANL).

A Federal Project Director with the appropriate certification level will be assigned to this project prior to CD-1 approval.

FY 2019 funds will initiate Project Engineering and Design, and Construction activities.

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2019	09/22/2017	N/A	4Q FY 2018	3Q FY 2019	2Q FY 2019	3Q FY 2019	N/A	4Q FY 2022

CD-0 – Approve Mission Need
Conceptual Design Complete – Actual date the conceptual design was completed
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
Final Design Complete – Actual date the final design was completed
CD-3 – Approve Start of Construction
D&D Complete – Completion of D&D Work (see section 9)
CD-4 – Approve Project Completion

	Performance Baseline Validation
FY 2019	N/A

3. Project Cost History

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC[a] Except D&D	OPC, D&D	OPC, Total	TPC
FY 2019	6,000	54,000	60,000	1,000	N/A	1,000	61,000

[a] Other Project Costs (OPC) are funded through laboratory overhead.

4. Project Scope and Justification

Scope

The scope of this project includes the design and construction of a new power supply to the site in a location physically separated from existing location such that redundancy is provided to prevent single point failure. Additionally, increased high voltage electrical capacity will be provided. Upgrades to supply lines and substations as well as redundant electrical connections will be analyzed and provided, if they prove to provide a positive benefit to cost ratio.

Key Performance Parameters (Preliminary)

The Key Performance Parameters are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve.

Description	Threshold Value (Minimum)	Objective Value (Maximum)
Provide new power supply	>150MVa	>200MVa
Provide increased high voltage electrical capacity	>60MVa	>110MVa
Upgrade existing 138kV supply line and 549A substation	Maintain 138kV supply line	Support >150MVa
Provide redundant electrical connections	Maintain existing electrical connections between major ANL substations	Between major ANL substations

Justification

The high voltage electrical distribution system consists of substations, transformers, high voltage electrical supply, and distribution cabling. High voltage power is supplied to the laboratory via a single ComEd managed substation facility. Once on site, electricity is distributed through laboratory managed substations, transformers, and finally facilities. Elements of the high voltage electrical distribution system are rated in poor condition due to age, limiting the ability to support the electricity requirements of new and expanding facilities and scientific programs. Much of the main electrical supply infrastructure was constructed in the 1960's and is now beyond its useful life.

Mission critical improvements to the high voltage electrical distribution systems are needed to support ANL's unique competencies and eliminate these gaps. Expansion of the electrical distribution system would significantly reduce the risk of inadequate electrical capacity to support future scientific program growth and/or new initiatives; specifically those associated with advanced computer science, visualization, and data, large scale user facilities/advanced instrumentation and nuclear physics core capabilities. By filling these gaps, there will be a significant reduction in operational risk associated with unplanned outages. The Electrical Capacity and Distribution Capability project will improve and expand critical electrical distribution systems to support the electrical capacity growth needed to support the SC/Advanced Scientific Computing Research program's planned delivery of an exascale computer to the ANL Leadership Computing Facility. Other science facilities will also be positively impacted by these critical high voltage electrical and distribution upgrades such as the Advanced Photo Source and the Center for Nanoscale Materials.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, Program and Project Management for the Acquisition of Capital Assets.

5. Financial Schedule

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Total Estimated Cost (TEC)			
Design			
FY 2019	6,000	6,000	6,000
Total, Design	6,000	6,000	6,000
Construction			
FY 2019	14,000	14,000	10,000
FY 2020	40,000	40,000	27,000
FY 2021	0	0	17,000
Total, Construction	54,000	54,000	54,000
TEC			
FY 2019	20,000	20,000	16,000
FY 2020	40,000	40,000	27,000
FY 2021	0	0	17,000
Total, TEC	60,000	60,000	60,000
Other Project Cost (OPC)[b]			
OPC except D&D			
FY 2018	1,000	1,000	1,000
Total, OPC	1,000	1,000	1,000
Total Project Cost (TPC)			
FY 2018	1,000	1,000	1,000
FY 2019	20,000	20,000	16,000
FY 2020	40,000	40,000	27,000
FY 2021	0	0	17,000
Total, TPC	61,000	61,000	61,000

6. Details of Project Cost Estimate

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	5,100	N/A	N/A
Contingency	900	N/A	N/A
Total, Design	6,000	N/A	N/A
Construction			
Construction	45,000	N/A	N/A
Contingency	9,000	N/A	N/A
Total, Construction	54,000	N/A	N/A

[a] Costs for FY 2018 and the outyears are estimates.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
	(dollars in thousands)		
Total, TEC	60,000	N/A	N/A
Contingency, TEC	9,900	N/A	N/A
Other Project Cost (OPC)[a]			
OPC except D&D			
Conceptual Planning	750	N/A	N/A
Conceptual Design	250	N/A	N/A
Contingency	0	N/A	N/A
Total, OPC	1,000	N/A	N/A
Contingency, OPC	0	N/A	N/A
Total, TPC	61,000	N/A	N/A
Total, Contingency	9,900	N/A	N/A

7. Schedule of Appropriation Requests

(dollars in thousands)

Request Year		FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	Total
FY 2019	TEC	0	20,000	40,000	0	0	0	0	60,000
	OPC[a]	1,000	0	0	0	0	0	0	1,000
	TPC	1,000	20,000	40,000	0	0	0	0	61,000

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy Expected……	4Q FY 2021
Useful Life……	50 years
Expected Future Start of D&D of this capital asset……	4Q FY 2071

(Related Funding Requirements)

(dollars in thousands)

	Annual Costs		Life-Cycle Costs	
	Current Total Estimates	Previous Total Estimates	Current Total Estimates	Previous Total Estimates
Operations	1,117	N/A	107,628	N/A
Utilities	162	N/A	21,571	N/A
Maintenance and Repair	536	N/A	51,646	N/A
Total – Operations and Maintenance	1,815	N/A	180,845	N/A

[a] Other Project Costs (OPC) are funded through laboratory overhead.

9. D&D Information

There is no new area being constructed in this construction project.

	Square Feet
New area being constructed by this project at *Argonne National Laboratory*……………………………………………………………………………………………	None
Area of D&D in this project at *Argonne National Laboratory*…………………………	None
Area at *Argonne National Laboratory* to be transferred, sold, and/or D&D outside the project including area previously banked”…………………………………	None[a]
Area of D&D in this project at other sites…………………………………………………	None
Area at other sites to be transferred, sold, and/or D&D outside the project including area previously “banked”…………………………………………………………	None
Total area eliminated…………………………………………………………………………	None

10. Acquisition Approach

Acquisition for this project will be performed by the Management and Operating (M&O) Contractor, UChicago Argonne, LLC, and will be overseen by the Argonne Site Office. Various acquisition approaches and project delivery methods will be evaluated prior to achieving CD-1. A tailored Design-Build approach is being considered as the overall best project delivery method with the lowest risk to DOE. The M&O Contractor is responsible for awarding and administering all subcontracts related to this project. Project performance metrics are included in the M&O Contractor’s annual performance evaluation and measurement plan.

[a] With the implementation of OMB’s Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

18-SC-71, Energy Sciences Capability
Pacific Northwest National Laboratory (PNNL), Richland, WA
Project is for Design and Construction

1. Significant Changes and Summary

Significant Changes
This Construction Project Data Sheet (CPDS) is an update of the FY 2018 CPDS and does not include a new start for FY 2019.

Summary
The FY 2019 Request for the Energy Sciences Capability (ESC) project is $4,000,000, consistent with the preliminary funding profile. The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on December 12, 2016. The Total Estimated Cost (TEC) range for this project is $70,000,000 to $96,000,000. The Total Project Cost (TPC) range for this project is $73,000,000 to $99,000,000.

A Federal Project Director with the appropriate certification level will be assigned to this project prior to CD-1 approval.

This project will provide a facility for the consolidation of multidisciplinary efforts related to the advancement of catalysis science which are currently located in multiple facilities, on and off the Pacific Northwest National Laboratory (PNNL) Richland campus.

FY 2019 funds will support Project Engineering and Design activities.

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2018	12/12/2016	N/A	4Q FY 2018	4Q FY 2019[a]	N/A	4Q FY 2020[a]	N/A	4Q FY 2025[a]
FY 2019	12/12/2016	3Q FY2018	2Q FY 2018	4Q FY 2019[a]	4Q FY 2019[a]	4Q FY 2019[a]	N/A	4Q FY 2025[a]

CD-0 – Approve Mission Need
Conceptual Design Complete – Actual date the conceptual design was completed (if applicable)
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
Final Design Complete – Estimated/Actual date the project design will be/was completed
CD-3– Approve Start of Construction
D&D Complete – Completion of D&D work (see Section 9)
CD-4 – Approve Project Completion

[a] This project is pre-CD-2 and schedule estimates are preliminary.

3. Project Cost History

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC[a] Except D&D	OPC, D&D	OPC, Total	TPC
FY 2018	9,000	81,000	90,000[b]	3,000	N/A	3,000	93,000[b]
FY 2019	9,000	81,000	90,000[b]	3,000	N/A	3,000	93,000[b]

4. Project Scope and Justification

Scope

The scope of the proposed project is to construct new capital assets, including utilities and infrastructure capabilities. The ESC project will design, construct and turnover facilities and infrastructure that provides nominally 110,000 to 145,000 gross square feet of wet chemistry, instrumentation, and computational space in 40 to 52 laboratory modules along with offices for 150 to 200 research and support staff.

Key Performance Parameters (Preliminary)

The Key Performance Parameters (KPPs) are preliminary and may change as the project continues towards CD-2. At CD-2 approval, the KPPs will be baselined. The Threshold KPPs represent the minimum acceptable performance that the project must achieve.

Description	Threshold Value (Minimum)	Objective Value (Maximum)
Multi-story Laboratory Building	110,000 gross square feet (GSF)	145,000 GSF

Justification

PNNL operates facilities for research in chemistry, materials sciences, subsurface science, biology, physics, medicine, and applied science, as well as for the study of a diverse range of advanced technologies. PNNL's science mission, which supports DOE's mission, is to understand, predict, and control complex adaptive systems for earth, energy, and security missions. PNNL's recognized Core Capabilities are essential to advance and accelerate research sponsored by BES, BER, and ASCR. All of these research areas benefit from multidisciplinary approaches that accelerate scientific advances.

The objective behind the ESC project is to increase the impact of chemical conversion research and development at PNNL and expand the reach of user programs. Ultimately, greater multidisciplinary collaboration, controlled environments, and increasing computational needs beyond current capabilities will be needed to accomplish this end state. Currently, key PNNL staff members and instrumentation driving multidisciplinary efforts are located in multiple facilities, separated miles apart, on and off of the PNNL Richland campus. With less than 0.25% available vacant lab space and less than 1.5% vacant office space scattered across the campus, PNNL needs a new facility to allow for collaboration. This consolidation will free up space that also allows for increased optimization and greater colocation of Environmental Molecular Sciences Laboratories and Atmospheric Radiation Measurement user missions.

The geographic separation of scientific capabilities at PNNL creates a capability gap by impacting collaborative work and limits interdisciplinary research required to realize the critical advances offered through integration (i.e., "convergence"). As stated in the report "The Convergence of the Life Sciences, Physical Sciences, and Engineering" from the Massachusetts Institute of Technology, convergence "involves the coming together of different fields of study—particularly engineering, physical sciences, and life sciences—through collaboration among research groups and the integration of approaches" and "is a new paradigm that can yield critical advances in a broad array of sectors, from health care to energy, food, climate, and water." It also entails "a broad rethinking of how all scientific research can be conducted, so that we capitalize on a range of knowledge bases."

[a] Other project costs (OPC) are funded through laboratory overhead.
[b] This project has not received CD-2 approval, therefore, funding estimates are preliminary. The preliminary TEC range for this project is $70,000,000 to $96,000,000. The preliminary TPC range for this project is $73,000,000 to $99,000,000.

The ESC project will provide for the needed space of the proper configuration and types to afford acceleration of convergent science—a need that can be achieved only through material means. It also will enable a cascade of moves to enable location of synergistic capabilities in optimal spaces without losing those capabilities for extended time periods and negatively impacting research. The ESC project also further advances the PNNL campus strategy to modernize and increase federal ownership of the Laboratory and seeks to directly impact PNNL's core capabilities by creating space that enables research in support of BES, BER, and ASCR programs.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, *Program and Project Management for the Acquisition of Capital Assets*.

5. Financial Schedule

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Total Estimated Cost (TEC)			
Design			
FY 2018	1,000	1,000	400
FY 2019	4,000	4,000	4,600
FY 2020	4,000	4,000	4,000
Total, Design	9,000	9,000	9,000
Construction			
FY 2020	4,194	4,194	0
FY 2021	22,209	22,209	12,000
FY 2022	30,500	30,500	18,000
FY 2023	24,097	24,097	22,000
FY 2024	0	0	29,000
Total, Construction	81,000	81,000	81,000
TEC			
FY 2018	1,000	1,000	400
FY 2019	4,000	4,000	4,600
FY 2020	8,194	8,194	4,000
FY 2021	22,209	22,209	12,000
FY 2022	30,500	30,500	18,000
FY 2023	24,097	24,097	22,000
FY 2024	0	0	29,000
Total, TEC[b]	90,000	90,000	90,000
Other Project Cost (OPC)[c]			
OPC except D&D			
FY 2017	1,100	1,100	1,100
FY 2018	1,500	1,500	1,500
FY 2023	400	400	400
Total, OPC except D&D	3,000	3,000	3,000

[a] Costs through 2016 reflect actual Costs; costs for FY 2017 and the outyears are estimates.
[b] This project has not received CD-2 approval, therefore, funding estimates are preliminary. The preliminary TEC range for this project is $70,000,000 to $96,000,000. The preliminary TPC range for this project is $73,000,000 to $99,000,000.
[c] Other Project Costs (OPC) are funded through laboratory overhead.

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Total Project Cost (TPC)			
FY 2017	1,100	1,100	1,100
FY 2018	2,500	2,500	1,900
FY 2019	4,000	4,000	4,600
FY 2020	8,194	8,194	4,000
FY 2021	22,209	22,209	12,000
FY 2022	30,500	30,500	18,000
FY 2023	24,497	24,497	22,400
FY 2024	0	0	29,000
Total, TPC[b]	93,000	93,000	93,000

6. Details of Project Cost Estimate

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	7,500	7,500	N/A
Contingency	1,500	1,500	N/A
Total, Design	9,000	9,000	N/A
Construction			
Construction	70,000	70,000	N/A
Contingency	11,000	11,000	N/A
Total, Construction	81,000	81,000	N/A
Total, TEC[b]	90,000	90,000	N/A
Contingency, TEC	12,500	12,500	N/A
Other Project Cost (OPC)[c]			
OPC except D&D	1,650	1,650	N/A
Conceptual Planning	100	100	N/A
Conceptual Design	1,000	1,000	N/A
Contingency	250	250	N/A
Total, OPC	3,000	3,000	N/A
Contingency, OPC	250	250	N/A
Total, TPC[b]	93,000	93,000	N/A
Total, Contingency	12,750	12,750	N/A

[a] Costs through 2016 reflect actual Costs; costs for FY 2017 and the outyears are estimates.
[b] This project has not received CD-2 approval, therefore, funding estimates are preliminary. The preliminary TEC range for this project is $70,000,000 to $96,000,000. The preliminary TPC range for this project is $73,000,000 to $99,000,000.
[c] Other Project Costs (OPC) are funded through laboratory overhead.

7. Schedule of Appropriation Requests

(dollars in thousands)

Request Year		Prior Years	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	Total
FY 2018	TEC	0	1,000	TBD	TBD	TBD	TBD	TBD	TBD	90,000[a]
	OPC[b]	0	0	0	0	0	0	0	0	3,000
	TPC	0	1,000	TBD	TBD	TBD	TBD	TBD	TBD	93,000[a]
FY 2019	TEC	0	1,000	4,000	8,194	22,209	30,500	24,097	0	90,000[a]
	OPC[b]	1,100	1,500	0	0	0	0	400	0	3,000
	TPC	1,100	2,500	4,000	8,194	22,209	30,500	24,497	0	93,000[a]

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy ………………………………………………………………………… 2Q FY 2025
Expected Useful Life………. 50 years
Expected Future Start of D&D of this capital asset………………………………………………………………. 2Q FY 2075

(Related Funding Requirements)

(dollars in thousands)

	Annual Costs		Life-Cycle Costs	
	Current Total Estimates	Previous Total Estimates	Current Total Estimates	Previous Total Estimates
Operations	480	N/A	23,989	N/A
Utilities	547	N/A	27,370	N/A
Maintenance and Repair	1,222	N/A	61,121	N/A
Total – Operations and Maintenance	2,249	N/A	112,480	N/A

9. D&D Information

The new area being constructed in this project is not replacing existing facilities.

	Square Feet
New area being constructed by this project at *Pacific Northwest National Laboratory*…………………………………………………………………………………………………	110,000 to 145,000
Area of D&D in this project at *Pacific Northwest National Laboratory*………	None
Area at *Pacific Northwest National Laboratory* to be transferred, sold, and/or D&D outside the project including area previously banked"…………………………	None
Area of D&D in this project at other sites………………………………………………………	None
Area at other sites to be transferred, sold, and/or D&D outside the project including area previously "banked"………………………………………………………………	None[c]
Total area eliminated…………………………………………………………………………………	None

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary. The preliminary TEC range for this project is $70,000,000 to $96,000,000. The preliminary TPC range for this project is $73,000,000 to $99,000,000.
[b] Other Project Costs (OPC) are funded through laboratory overhead.
[c] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

10. Preliminary Acquisition Approach

Acquisition for this project will be performed by the Management and Operating (M&O) contractor, Battelle Memorial Institute and overseen by the Pacific Northwest Site Office. Various acquisition approaches and project delivery methods will be considered prior to achieving CD-1. The M&O contractor will be responsible for awarding and administering all subcontracts related to this project. Project performance metrics are included in the M&O contractor's annual performance evaluation and measurement plan.

17-SC-71, Integrated Engineering Research Center
Fermi National Accelerator Laboratory (FNAL), Batavia, IL
Project is for Design and Construction

1. Summary

Significant Changes

This Construction Project Data Sheet (CPDS) is an update of the FY 2018 CPDS and does not include a new start for FY 2019.

Summary

The FY 2019 Request for the Integrated Engineering Research Center project is $5,000,000. The most recent DOE Order 413.3B Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, which was approved on April 18, 2017. The Total Estimated Cost (TEC) range for this project is $73,000,000 to $98,000,000. The Total Project Cost (TPC) range for this project is $74,000,000 to $99,000,000.

A Federal Project Director with the appropriate certification level has been assigned to this project.

This project will design and construct new space to accommodate increased collaboration and interactions among FNAL staff. The project is intended to close an infrastructure capability gap which will impede the establishment of an international neutrino campus as recommended by the Particle Physics Project Prioritization Panel (P5).

FY 2019 funds will support Project Engineering and Design activities as well as construction and associated activities.

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2/3A	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2017	07/17/2015	N/A	1Q FY 2017	3Q FY 2018[a]	N/A	3Q FY 2019[a]	N/A	4Q FY 2023[a]
FY 2018	07/17/2015	N/A	4/18/2017	3Q FY 2019[a]	N/A	3Q FY 2020[a]	N/A	4Q FY 2024[a]
FY 2019	07/17/2015	3Q FY 2018	4/18/2017[a]	3Q FY 2019[a]	3Q FY 2019[a]	3Q FY 2020[a]	N/A	4Q FY 2024[a]

CD-0 – Approve Mission Need
Conceptual Design Complete – Actual date the conceptual design was completed
CD-1 – Approve Alternative Selection and Cost Range
CD-2/3A – Approve Performance Baseline/Long Lead Procurement
Final Design Complete – Actual date the final design was completed
CD-3 – Approve Start of Construction
D&D Complete – Completion of D&D Work (see section 9)
CD-4 – Approve Project Completion

	Performance Baseline Validation
FY 2017	N/A
FY 2018	N/A
FY 2019	3Q FY 2019

[a] This project is pre-CD-2 and schedule estimates are preliminary.

3. Project Cost History

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC[a] Except D&D	OPC, D&D	OPC, Total	TPC
FY 2017	10,000	75,000[b]	85,000[b]	2,000	N/A	2,000	87,000[b]
FY 2018	10,000	75,000[b]	85,000[b]	1,000	N/A	1,000	86,000[b]
FY 2019	7,000	78,000[b]	85,000[b]	1,000	N/A	1,000	86,000[b]

4. Project Scope and Justification

Scope

The Integrated Engineering Research Center project will construct a scientific user support facility to accommodate increased collaboration and interactions among staff at Fermilab (FNAL), who will in turn be working with scientific collaborators and international partners in the design, construction, and operation of physics experiments.

This project has not yet received CD-2 approval; therefore the Key Performance Parameters (KPPs) are not yet established. The table below outlines preliminary KPPs.

Key Performance Parameters (Preliminary)

Description	Threshold Value (Minimum)	Objective Value (Maximum)
Multistory Laboratory/Office Building	67,000 gross square feet	134,000 gross square feet

Justification

In May 2014, the Particle Physics Project Prioritization Panel (P5) issued a report that included recommendations to "…develop a coherent short- and long-baseline neutrino program hosted at Fermilab," and to "reformulate the long-baseline neutrino program as an internationally designed, coordinated, and funded program with [Fermi National Accelerator Laboratory, FNAL or Fermilab] as host." SC and the High Energy Physics (HEP) program accepted the recommendations in the P5 report and are committed to implementing a successful program based on this new vision.

Implementing these recommendations will require significantly increased collaboration and interactions among FNAL staff, who will in turn be working with scientific collaborators and international partners in the design, construction, and operation of physics experiments. Currently, these staff and their associated manufacturing, assembly, engineering, and technical facilities are scattered among three parts of the campus – the Silicon Detector Complex, the Village, and Wilson Hall. As a result, they are unable to efficiently collaborate on ongoing and planned projects in support of the laboratory's mission.

Co-location of these staff will improve collaboration because it will increase interactions among the various groups and reduce down-time spent traveling across the site. From an infrastructure standpoint, however, FNAL currently lacks sufficient space to do this. Continuing the previous example, groups from the three Divisions noted above total approximately 300 staff occupying more than 170,000 square feet of laboratories, technical areas, and offices in 15 buildings and trailers. In addition, many of these spaces are inadequate to accommodate current and planned scientific programs because they are obsolete (e.g., leaking roofs, inadequate HVAC systems) and do not support the configuration or specification needs of current and future technical programs. The Integrated Engineering Research Center will provide FNAL with a collaborative, multi-divisional, and interdisciplinary research center. This research center will close existing capability and infrastructure gaps by reducing the overall footprint of outdated facilities, and collocating engineering and associated research staff in a new or renovated facility near the central campus. This approach will complement the ongoing and planned renovations of Wilson Hall by establishing the main campus as the anchor point of the site. It will improve

[a] Other project costs (OPC) are funded through laboratory overhead.

[b] This project has not received CD-2 approval; funding estimates are consistent with the approved cost ranges. The approved TEC for this project is $73,000,000 to $98,000,000. The approved TPC range for this project is $74,000,000 to $99,000,000.

operational efficiency and collaboration because groups working on key projects would be in close proximity to one another. Such a facility will provide technical and engineering staff the necessary environment for interdisciplinary collaboration necessary to establish an international neutrino program and support other HEP science opportunities described in the P5 report.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, Program and all Project Management for the Acquisition of Capital Assets.

5. Financial Schedule

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Total Estimated Cost (TEC)			
Design			
FY 2017	2,500	2,500	38
FY 2018	1,500	1,500	3,962
FY 2019	3,000	3,000	3,000
Total, Design	7,000	7,000	7,000
Construction			
FY 2019	2,000	2,000	0
FY 2020	20,000	20,000	17,000
FY 2021	28,096	28,096	23,000
FY 2022	27,904	27,904	20,000
FY 2023	0	0	18,000
Total, Construction	78,000	78,000	78,000
TEC			
FY 2017	2,500	2,500	38
FY 2018	1,500	1,500	3,962
FY 2019	5,000	5,000	3,000
FY 2020	20,000	20,000	17,000
FY 2021	28,096	28,096	23,000
FY 2022	27,904	27,904	20,000
FY 2023	0	0	18,000
Total, TEC[b]	85,000	85,000	85,000
Other Project Cost (OPC)[c]			
OPC except D&D			
FY 2015	120	120	120
FY 2016	510	510	510
FY 2017	300	300	300
FY 2022	70	70	70
Total, OPC except D&D	1,000	1,000	1,000

[a] Costs through 2017 reflect actual Costs; costs for FY 2018 and the outyears are estimates.
[b] This project has not received CD-2 approval; funding estimates are consistent with the approved cost ranges. The approved TEC for this project is $73,000,000 to $98,000,000. The approved TPC range for this project is $74,000,000 to $99,000,000.
[c] Other Project Costs (OPC) are funded through laboratory overhead.

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Total Project Cost (TPC)			
FY 2015	120	120	120
FY 2016	510	510	510
FY 2017	2,800	2,800	338
FY 2018	1,500	1,500	3,962
FY 2019	5,000	5,000	3,000
FY 2020	20,000	20,000	17,000
FY 2021	28,096	28,096	23,000
FY 2022	27,974	27,974	20,070
FY 2023	0	0	18,000
Total, TPC[b]	86,000	86,000	86,000

6. Details of Project Cost Estimate

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	6,000	8,000	N/A
Contingency	1,000	2,000	N/A
Total, Design	7,000	10,000	N/A
Construction			
Construction	63,000	61,000	N/A
Contingency	15,000	14,000	N/A
Total, Construction	78,000	75,000	N/A
			N/A
Total, TEC[b]	85,000	85,000	N/A
Contingency, TEC	16,000	16,000	N/A
Other Project Cost (OPC)[c]			
OPC except D&D			
Conceptual Planning	250	250	N/A
Conceptual Design	530	530	N/A
Start-up	150	150	N/A
Contingency	70	70	N/A
Total, OPC	1,000	1,000	N/A
Total, TPC[b]	86,000	86,000	N/A
Total, Contingency	16,070	16,070	N/A

[a] Costs through 2017 reflect actual Costs; costs for FY 2018 and the outyears are estimates.
[b] This project has not received CD-2 approval; funding estimates are consistent with the approved cost ranges. The approved TEC for this project is $73,000,000 to $98,000,000. The approved TPC range for this project is $74,000,000 to $99,000,000.
[c] Other Project Costs (OPC) are funded through laboratory overhead.

7. Schedule of Appropriation Requests

(dollars in thousands)

Request Year		Prior Years	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023	Total
FY 2017	TEC	0	2,500	TBD	TBD	TBD	TBD	TBD	TBD	85,000[a]
	OPC[b]	500	0	TBD	TBD	TBD	TBD	TBD	TBD	2,000
	TPC	0	2,500	TBD	TBD	TBD	TBD	TBD	TBD	87,000[a]
FY 2018	TEC	0	2,500	1,500	TBD	TBD	TBD	TBD	TBD	85,000[a]
	OPC[b]	500	0	500	0	0	0	0	0	1,000
	TPC	500	2,500	2,000	TBD	TBD	TBD	TBD	TBD	86,000[a]
FY 2019	TEC	0	2,500	1,500	5,000	20,000	28,096	27,904	0	85,000[a]
	OPC[b]	630	300	0	0	0	0	70	0	1,000
	TPC	630	2,800	1,500	5,000	20,000	28,096	27,974	0	86,000[a]

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy Expected.. 4Q FY 2024
Expected Useful Life.. 50 years
Expected Future Start of D&D of this capital asset.. 4Q FY 2074

(Related Funding Requirements)

(dollars in thousands)

	Annual Costs		Life-Cycle Costs	
	Current Total Estimates	Previous Total Estimates	Current Total Estimates	Previous Total Estimates
Operations	508	N/A	25,428	N/A
Utilities	94	N/A	4,670	N/A
Maintenance and Repair	1,525	N/A	76,285	N/A
Total – Operations and Maintenance	2,127	N/A	106,383	N/A

[a] This project has not received CD-2 approval; funding estimates are consistent with the approved cost ranges. The approved TEC for this project is $73,000,000 to $98,000,000. The approved TPC range for this project is $74,000,000 to $99,000,000.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

9. D&D Information

The new area being constructed in this project is not replacing existing facilities.

	Square Feet
New area being constructed by this project at *Fermi National Accelerator Laboratory*………………………………………………………………………………………………	67,000 to 134,000
Area of D&D in this project at *Fermi National Accelerator Laboratory* ………	None
Area at *Fermi National Accelerator Laboratory* to be transferred, sold, and/or D&D outside the project including area previously banked”………………………	55,200
Area of D&D in this project at other sites………………………………………………………	None
Area at other sites to be transferred, sold, and/or D&D outside the project including area previously “banked”…………………………………………………………………	None[a]
Total area eliminated……………………………………………………………………………………	55,200

10. Preliminary Acquisition Approach

Acquisition for this project will be performed by the Management and Operating (M&O) contractor, Fermi Research Alliance, LLC and overseen by the Fermi Site Office. Various acquisition approaches and project delivery methods were evaluated prior to achieving CD-1. A Construction Manager/General Contractor (CM/GC) project delivery with best value procurement approach was selected as the overall best delivery method with the lowest risk to DOE. The M&O contractor is responsible for awarding and administering all subcontracts related to this project. Project performance metrics are included in the M&O contractor's annual performance evaluation and measurement plan.

[a] With the implementation of OMB’s Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

17-SC-73, Core Facility Revitalization
Brookhaven National Laboratory (BNL), Upton, NY
Project is for Design and Construction

1. Significant Changes and Summary

Significant Changes
This Construction Project Data Sheet (CPDS) is an update of the FY 2018 CPDS and does not include a new start for FY 2019.

Summary
The FY 2019 Request for the Core Facility Revitalization project is $13,632,000. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, which was approved on April 18, 2017.

The Total Estimated Cost (TEC) range for this project is $67,650,000 to $83,650,000. The Total Project Cost (TPC) range for this project is $68,500,000 to $84,500,000.

A Federal Project Director with the appropriate certification level has been assigned to this project.

This project will provide the most urgent computation and data storage capabilities in time to support BNL's expanding core mission computing requirements, such as the computationally-intensive research associated with the Relativistic Heavy Ion Collider (RHIC) and the US-A Toroidal Large Hadron Collider Apparatus (US-ATLAS) at the European Organization for Nuclear Research (CERN) in Geneva, Switzerland.

FY 2019 funds will support Project Engineering and Design activities as well as construction and associated activities.

2. Critical Milestone History

(fiscal quarter to date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2017	9/10/2015	08/05/2016	3Q FY 2017	3Q FY 2019[a]	3Q FY 2020	3Q FY 2020[a]	N/A	4Q FY 2024[a]
FY 2018	9/10/2015	08/05/2016	04/18/2017	3Q FY 2019[a]	1Q FY 2020	1Q FY 2020[a]	N/A	4Q FY 2024[a]
FY 2019	9/10/2015	08/05/2016	04/18/2017	2Q FY 2019[a]	4Q FY 2019	4Q FY 2019[a]	N/A	4Q FY 2024[a]

CD-0 – Approve Mission Need
Conceptual Design Complete – Actual date the conceptual design was completed
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
Final Design Complete – Actual date the final design was completed
CD-3– Approve Start of Construction
D&D Complete – Completion of D&D Work (see section 9)
CD-4 – Approve Project Completion

	Performance Baseline Validation
FY 2017	N/A
FY 2018	N/A
FY 2019	N/A

[a] This project is pre-CD-2 and schedule estimates are preliminary.

3. Project Cost History

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC[a] Except D&D	OPC, D&D	OPC, Total	TPC
FY 2017	6,400	57,000[b]	63,400[b]	1,100	N/A	1,100	64,500[b]
FY 2018	7,000	67,000[b]	74,000[b]	850	N/A	850	74,850[b]
FY 2019	7,000	67,000[b]	74,000[b]	850	N/A	850	74,850[b]

4. Project Scope and Justification

Scope

The Core Facility Revitalization project will provide facilities and infrastructure to enable the computational requirements of the Office of Science's (SC) Nuclear Physics (NP) program, High Energy Physics (HEP) program, and other research programs physically conducted at Brookhaven National Laboratory (BNL) and other locations.

This project has not yet received CD-2 approval; therefore the Key Performance Parameters (KPPs) are not yet established. The table below outlines preliminary KPPs.

Key Performance Parameters (Preliminary)

Description	Threshold Value (Minimum)	Objective Value (Maximum)
Deliver identified Computing Facility IT power and emergency back-up power/cooling capabilities	3.6 MW IT power, 1.2 MW emergency back-up capabilities	3.6 MW IT power, 2.4 MW emergency back-up capabilities
Renovation of space to support the computing equipment and associated infrastructure	40,400 gross square feet	60,600 gross square feet

Justification

BNL is a multi-purpose research institution funded primarily by SC to operate facilities for studies in physics, chemistry, biology, medicine, applied science, and a wide range of advanced technologies. Among BNL's core capabilities are: nuclear physics, particle physics, large-scale user facilities for advanced instrumentation, and programmatic strengths in data-centric and high-throughput "mid-scale" computational science.

A significant amount of computation and data storage is currently conducted within the RHIC ATLAS Computing Facility (RACF) located on the BNL campus. The RACF directly supports RHIC research operations funded by SC's NP and US-ATLAS research operations funded by SC's HEP. The RACF also provides mid-scale computing support to other research programs funded by SC, research efforts funded by strategic partners, and computationally-intensive research, which indirectly supports the broader SC mission. In addition, other SC program offices may conduct additional core mission computing activities enabled by infrastructure upgrades within this project.

The data volume generated by the RHIC experiments and ATLAS is expected to increase three to six times over the next ten years and will require proportional increases in computation and data storage capacities. Almost half of the current RACF computing and data storage facility is expected to become functionally obsolete and incapable of accommodating future generations of computation and data storage technologies over the next five to ten years. Therefore, the projected capability gaps in computing infrastructure are due to a combination of decreases due to degrading capacities and increases

[a] Other project costs (OPC) are funded through laboratory overhead.

[b] This project has not received CD-2 approval; funding estimates are consistent with the approved cost ranges. The approved TEC for this project is $67,650,000 to $83,650,000. The approved TPC range for this project is $68,500,000 to $84,500,000.

in future requirements of mid-scale computing performed by RACF. Increases in computation and data storage will drive increased requirements for space, power, and cooling of computing facilities. Similarly, as research experiments utilizing the beamlines at BNL's National Synchrotron Light Source-II, and funded by SC's Basic Energy Science program office are fully developed, additional core mission computing will be required. A mission need therefore exists to provide sufficient, mid-range computation and data storage capabilities to support the current and planned experiments at BNL.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, Program and Project Management for the Acquisition of Capital Assets.

5. Financial Schedule

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Total Estimated Cost (TEC)			
Design			
FY 2017	1,800	1,800	28
FY 2018	1,500	1,500	2,500
FY 2019	3,700	3,700	4,472
Total, Design	7,000	7,000	7,000
Construction			
FY 2019	9,932	9,932	8,000
FY 2020	25,000	25,000	20,000
FY 2021	32,068	32,068	25,000
FY 2022	0	0	14,000
Total, Construction	67,000	67,000	67,000
TEC			
FY 2017	1,800	1,800	28
FY 2018	1,500	1,500	2,500
FY 2019	13,632	13,632	12,472
FY 2020	25,000	25,000	20,000
FY 2021	32,068	32,068	25,000
FY 2022	0	0	14,000
Total, TEC[b]	74,000	74,000	74,000
Other Project Cost (OPC)[c]			
OPC except D&D			
FY 2016	659	659	659
FY 2017	80	80	80
FY 2023	111	111	111
Total, OPC	850	850	850

[a] Costs through FY 2017 reflect actual costs; costs for FY 2018 and the outyears are estimates.
[b] This project has not received CD-2 approval; funding estimates are consistent with the approved cost ranges. The approved TEC for this project is $67,650,000 to $83,650,000. The approved TPC range for this project is $68,500,000 to $84,500,000.
[c] Other Project Costs (OPC) are funded through laboratory overhead.

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Total Project Cost (TPC)			
FY 2016	850	850	659
FY 2017	1,800	1,800	108
FY 2018	1,500	1,500	2,500
FY 2019	13,632	13,632	12,472
FY 2020	25,000	25,000	20,000
FY 2021	32,068	32,068	25,000
FY 2022	0	0	14,000
FY 2023	0	0	111
Total, TPC[b]	74,850	74,850	74,850

6. Details of Project Cost Estimate

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	5,600	5,600	N/A
Contingency	1,400	1,400	N/A
Total, Design	7,000	7,000	N/A
Construction			
Construction	53,600	53,600	N/A
Contingency	13,400	13,400	N/A
Total, Construction	67,000	67,000	N/A
			N/A
Total, TEC[b]	74,000	74,000	N/A
Contingency, TEC	14,800	14,800	N/A
Other Project Cost (OPC)[c]			
OPC except D&D			
Conceptual Planning	534	229	N/A
Conceptual Design	201	451	N/A
Start-up	72	0	N/A
Contingency	43	170	N/A
Total, OPC	850	850	N/A
Contingency, OPC	43	170	N/A
Total, TPC[b]	74,850	74,850	N/A
Total, Contingency	14,843	14,970	N/A

[a] Costs through FY 2017 reflect actual costs; costs for FY 2018 and the outyears are estimates.
[b] This project has not received CD-2 approval; funding estimates are consistent with the approved cost ranges. The approved TEC for this project is $67,650,000 to $83,650,000. The approved TPC range for this project is $68,500,000 to $84,500,000.
[c] Other Project Costs (OPC) are funded through laboratory overhead.

7. Schedule of Appropriation Requests

(dollars in thousands)

Request Year		FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	Total
FY 2017	TEC	0	1,800	TBD	TBD	TBD	TBD	TBD	74,000[a]
	OPC[b]	850	0	TBD	TBD	TBD	TBD	TBD	850
	TPC	850	1,800	TBD	TBD	TBD	TBD	TBD	74,850[a]
FY 2018	TEC	0	1,800	1,500	TBD	TBD	TBD	TBD	74,000[a]
	OPC[b]	850	0	0	TBD	TBD	TBD	TBD	850
	TPC	850	1,800	1,500	TBD	TBD	TBD	TBD	74,850[a]
FY 2019	TEC	0	1,800	1,500	13,632	25,000	32,068	0	74,000[a]
	OPC[b]	850	0	0	0	0	0	0	850
	TPC	850	1,800	1,500	13,632	25,000	32,068	0	74,850[a]

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	4Q FY 2024
Expected Useful Life	25 years
Expected Future Start of D&D of this capital asset	N/A

(Related Funding requirements)

(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Current Total Estimate	Previous Total Estimate	Current Total Estimate	Previous Total Estimate
Operations	N/A	N/A	N/A	N/A
Utilities	2,000	N/A	44,284	N/A
Maintenance and Repair	723	N/A	16,011	N/A
Total, Operations & Maintenance	2,723	N/A	60,295	N/A

9. D&D Information

The new area that will be constructed in this project will not replace existing facilities.

	Square Feet
New area being constructed by this project at Brookhaven *National Laboratory*……………………	None
Area of D&D in this project at Brookhaven *National Laboratory* ……………………………………………	None
Area at Brookhaven *National Laboratory* to be transferred, sold, and/or D&D outside the project including area previously "banked…………………………………………………………………………….	None[c]
Area of D&D in this project at other sites…………………………………………………………………………	None
Area at other sites to be transferred, sold, and/or D&D outside the project including area previously "banked……	None
Total area eliminated…………………………………………………………………………………………………	None

[a] This project has not received CD-2 approval; funding estimates are consistent with the approved cost ranges. The approved TEC for this project is $67,650,000 to $83,650,000. The approved TPC range for this project is $68,500,000 to $84,500,000.
[b] Other Project Costs (OPC) are funded through laboratory overhead.
[c] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

10. Acquisition Approach

Acquisition for this project will be performed by the BNL Management and Operating (M&O) Contractor, Brookhaven Science Associates, and overseen by the Brookhaven Site Office. Various acquisition and project delivery methods were evaluated prior to achieving CD-1. A Construction Manager/General Contractor (CM/GC) project delivery with best value procurement approach was selected as the overall best delivery method with the lowest risk to DOE. The M&O Contractor is responsible for awarding and administering all subcontracts related to this project. Project performance metrics are included in the M&O Contractor's annual performance and evaluation measurement plan.

15-SC-76, Materials Design Laboratory
Argonne National Laboratory (ANL), Argonne, IL
Project is for Design and Construction

1. Significant Changes and Summary

Significant Changes
This Construction Project Data Sheet (CPDS) is an update of the FY 2018 CPDS and does not include a new start for FY 2019.

Summary
The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-3, Approve Start of Construction, which was approved on August 12, 2016. The approved Total Estimated Cost (TEC) for this project is $95,000,000. The approved Total Project Cost (TPC) for this project is $96,000,000.

A Federal Project Director with the appropriate certification level has been assigned to this project and has approved this CPDS.

This project will provide new laboratory and office space to support basic energy-related materials science and engineering research. Final Design was completed in May 2016. Construction began in February 2017.

FY 2019 funds represent final funding for the project and will be used to complete construction.

2. Critical Milestone History

(fiscal quarter or date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2015	08/27/2010	N/A	4Q FY 2014	4QFY 2015	4Q FY 2016	3Q FY 2016	N/A	2Q FY 2020
FY 2016	08/27/2010	1Q FY 2015	2Q FY 2015	2Q FY 2016	3Q FY 2017	1Q FY 2017	N/A	3Q FY 2020
FY 2017	08/27/2010	11/12/2014	01/30/2015	2Q FY 2016	3Q FY 2017	1Q FY 2017	N/A	3Q FY 2020
FY 2018	08/27/2010	11/12/2014	01/30/2015	03/18/2016	05/09/2016	08/12/2016	N/A	3Q FY 2021
FY 2019	08/27/2010	11/12/2014	01/30/2015	03/18/2016	05/09/2016	08/12/2016	N/A	3Q FY 2021

CD-0 – Approve Mission Need
Conceptual Design Complete – Actual date the conceptual design was completed
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
Final Design Complete – Actual date the final design was completed
CD-3 – Approve Start of Construction
D&D Complete – Completion of D&D Work (see section 9)
CD-4 – Approve Project Completion

	Performance Baseline Validation
FY 2015	N/A
FY 2016	1Q FY 2017
FY 2017	3Q FY 2016
FY 2018	03/18/2016
FY 2019	03/18/2016

3. Project Cost History

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC[a] Except D&D	OPC, D&D	OPC, Total	TPC
FY 2015	7,000	88,000	95,000	1,000	N/A	1,000	96,000
FY 2016	7,000	88,000	95,000	1,000	N/A	1,000	96,000
FY 2017	7,000	88,000	95,000	1,000	N/A	1,000	96,000
FY 2018	7,000	88,000	95,000	1,000	N/A	1,000	96,000
FY 2019	7,000	88,000	95,000	1,000	N/A	1,000	96,000

4. Project Scope and Justification

Scope

The scope of this project includes the design and construction of a Materials Design Laboratory building approximately 115,000 gross square feet in size and located adjacent to the recently completed Energy Sciences Building.

Justification

The mission need of this project is to provide flexible and sustainable laboratory and office space needed to support scientific theory/simulation, materials discovery, characterization, and application of new energy-related materials and processes. The Materials Design Laboratory project will provide the modern collaborative scientific environment critical for this initiative to thrive and will focus on four themes central to implementing the Materials for Energy strategy:

- Frontiers of materials and molecular synthesis, and fabrication of devices;
- Interfacial engineering for energy applications;
- Materials under extreme conditions; and
- *In situ* characterization and modeling.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, Program and all Project Management for the Acquisition of Capital Assets.

The table below outlines the Key Performance Parameters.

Key Performance Parameters

Description	Threshold Value (Minimum)	Objective Value (Maximum)
Multi-story laboratory building	97,000 gross square feet	130,000 gross square feet

5. Financial Schedule

(dollars in thousands)

	Appropriations	Obligations	Costs[b]
Total Estimated Cost (TEC)			
Design			
FY 2015	7,000	7,000	2,773
FY 2016	0	0	3,998
FY 2017	0	0	229
Total, Design	7,000	7,000	7,000

[a] Other project costs (OPC) are funded through laboratory overhead.
[b] Costs through FY 2017 reflect actual costs; costs for FY 2018 and the outyears are estimates.

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Construction			
FY 2016	23,910	23,910	0
FY 2017	19,590	19,590	17,551
FY 2018	24,500	24,500	27,000
FY 2019	20,000	20,000	32,000
FY 2020	0	0	11,449
Total, Construction	88,000	88,000	88,000
TEC			
FY 2015	7,000	7,000	2,773
FY 2016	23,910	23,910	3,998
FY 2017	19,590	19,590	17,780
FY 2018	24,500	24,500	27,000
FY 2019	20,000	20,000	32,000
FY 2020	0	0	11,449
Total, TEC	95,000	95,000	95,000
Other Project Cost (OPC)[b]			
OPC except D&D			
FY 2010	382	382	382
FY 2011	0[c]	0[c]	0[c]
FY 2014	328	328	328
FY 2015	290	290	290
Total, OPC except D&D	1,000	1,000	1,000
Total Project Cost (TPC)			
FY 2010	382	382	382
FY 2011	0[c]	0[c]	0[c]
FY 2014	328	328	328
FY 2015	7,290	7,290	3,063
FY 2016	23,910	23,910	3,998
FY 2017	19,590	19,590	17,780
FY 2018	24,500	24,500	27,000
FY 2019	20,000	20,000	32,000
FY 2020	0	0	11,449
Total, TPC	96,000	96,000	96,000

[a] Costs through FY 2017 reflect actual costs; costs for FY 2018 and the outyears are estimates.
[b] OPC are funded through laboratory overhead.
[c] OPC Funding was adjusted to reflect FY 2010 actuals ($382,000 for OPC funding in FY 2010).

6. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	7,000	6,000	6,647
Contingency	0	1,000	353
Total, Design	7,000	7,000	7,000
Construction			
Construction	76,004	73,000	76,362
Contingency	11,996	15,000	11,638
Total, Construction	88,000	88,000	88,000
Total, TEC	95,000	95,000	95,000
Contingency, TEC	11,996	16,000	11,991
Other Project Cost (OPC)[a]			
OPC except D&D			
Conceptual Planning	382	382	382
Conceptual Design	618	500	618
Contingency	0	118	0
Total, OPC	1,000	1,000	1,000
Contingency, OPC	0	118	0
Total, TPC	96,000	96,000	96,000
Total, Contingency	11,996	16,118	11,991

7. Schedule of Appropriation Requests

(dollars in thousands)

Request Year		Prior Years	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	Total
FY 2015	TEC	0	0	7,000	24,003	36,466	27,531	0	95,000
	OPC[a]	382	500	0	0	0	118	0	1,000
	TPC	382	500	7,000	24,003	36,466	27,649	0	96,000
FY 2016	TEC	0	0	7,000	23,910	25,090	39,000	0	95,000
	OPC[a]	382	300	0	0	0	318	0	1,000
	TPC	382	300	7,000	23,910	25,090	39,318	0	96,000
FY 2017	TEC	0	0	7,000	23,910	25,090	39,000	0	95,000
	OPC[a]	382	300	0	0	0	318	0	1,000
	TPC	382	300	7,000	23,910	25,090	39,318	0	96,000
FY 2018	TEC	0	0	7,000	23,910	19,590	24,500	20,000	95,000
	OPC[a]	382	328	290	0	0	0	0	1,000
	TPC	382	328	7,290	23,910	19,590	24,500	20,000	96,000

[a] OPC are funded through laboratory overhead.

(dollars in thousands)									
Request Year		Prior Years	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	Total
FY 2019	TEC	0	0	7,000	23,910	19,590	24,500	20,000	95,000
	OPC[a]	382	328	290	0	0	0	0	1,000
	TPC	382	328	7,290	23,910	19,590	24,500	20,000	96,000

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy Expected…………………………………………………………………………	2Q FY 2021
Useful Life………	50 years
Expected Future Start of D&D of this capital asset………………………………………………………………………	2Q FY 2071

(Related Funding Requirements)

	(dollars in thousands)			
	Annual Costs		Life-Cycle Costs	
	Current Total Estimates	Previous Total Estimates	Current Total Estimates	Previous Total Estimates
Operations	376	376	18,800	18,800
Utilities	429	429	21,450	21,450
Maintenance and Repair	958	958	47,900	47,900
Total – Operations and Maintenance	1,763	1,763	88,150	88,150

9. D&D Information

The new area being constructed in this project is not replacing existing facilities.

	Square Feet
New area being constructed by this project at *Argonne National Laboratory*………………………………………………………………………………………… ..	115,000
Area of D&D in this project at *Argonne National Laboratory*…………………………..	None
Area at *Argonne National Laboratory* to be transferred, sold, and/or D&D outside the project including area previously banked”…………………………………	None
Area of D&D in this project at other sites………………………………………………………..	None
Area at other sites to be transferred, sold, and/or D&D outside the project including area previously "banked"……………………………………………………………….	None[b]
Total area eliminated……………………………………………………………………………………	None

[a] OPC are funded through laboratory overhead.

[b] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

10. Acquisition Approach

Acquisition for this project will be performed by the Management and Operating (M&O) Contractor, UChicago Argonne, LLC, and will be overseen by the Argonne Site Office. Various acquisition approaches and project delivery methods were evaluated prior to achieving CD-1. A tailored Design-Bid-Build approach was selected as the overall best project delivery method with the lowest risk to DOE. The M&O Contractor is responsible for awarding and administering all subcontracts related to this project. Project performance metrics are included in the M&O Contractor's annual performance evaluation and measurement plan.

15-SC-78, Integrative Genomics Building
Lawrence Berkeley National Laboratory (LBNL), Berkeley, CA
Project is for Design and Construction

1. Significant Changes and Summary

Significant Changes
This Construction Project Data Sheet (CPDS) is an update of the FY 2018 CPDS and does not include a new start for FY 2019.

Summary
The most recent DOE Order 413.3B Critical Decision (CD) is CD-3, Approve Start of Construction, was approved on October 7, 2016. The approved Total Estimated Cost (TEC) for this project is $90,000,000. The approved Total Project Cost (TPC) for this project is $91,500,000.

A Federal Project Director with the appropriate certification level has been assigned to this project and has approved this CPDS.

This project will provide new space necessary to relocate a significant fraction of biosciences research currently occupying leased commercial space onto the main Lawrence Berkeley National Laboratory (LBNL) campus. Final Design was completed in May 2016. Construction started in December 2016.

FY 2019 funds represent final funding for the project and will be used to complete construction.

2. Critical Milestone History

(fiscal quarter to date)

	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2015	9/17/2013	N/A	1Q FY 2015	3Q FY 2016	4Q FY 2016	3Q FY 2016	N/A	1Q FY 2021
FY 2016	9/17/2013	1Q FY 2015	2Q FY 2015	2Q FY 2016	3Q FY 2016	4Q FY 2016	N/A	1Q FY 2021
FY 2017	9/17/2013	10/28/2014	02/20/2015	2Q FY 2016	3Q FY 2016	1Q FY 2017	N/A	1Q FY 2021
FY 2018	9/17/2013	10/28/2014	02/20/2015	3/18/2016	5/2/2016	10/7/2016	N/A	1Q FY 2021
FY 2019	9/17/2013	10/28/2014	02/20/2015	3/18/2016	5/2/2016	10/7/2016	N/A	1Q FY 2021

CD-0 – Approve Mission Need
Conceptual Design Complete – Actual date the conceptual design was completed
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
Final Design Complete – Estimated date the project design will be completed
CD-3– Approve Start of Construction
D&D Complete – Completion of D&D work (see Section 9)
CD-4 – Approve Project Completion

	Performance Baseline Validation
FY 2015	N/A
FY 2016	N/A
FY 2017	2Q FY 2016
FY 2018PB	3/18/2016
FY 2019	3/18/2016

3. Project Cost History

(dollars in thousands)

	TEC, Design	TEC, Construction	TEC, Total	OPC[a] Except D&D	OPC, D&D	OPC, Total	TPC
FY 2015	12,090	77,910	90,000	1,500	0	1,500	91,500
FY 2016	9,590	80,410	90,000	1,500	0	1,500	91,500
FY 2017	6,500	83,500	90,000	1,500	0	1,500	91,500
FY 2018	6,900	83,100	90,000	1,500	0	1,500	91,500
FY 2019	6,900	83,100	90,000	1,500	0	1,500	91,500

4. Project Scope and Justification

Scope

The scope of this project includes the design and construction of a new state-of-the-art facility for bioscience research approximately 80,800 gross square feet in size and located on the main LBNL campus in Berkeley, California. The facility will be physically located on the former site of the demolished Bevatron particle accelerator.

The table below outlines the Key Performance Parameters.

Key Performance Parameters

Description	Threshold Value (Minimum)	Objective Value (Maximum)
Biosciences and other research space	79,000 gross square feet	95,000 gross square feet

Justification

The mission need of this project is to increase the synergy and efficiency of biosciences and other research at LBNL. LBNL has grown from a pioneering particle and nuclear physics laboratory into a multidisciplinary research facility with broad capabilities in physical, chemical, computational, biological, and environmental systems research in support of the Department of Energy (DOE) mission. Portions of the biosciences program at LBNL are located off-site, away from the main laboratory, and dispersed across several locations approximately twenty miles apart. This arrangement has produced research and operational capability gaps that limit scientific progress, in genomics-based biology related to energy and the environment. This project will close the present capability gaps by providing a state-of-the-art facility that will collocate biosciences research and other programs.

FY 2019 funds will be used for construction and project management and support activities.

The project is being conducted in accordance with the project management requirements in DOE Order 413.3B, Program and all Project Management for the Acquisition of Capital Assets.

[a] Other project costs (OPC) are funded through laboratory overhead.

5. Financial Schedule

	(dollars in thousands)		
	Appropriations	Obligations	Costs[a]
Total Estimated Cost (TEC)			
Design			
FY 2015	6,900	6,900	2,086
FY 2016	0	0	4,541
FY 2017	0	0	273
Total, Design	6,900	6,900	6,900
Construction			
FY 2015	5,190	5,190	0
FY 2016	20,000	20,000	0
FY 2017	19,561	19,561	18,077
FY 2018	24,800	24,800	50,000
FY 2019	13,549	13,549	15,023
Total, Construction	83,100	83,100	83,100
TEC			
FY 2015	12,090	12,090	2,086
FY 2016	20,000	20,000	4,541
FY 2017	19,561	19,561	18,350
FY 2018	24,800	24,800	50,000
FY 2019	13,549	13,549	15,023
Total, TEC	90,000	90,000	90,000
Other Project Cost (OPC)[b]			
OPC except D&D			
FY 2014	1,145	1,145	1,145
FY 2015	355	355	355
Total, OPC	1,500	1,500	1,500
Total Project Cost (TPC)			
FY 2014	1,145	1,145	1,145
FY 2015	12,445	12,445	2,441
FY 2016	20,000	20,000	4,541
FY 2017	19,561	19,561	18,350
FY 2018	24,800	24,800	50,000
FY 2019	13,549	13,549	15,023
Total, TPC	91,500	91,500	91,500

[a] Costs through FY 2017 reflect actual costs; costs for FY 2018 and the outyears are estimates.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

6. Details of Project Cost Estimate

	(dollars in thousands)		
	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	6,900	5,964	6,216
Contingency	0	536	684
Total, Design	6,900	6,500	6,900
Construction			
Construction	73,950	71,265	71,495
Contingency	9,150	12,235	11,605
Total, Construction	83,100	83,500	83,100
Total, TEC	90,000	90,000	90,000
Contingency, TEC	9,150	12,771	12,289
Other Project Cost (OPC)[a]			
OPC except D&D			
Conceptual Planning	400	355	355
Conceptual Design	1,000	1,145	1,145
Contingency	100	0	0
Total, OPC	1,500	1,500	1,500
Contingency, OPC	100	0	0
Total, TPC	91,500	91,500	91,500
Total, Contingency	9,250	12,771	12,289

7. Schedule of Appropriation Requests

Request Year		FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	Total
		(dollars in thousands)						
FY 2015	TEC	0	12,090	17,299	30,148	30,463	0	90,000
	OPC[a]	1,300	0	0	0	0	200	1,500
	TPC	1,300	12,090	17,299	30,148	30,463	200	91,500
FY 2016	TEC	0	12,090	20,000	25,064	32,846	0	90,000
	OPC[a]	1,500	0	0	0	0	0	1,500
	TPC	1,500	12,090	20,000	25,064	32,846	0	91,500
FY 2017	TEC	0	12,090	20,000	19,561	38,349	0	90,000
	OPC[a]	1,145	355	0	0	0	0	1,500
	TPC	1,145	12,445	20,000	19,561	38,349	0	91,500
FY 2018	TEC	0	12,090	20,000	19,561	24,800	13,549	90,000
	OPC[a]	1,500	0	0	0	0	0	1,500
	TPC	1,500	12,090	20,000	19,561	24,800	13,549	91,500

[a] Other Project Costs (OPC) are funded through laboratory overhead.

Request Year		(dollars in thousands) FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	Total
FY 2019	TEC	0	12,090	20,000	19,561	24,800	13,549	90,000
	OPC[a]	1,500	0	0	0	0	0	1,500
	TPC	1,500	12,090	20,000	19,561	24,800	13,549	91,500

8. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	1QFY 2021
Expected Useful Life	50 years
Expected Future Start of D&D of this capital asset	1QFY 2071

(Related Funding requirements)

(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Current Total Estimate	Previous Total Estimate	Current Total Estimate	Previous Total Estimate
Operations	179	179	5,735	5,735
Utilities	324	324	11,919	11,919
Maintenance and Repair	644	644	20,662	20,662
Total, Operations & Maintenance	1,147	1,147	38,316	38,316

9. D&D Information

The new area that will be constructed in this project will not replace existing facilities.

	Square Feet
New area being constructed by this project at *Lawrence Berkeley National Laboratory*……………………………………………………………………………………………………..	80,880
Area of D&D in this project at *Lawrence Berkeley National Laboratory* …………………	None
Area at *Lawrence Berkeley National Laboratory* to be transferred, sold, and/or D&D outside the project including area previously "banked"………………………………	None[b]
Area of D&D in this project at other sites…………………………………………………………….	None
Area at other sites to be transferred, sold, and/or D&D outside the project including area previously "banked"…………………………………………………………………….	None
Total area eliminated………………………………………………………………………………………	None

10. Acquisition Approach

Acquisition for this project will be performed by the Management and Operating (M&O) Contractor, University of California, and overseen by the Berkeley Site Office. Various acquisition approaches and project delivery methods were evaluated prior to achieving CD-1. A tailored Design-Bid-Build approach with a Construction Manager as General Contractor was selected as the overall best project delivery method with the lowest risk to DOE. The M&O contractor is responsible for awarding and administering all subcontracts related to this project. Project performance metrics are included in the M&O contractor's annual performance evaluation and measurement plan.

[a] Other Project Costs (OPC) are funded through laboratory overhead.

[b] With the implementation of OMB's Reduce the Footprint initiative, DOE no longer maintains the space bank. Footprint is managed using the Facility Information Management System, with decisions on additions and offsets made in accordance with the DOE Real Property Efficiency Plan.

Safeguards and Security

Overview
The Office of Science (SC) Safeguards and Security (S&S) program is designed to ensure appropriate security measures are in place to support the SC mission requirements of open scientific research and protecting critical assets within SC laboratories. Accomplishing this mission depends on providing physical controls that will mitigate possible risks to the laboratories' employees, nuclear and special materials, classified and sensitive information, and facilities. The SC S&S program also provides funding for cybersecurity for the laboratories' information technology systems to protect computers, networks, and data from unauthorized access.

Highlights of the FY 2019 Budget Request
The FY 2019 Request supports sustained levels of operations in S&S program elements, including Protective Forces, Security Systems, Information Security, Personnel Security, Material Control and Accountability, and Program Management.

The highest priority in the S&S program is to ensure adequate security for the special nuclear material housed in Building 3019 at the Oak Ridge National Laboratory (ORNL).

Another key priority in the FY 2019 Request is to ensure that the Cyber Security element maintains the ability to detect, mitigate, and recover from cyber intrusions and attacks against protected information. In addition, the Request addresses cybersecurity infrastructure necessary to provide security for commensurate investments in IT.

Within the S&S FY 2019 Request, SC supports the Cybersecurity Departmental Crosscut. This includes the Department's CyberOne strategy for managing enterprise-wide cybersecurity and identity authentication for Department of Energy (DOE) IT systems. The CyberOne strategy provides improved Department-wide capabilities for incident management and logical access to federal IT systems.

FY 2019 Crosscuts ($K)

	Cybersecurity
Safeguards and Security	35,332[a]

Description
The S&S program is organized into seven program elements: Protective Forces, Security Systems, Information Security, Cyber Security, Personnel Security, Material Control and Accountability, and Program Management.

Protective Forces

The Protective Forces program element supports security officers, access control officers, and security policy officers assigned to protect S&S interests, along with their related equipment and training. Activities within this program element include access control and security response operations as well as physical protection of the Department's critical assets and SC facilities. The Protective Forces mission includes providing effective response to emergency situations, random prohibited article inspections, security alarm monitoring, and performance testing of the protective force response to various event scenarios.

Security Systems

The Security Systems program element provides physical protection of Departmental personnel, material, equipment, property, and facilities, and includes fences, barriers, lighting, sensors, surveillance devices, entry control devices, access control systems, and power systems operated and used to support the protection of DOE property, classified information, and other interests of national security.

[a] The Cyber Security amount includes $6,435,000 for CyberOne funded through the Working Capital Fund (WCF).

Information Security
The Information Security program element provides support to ensure that sensitive and classified information is accurately, appropriately, and consistently identified, reviewed, marked, protected, transmitted, stored, and ultimately destroyed. Specific activities within this element include management, planning, training, and oversight for maintaining security containers and combinations, marking documents, and administration of control systems, operations security, special access programs, technical surveillance countermeasures, and classification and declassification determinations.

Cyber Security
SC is engaged in protecting the enterprise from a range of cyber threats that can adversely impact mission capabilities. The Cyber Security program element, which supports the Cybersecurity Departmental Crosscut, provides central coordination of the strategic and operational aspects of cybersecurity and facilitates cooperative efforts such as the Joint Cybersecurity Coordination Center (JC3) for incident response and the implementation of Department-wide Identity, Credentials, and Access Management (ICAM).

Personnel Security
The Personnel Security program element encompasses the processes for employee suitability and security clearance determinations at each site to ensure that individuals are trustworthy and eligible for access to classified information or matter. This element also includes the management of security clearance programs, adjudications, security education, awareness programs for Federal and contractor employees, and processing and hosting approved foreign visitors.

Material Control and Accountability (MC&A)
The MC&A program element provides assurance that Departmental materials are properly controlled and accounted for at all times. This element supports administration, including testing performance and assessing the levels of protection, control, and accountability required for the types and quantities of materials at each facility; documenting facility plans for materials control and accountability; assigning authorities and responsibilities for MC&A functions; and establishing programs to detect and report occurrences such as material theft, the loss of control or inability to account for materials, or evidence of malevolent acts.

Program Management
The Program Management program element coordinates the management of Protective Forces, Security Systems, Information Security, Personnel Security, Cyber Security, and MC&A to achieve and ensure appropriate levels of protections are in place.

Safeguards and Security
Funding ($K)

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Protective Forces	39,638	–	41,559	+1,921
Security Systems	10,357	–	10,370	+13
Information Security	4,467	–	4,356	-111
Cyber Security[b]	33,236	–	35,332	+2,096
Personnel Security	6,086	–	5,444	-642
Material Control and Accountability	2,458	–	2,431	-27
Program Management	6,758	–	6,618	-140
Total, Safeguards and Security	**103,000**	**102,301**	**106,110**	**+3,110**

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

[b]The Cyber Security amount includes $6,039,000 in FY 2017 and $6,435,000 in FY 2019 for CyberOne through the Working Capital Fund (WCF).

Safeguards and Security

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Protective Forces $39,638,000	**$41,559,000**	**+$1,921,000**
Provided funding to maintain proper protection levels, equipment, and technical training needed to ensure effective performance at all SC laboratories.	Continues funding to maintain proper protection levels, equipment, and technical training needed to ensure effective performance at all SC laboratories.	The increase supports protection of the special nuclear material housed in Building 3019 at ORNL, addresses contractual cost of living adjustments, and supports sustained levels of operations across all SC laboratories.
Security Systems $10,357,000	**$10,370,000**	**+$13,000**
Provided funding to maintain the security systems currently in place.	Continues funding to maintain the security systems currently in place.	The increase will ensure proper physical security systems are in place across the SC complex.
Information Security $4,467,000	**$4,356,000**	**-$111,000**
Provided funding to maintain personnel, equipment, and systems necessary to ensure sensitive and classified information is safeguarded at SC laboratories.	Continues funding to maintain personnel, equipment, and systems necessary to ensure sensitive and classified information is safeguarded at SC laboratories.	Information Security decreases to focus efforts on high priority cybersecurity activities.
Cyber Security $33,236,000	**$35,332,000**	**+$2,096,000**
Provided funding to maintain protection of laboratory computers, networks, and data from unauthorized access. This level also continued support of the Department's CyberOne strategy.	Continues funding to maintain a proper level of protection of laboratory computers, networks, and data from unauthorized access. The Request also continues support of the Department's CyberOne strategy.	The increase will provide funding to support enhanced Cyber Security protection from cyber intrusions and attacks against protected information. The increase also supports the Department's CyberOne strategy.
Personnel Security $6,086,000	**$5,444,000**	**-$642,000**
Provided funding to maintain Personnel Security efforts at SC laboratories.	Continues funding to maintain Personnel Security efforts at SC laboratories. Funding is requested to support SC Headquarters security investigations.	Personnel Security decreases to focus efforts on high priority cybersecurity activities. The Request includes additional funding for security investigations that will support the consolidation of Headquarters security investigations and clearances in SC.

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Materials Control and Accountability $2,458,000	**$2,431,000**	**-$27,000**
Provided funding to maintain protection of material at SC laboratories.	Continues funding to maintain protection of material at SC laboratories.	Materials Control and Accountability decreases slightly to focus efforts on high priority cybersecurity activities.
Program Management $6,758,000	**$6,618,000**	**-$140,000**
Provided funding to maintain oversight, administration, and planning for security programs at SC laboratories and supported security procedures and policy support for SC Research missions.	Continues funding to maintain oversight, administration, and planning for security programs at SC laboratories and will support security procedures and policy support for SC Research missions.	Program management decreases to focus efforts on high priority cybersecurity activities.

Estimates of Cost Recovered for Safeguards and Security Activities ($K)

In addition to the direct funding received from S&S, sites recover Safeguards and Security costs related to Strategic Partnerships Projects (SPP) activities from SPP customers, including the cost of any unique security needs directly attributable to the customer. Estimates of those costs are shown below.

	FY 2017 Planned Costs	FY 2018 Planned Costs	FY 2019 Planned Costs
Ames National Laboratory	40	40	75
Argonne National Laboratory	1,100	1,100	1,500
Brookhaven National Laboratory	1,218	915	911
Lawrence Berkeley National Laboratory	1,010	1,007	966
Oak Ridge Institute for Science and Education	677	509	512
Oak Ridge National Laboratory	4,710	5,428	5,428
Pacific Northwest National Laboratory	4,781	5,000	5,001
Princeton Plasma Physics Laboratory	50	55	55
SLAC National Accelerator Laboratory	135	158	235
Total, Security Cost Recovered	**13,721**	**14,212**	**14,683**

Program Direction

Overview

Program Direction (PD) in the Office of Science (SC) supports a highly skilled federal workforce to develop and oversee SC investments in basic research and construction and operation of scientific user facilities, which are critical to the American scientific enterprise. SC is the largest federal sponsor of basic research in the physical sciences in the U.S. SC research and facility investments transform our understanding of nature and advance the energy, economic, and national security of the United States. In addition, SC accelerates discovery and innovation by providing broad public access to all DOE research and development findings.

SC requires sophisticated and experienced scientific and technical program and project managers, as well as experts in acquisition; finance; legal; construction management; and environmental, safety, and health oversight. The SC basic research portfolio includes extramural grants and contracts supporting over 22,000 researchers located at over 300 institutions and the 17 DOE national laboratories, spanning all fifty states and the District of Columbia. The portfolio of 26 scientific user facilities serves nearly 32,000 users per year.

Headquarters (HQ)

The SC HQ includes the six SC research program offices (Advanced Scientific Computing Research, Basic Energy Sciences, Biological and Environmental Research, Fusion Energy Sciences, High Energy Physics, and Nuclear Physics), Workforce Development for Teachers and Scientists, Project Assessment, and SBIR/STTR Programs Offices, as well as several resource management functions, and HQ-based field management functions. The SC HQ federal staff:

- Conduct scientific program and research infrastructure planning, execution, and management across SC, in part by extensive engagement with the scientific community to identify research opportunities and develop priorities.
- Establish and maintain competitive research portfolios, which include high-risk, high-reward research, to achieve mission goals and objectives.
- Conduct rigorous external peer review of research proposals and ongoing programs. Each year, SC manages nearly 5,000 ongoing laboratory, university, non-profit, and private industry research awards and conducts over 12,000 peer reviews of new and renewal proposals.
- Provide safety, security, and infrastructure oversight and management of all SC user facilities and other current research investments.
- Ensure the production, certification, and distribution of nuclear reference materials for a wide variety of users.
- Provide oversight and management of all line item construction projects and other capital asset projects.
- Provide oversight and management of the maintenance and operational integrity of the ten SC-stewarded national laboratories.
- Provide policy, strategy, and resource management in the areas of laboratory oversight, information technology, grants and contracts, budget, and human capital.

Office of Scientific and Technical Information (OSTI)

OSTI fulfills the Department’s responsibilities for providing public access to the unclassified results of its research investments and limited access to classified research results. DOE researchers produce over 50,000 research publications, datasets, software, and patents annually. OSTI's physical and electronic collections exceed one million research outputs from the 1940s to the present, providing access to the results of DOE’s research investments. OSTI implements DOE’s public access mandates, including the government-wide requirement that peer-reviewed publications resulting from federal funding is made available to the public within 12 months of publication in a journal.

Integrated Support Center (ISC)

The ISC, located at the Chicago and Oak Ridge Offices, provides business management to support SC’s federal responsibilities. These functions include legal and technical support; financial management; grant and contract processing; safety, security, and health management; intellectual property and patent management; environmental compliance; facility infrastructure operations and maintenance; and information systems development and support. As part of this, the ISC:

- Monitors the multi-appropriation, multi-program allotments for all ten SC national laboratories through administration of laboratory Management and Operating (M&O) contracts and is responsible for over 3,000 grants per year to university-based researchers.
- Provides support to SC and other DOE programs for solicitations and funding opportunity announcements, as well as the negotiation, award, administration, and closeout of contracts and financial assistance awards using certified contracting officers and professional acquisition staff.

Site Offices

SC site offices provide contract management and critical support for the scientific mission execution at ten SC national laboratories. This includes day-to-day business management; approvals to operate hazardous facilities; safety and security oversight; leases; property transfers; sub-contracts; and activity approvals required by laws, regulations, and DOE policy. As part of this, the site offices:

- Maintain a comprehensive contract management program to ensure contractual mechanisms are managed effectively and consistently with guidelines and regulations.
- Evaluate laboratory activities including nuclear, radiological, and other complex hazards.
- Provide federal project directors to oversee construction projects and other major capital asset projects.

Highlights of the FY 2019 Request

The FY 2019 Request of $180,000,000 will support a total level of approximately 835 FTEs. SC will utilize available human capital workforce reshaping tools to manage its FTEs in a manner consistent with its long-term workforce restructuring plan as part of the DOE Agency Reform Plan[a]. SC will continue to review, analyze, and prioritize mission requirements and identify those organizations and functions aligning with Administration and Department program objectives and SC strategic goals while maximizing efficiency through functional consolidation.

The FY 2019 Request includes:
- Two (2) FTEs in the Office of Planning and Management Oversight to support the Office of the Under Secretary for Science.
- Twenty-two (22) FTEs in the Office of the Chief Human Capital Officer operating the Shared Service Center (SSC) and supporting HR Advisory Offices.
- Three-hundred and four (304) SC Headquarters (HQ) federal staff, spread among the six research program offices, Workforce Development for Teachers and Scientists, Project Assessment, and SBIR/STTR Programs Offices, as well as several resource management functions, and HQ-based field management functions, including the NBL Program Office. The NBL Program Office was established in 2016 as part of a reorganization that restructured the functions and dispositioned the inventory of the New Brunswick Laboratory. The NBL Program Office is organized under the Deputy Director for Field Operations with responsibility for ensuring the production, certification, and distribution of nuclear reference materials for a wide variety of users.
- Forty (40) OSTI federal staff to manage SC's public access program.
- Four-hundred and sixty-seven (467) Integrated Service Center (ISC) and site office federal staff.

[a] OMB Memo M-17-22

Science Program Direction
Funding ($K)

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Headquarters				
Science HQ				
Salaries and Benefits	57,652	–	57,075	-577
Travel	1,151	–	1,513	+362
Support Services	16,956	–	15,040	-1,916
Other Related Expenses	2,706	–	4,345	+1,639
Working Capital Fund	8,142	–	8,150	+8
Total, Science HQ	**86,607**	**–**	**86,123**	**-484**
Under Secretary for Science				
Salaries and Benefits	460	–	440	-20
Other Related Expenses	0	–	400	+400
Total, Under Secretary for Science	**460**	**–**	**840**	**+380**
Human Capital Shared Service Center		–		
Salaries and Benefits	3,455	–	2,750	-705
Other Related Expenses	456	–	400	-56
Total, Human Capital Shared Service Center	**3,911**	**–**	**3,150**	**-761**
Total Headquarters				
Salaries and Benefits	61,567	–	60,265	-1,302
Travel	1,151	–	1,513	+362
Support Services	16,956	–	15,040	-1,916
Other Related Expenses	3,162	–	5,145	+1,983
Working Capital Fund	8,142	–	8,150	+8
Total, Headquarters	**90,978**	**–**	**90,113**	**-865**

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Office of Scientific and Technical Information				
Salaries and Benefits	6,020	–	5,720	-300
Travel	65	–	76	+11
Support Services	1,569	–	1,931	+362
Other Related Expenses	903	–	920	+17
Total, Office of Scientific and Technical Information	**8,557**	**–**	**8,647**	**+90**
Field Offices				
Chicago Office				
Salaries and Benefits	21,312	–	20,562	-750
Travel	124	–	210	+86
Support Services	411	–	680	+269
Other Related Expenses	1,767	–	2,269	+502
Total, Chicago Office	**23,614**	**–**	**23,721**	**+107**
Oak Ridge Office				
Salaries and Benefits	18,864	–	18,492	-372
Travel	173	–	220	+47
Support Services	659	–	1,937	+1,278
Other Related Expenses	3,943	–	3,362	-581
Total, Oak Ridge Office	**23,639**	**–**	**24,011**	**+372**
Ames Site Office				
Salaries and Benefits	636	–	620	-16
Travel	11	–	20	+9
Support Services	2	–	2	0
Total, Ames Site Office	**649**	**–**	**642**	**-7**
Argonne Site Office				
Salaries and Benefits	3,680	–	4,150	+470
Travel	40	–	70	+30
Support Services	138	–	195	+57
Other Related Expenses	39	–	20	-19
Total, Argonne Site Office	**3,897**	**–**	**4,435**	**+538**

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Berkeley Site Office				
Salaries and Benefits	3,114	–	3,560	+446
Travel	30	–	65	+35
Support Services	144	–	215	+71
Other Related Expenses	131	–	105	-26
Total, Berkeley Site Office	**3,419**	**–**	**3,945**	**+526**
Brookhaven Site Office				
Salaries and Benefits	4,163	–	4,071	-92
Travel	63	–	80	+17
Support Services	360	–	334	-26
Other Related Expenses	220	–	287	+67
Total, Brookhaven Site Office	**4,806**	**–**	**4,772**	**-34**
Fermi Site Office				
Salaries and Benefits	2,535	–	2,240	-295
Travel	38	–	80	+42
Support Services	50	–	42	-8
Other Related Expenses	40	–	28	-12
Total, Fermi Site Office	**2,663**	**–**	**2,390**	**-273**
New Brunswick Laboratory Program Office[b]				
Salaries and Benefits	1,043	–	0	-1,043
Travel	63	–	0	-63
Support Services	489	–	0	-489
Other Related Expenses	898	–	0	-898
Total, New Brunswick Laboratory Program Office	**2,493**	**–**	**0**	**-2,493**

[b] The New Brunswick Laboratory was closed and functions have been distributed across multiple national laboratories with a HQ program office overseeing operations. FY 2019 Request for Science HQ will support the NBL Program Office.

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Oak Ridge National Laboratory Site Office				
Salaries and Benefits	5,776	–	5,145	-631
Travel	50	–	80	+30
Support Services	330	–	215	-115
Other Related Expenses	30	–	25	-5
Total, Oak Ridge National Laboratory Site Office	**6,186**	**–**	**5,465**	**-721**
Pacific Northwest Site Office				
Salaries and Benefits	4,896	–	4,970	+74
Travel	67	–	110	+43
Support Services	38	–	34	-4
Other Related Expenses	104	–	56	-48
Total, Pacific Northwest Site Office	**5,105**	**–**	**5,170**	**+65**
Princeton Site Office				
Salaries and Benefits	1,540	–	1,859	+319
Travel	19	–	45	+26
Support Services	14	–	15	+1
Other Related Expenses	74	–	59	-15
Total, Princeton Site Office	**1,647**	**–**	**1,978**	**+331**
SLAC Site Office				
Salaries and Benefits	2,220	–	2,340	+120
Travel	25	–	45	+20
Support Services	140	–	198	+58
Other Related Expenses	57	–	40	-17
Total, SLAC Site Office	**2,442**	**–**	**2,623**	**+181**
Thomas Jefferson Site Office				
Salaries and Benefits	1,831	–	2,004	+173
Travel	30	–	45	+15
Support Services	10	–	8	-2
Other Related Expenses	34	–	31	-3
Total, Thomas Jefferson Site Office	**1,905**	**–**	**2,088**	**+183**

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Total Field Offices				
Salaries and Benefits	71,610	–	70,013	-1,597
Travel	733	–	1,070	+337
Support Services	2,785	–	3,875	+1,090
Other Related Expenses	7,337	–	6,282	-1,055
Total, Field Offices	**82,465**	**–**	**81,240**	**-1,225**
Total Program Direction				
Salaries and Benefits	139,197	–	135,998	-3,199
Travel	1,949	–	2,659	+710
Support Services	21,310	–	20,846	-464
Other Related Expenses	11,402	–	12,347	+945
Working Capital Fund	8,142	–	8,150	+8
Total, Program Direction	**182,000**	**180,764**	**180,000**	**-2,000**
Federal FTEs	**870**	**–**	**835**	**-35**
Technical Support				
Development of specifications	500	–	0	-500
System review and reliability analyses	884	–	973	+89
Surveys or reviews of technical operations	462	–	0	-462
Total, Technical Support	**1,846**	**–**	**973**	**-873**
Management Support				
Automated data processing	10,390	–	9,080	-1,310
Training and education	718	–	740	+22
Reports and analyses, management, and general administrative services	8,356	–	10,053	+1,697
Total, Management Support	**19,464**	**–**	**19,873**	**+409**
Total, Support Services	**21,310**	**–**	**20,846**	**-464**

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Other Related Expenses				
Rent to GSA	960	–	612	-348
Rent to others	1,173	–	1,374	+201
Communications, utilities, and miscellaneous	2,511	–	2,623	+112
Other services	1,454	–	2,379	+925
Operation and maintenance of equipment	142	–	2	-140
Operation and maintenance of facilities	1,413	–	1,242	-171
Supplies and materials	853	–	690	-163
Equipment	2,896	–	3,425	+529
Total, Other Related Expenses	**11,402**	**–**	**12,347**	**+945**
Working Capital Fund	**8,142**	**–**	**8,150**	**+8**

Program Direction

Activities and Explanation of Changes

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Program Direction $182,000,000	**$180,000,000**	**-$2,000,000**
Salaries and Benefits $139,197,000	**$135,998,000**	**-$3,199,000**
The FY 2017 Enacted level supported 870 FTEs to perform scientific oversight, program and project management, essential operations support associated with science program portfolio management, and support for the Office of the Chief Human Capital Officer operating the SSC and supporting HR Advisory Offices. Funding also supported expenses such as increases in general schedule pay rates, health insurance costs and retirement allocations in the Federal Employees Retirement System.	The FY 2019 Request will support 835 FTEs to perform scientific oversight, program and project management, essential operations support associated with science program portfolio management, and support for the Office of the Chief Human Capital Officer operating the SSC and supporting HR Advisory Offices. This funding will also support health insurance costs and retirement allocations in the Federal Employees Retirement System.	The reduction in salaries and benefits will be driven by ongoing and planned reductions in federal staff consistent with SC's long-term workforce restructuring plans and the DOE Agency Reform Plan.
Travel $1,949,000	**$2,659,000**	**+$710,000**
Ensuring scientific management, compliance, safety oversight, and external review of research funding across all SC programs requires staff to travel, since SC senior program managers are not co-located with grantees or at national laboratories. The Enacted level supported facility visits where the use of electronic telecommunications were not practical for mandated on-site inspections and facility operations reviews.	Ensuring scientific management, compliance, safety oversight, and external review of research funding across all SC programs requires staff to travel, since SC senior program managers are not co-located with grantees or at national laboratories. The FY 2019 Request will support facility visits where the use of electronic telecommunications are not practical for mandated on-site inspections and facility operations reviews.	The increase in travel funding will allow for increased SC program manager participation in major scientific meetings and provide effective management and oversight of major programs and user facilities through on-site visits.

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Funding also supported travel for the SC Federal Advisory Committees which included over 170 representatives from universities, national laboratories, and industry, representing a diverse balance of disciplines, professional experience, and geography. Each of the six advisory committees provides valuable, independent advice to the Department regarding the complex scientific and technical issues that arise in the planning, management, and implementation of SC programs.	The Request will also support travel for the SC Federal Advisory Committees, which will include over 170 representatives from universities, national laboratories, and industry, representing a diverse balance of disciplines, professional experience, and geography. Each of the six advisory committees provides valuable, independent advice to the Department regarding the complex scientific and technical issues that arise in the planning, management, and implementation of SC programs.	
Support Services $21,310,000	**$20,846,000**	**-$464,000**
The FY 2017 Enacted level supported select administrative and professional services including: support for the Small Business Innovation Research/Small Business Technology Transfer program; grants and contract processing and close-out activities; accessibility to DOE's corporate multi-billion dollar R&D program through information systems managed and administered by OSTI; travel processing; correspondence control; select reports or analyses directed toward improving the effectiveness, efficiency, and economy of services and processes; and safeguards and security oversight functions. The FY 2017 Enacted level supported essential information technology infrastructure, ongoing operations and maintenance of IT systems and safety management support. Funding also supported federal staff training and education to maintain appropriate certification and update skills.	The FY 2019 Request will support select administrative and professional services including: support for the Small Business Innovation Research/Small Business Technology Transfer program; grants and contract processing and close-out activities; accessibility to DOE's corporate multi-billion dollar R&D program through information systems managed and administered by OSTI; travel processing; correspondence control; select reports or analyses directed toward improving the effectiveness, efficiency, and economy of services and processes; and safeguards and security oversight functions. The FY 2019 Request will support essential information technology infrastructure, ongoing operations and maintenance of IT systems and safety management support. The FY 2019 Request will fund federal staff training and education to maintain appropriate certification and update skills.	The decrease will come from reductions in contractor staff. SC continuously reviews PD-funded support contract requirements and identifies functions or tasks that can be eliminated or scaled back to achieve savings. Through these analyses and ongoing efforts, a reduction of contractor staff will be achieved.

FY 2017 Enacted	FY 2019 Request	Explanation of Changes FY 2019 Request vs FY 2017 Enacted
Other Related Expenses $11,402,000	**$12,347,000**	**+$945,000**
The FY 2017 Enacted level supported fixed requirements associated with rent, utilities, and telecommunications; building and grounds maintenance; computer/video maintenance and support; IT equipment leases, purchases, and maintenance; and site-wide health care units. It also included miscellaneous purchases for supplies, materials, and subscriptions.	The FY 2019 Request will support fixed requirements associated with rent, utilities, and telecommunications; building and grounds maintenance; computer/video maintenance and support; IT equipment leases, purchases, and maintenance; and site-wide health care units. It will also include miscellaneous purchases for supplies, materials, and subscriptions.	The increase will support normal inflation for requirements such as rent and utilities. The increase will also support critical IT investments which have been deferred in previous years.
Working Capital Fund $8,142,000	**$8,150,000**	**+$8,000**
The FY 2017 Enacted level provided SC's contribution to the WCF for business lines: building occupancy, supplies, printing and graphics, health services, corporate training services, and corporate business systems. Other SC programs also contribute to additional WCF business lines.	The FY 2019 Request will support the SC contribution to the WCF for business lines: building occupancy, supplies, printing and graphics, health services, corporate training services, and corporate business systems. Other SC programs also contribute to WCF.	The increase will support current estimates for the WCF business lines for PD.

Isotope Production and Distribution Program Fund

Overview

The Department of Energy's Isotope Program produces and sells radioactive and stable isotopes, byproducts, surplus materials, and related isotope services world-wide. It operates under a revolving fund, the Isotope Production and Distribution Program Fund, established by the 1990 Energy and Water Development Appropriations Act (Public Law 101-101), as amended by the 1995 Energy and Water Development Appropriations Act (Public Law 103-316). Funding for the Isotope Production and Distribution Program Fund is provided by the combination of annual appropriations from the Isotope Development and Production for Research and Applications subprogram within the Nuclear Physics (NP) program in the Science appropriation account, and collections from isotope sales; both are needed to maintain the Isotope Program's viability. This revolving fund allows continuous and smooth operations of isotope production, sales, and distribution independent of the federal budget cycle and fluctuating sales revenue. An independent cost review of the fund's revenues and expenses is conducted annually by an external contractor.

Annual appropriations in NP funds a payment into the revolving fund to maintain mission-readiness of facilities, including the support of core scientists and engineers needed to carry out the Isotope Program and the maintenance of isotope facilities to assure reliable production. In addition, appropriated funds provide support for research and development (R&D) activities associated with development of new production and processing techniques for isotopes, production of research isotopes, and training of new personnel in isotope production. Each site's production expenses, including processing and distributing isotopes, are offset by revenue generated from sales. About 80 percent of the resources in the revolving fund are used for operations, maintenance, isotope production, and R&D for new isotope production techniques, with approximately 20 percent available for process improvements, unanticipated changes in volume, and purchases of small capital equipment, such as assay equipment and shipping containers needed to ensure on-time deliveries.

The Department supplies isotopes and related services to the Nation under the authority of the Atomic Energy Act of 1954, which specifies the role of the U.S. Government in isotope distribution. Substantial national and international scientific, medical, and research infrastructure relies upon the use of isotopes and is strongly dependent on the Department's products and services. Isotopes are used for hundreds of applications that benefit society every day, such as diagnostic medical imaging, cancer therapy, smoke detectors, neutron detectors for homeland security applications, explosives detection, oil exploration, and tracers for environmental research. For example, radioisotopes are used in the diagnosis or treatment of about one-third of all patients admitted to hospitals.[a] Nearly 18 million Americans undergo nuclear medicine procedures each year for a variety of conditions, including cancer, cardiovascular disease, neurological conditions, and other physiological problems.[b] Such nuclear procedures are among the safest and most effective diagnostic tests available and enhance patient care by avoiding exploratory surgery and other invasive procedures. The Isotope Program continuously assesses isotope needs to inform program direction including biennial Federal workshops to evaluate stakeholder requirements in order to optimize the utilization of resources and assure the greatest availability of isotopes.

Isotopes are primarily produced and processed at three facilities stewarded by the Isotope Program: the Brookhaven Linac Isotope Producer (BLIP) and associated processing labs at Brookhaven National Laboratory (BNL), the Isotope Production Facility (IPF) and associated processing labs at Los Alamos National Laboratory (LANL), and processing facilities and the Enriched Stable Isotope Prototype Plant (ESIPP) at Oak Ridge National Laboratory (ORNL). In addition, production and distribution activities are supported at the Advanced Test Reactor (ATR) at Idaho National Laboratory, the High Flux Isotope Reactor (HFIR) at ORNL, the Y-12 National Security Complex at ORNL, the Low Energy Accelerator Facility at Argonne National Laboratory, and processing facilities at the Pacific Northwest National Laboratory and the Savannah River Site. IPF and BLIP provide accelerator production capabilities, while HFIR and ATR provide reactor production capability. HFIR has the highest neutron flux available for isotope production in the United States. ESIPP represents the re-establishment of general enriched stable isotope production capabilities in the U.S. and started operations in 2016. The Isotope Program is further broadening capability by including university-supported accelerator and reactor facilities used for research, education, and isotope production that can provide cost-effective and unique production capabilities, as the University of Washington and

[a] http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/med-use-radioactive-materials.html
[b] http://interactive.snm.org/docs/whatisnucmed2.pdf

the Missouri University Research Reactor are now part of the DOE Isotope Program University Production Network. Many other universities have expressed interest in participating in the network.

In FY 2017, a total of $93.22 million was deposited into the revolving fund. This consists of the FY 2017 appropriation of $28.85 million paid into the revolving fund from the Nuclear Physics program, plus collections of $64.37 million to recover costs related to isotope production and isotope services. Collections in FY 2017 included sales of actinium-227, californium-252, helium-3, selenium-75, cobalt-60, nickel-63, germanium-68, actinium-225, and strontium-82. Actinium-227 provides radium-223 for Xofigo, which was recently the first alpha particle-emitting radioisotopic drug approved by the FDA; Xofigo extends patient survival and alleviates the excruciating pain associated with cancer that has metastasized to bone. Californium-252 has a variety of industrial applications, including oil and gas well-logging, and fission start-up in nuclear reactors; helium-3 is used in neutron detectors for national security; selenium-75 is used as a radiography source; cobalt-60 is used in gamma-ray cancer surgery; nickel-63 enhances national security through its use in detectors for explosives and illicit material; germanium-68 supports development of gallium-68 diagnostic imaging pharmaceuticals; actinium-225 is used in pharmaceuticals being developed to more effectively treat cancer and other diseases; and strontium-82 has gained world-wide acceptance for use in heart imaging. In FY 2017, the Isotope Program sold 172 different radioactive and stable isotopes to a broad range of research and commercial customers, including major pharmaceutical companies, industrial users, and researchers at hospitals, national laboratories, other Federal agencies, universities, and private companies. Among the isotopes produced, nine are high-volume, moderately priced isotopes; the remaining are low-volume research isotopes, which are more expensive to produce. Commercial isotopes are priced to recover full cost or the market price, whichever is higher.

Program Accomplishments

An Enriching Experience with Stable Isotopes. To re-establish a general capability for stable isotope enrichment in the U.S. that has not existed since 1998, the DOE Isotope Program made investments in R&D and prototype capabilities to develop a Federal stable isotope enrichment capability, as recommended by the Nuclear Science Advisory Committee. This prototype facility, which uses state-of-the art electromagnetic and gas centrifuge enrichment devices at ORNL, commenced operation in 2017. U.S. inventories of important enriched stable isotopes have started to be replenished, and research quantities of enriched stable isotopes will be fabricated to support a broad range of U.S. research in fields such as medicine, biology, chemistry, physics, and national security. This prototype facility is the basis for the Stable Isotope Production Facility (SIPF) Major Item of Equipment (MIE), which will enable production of kilogram quantities of high priority isotopes, reducing U.S. dependency on foreign supplies.

Adding Functionality, Efficiency, and Reliability to Dramatically Increase Isotope Production at IPF. The growth in demand of isotopes produced at the Isotope Production Facility (IPF) at LANL drove the need for increased production capabilities. To address this need, the DOE Isotope Program implemented an upgrade to the IPF. The goal of this increased capability was to increase beam current and to design and install an “active-adjustable collimator” and beam monitoring detectors. These improvements enhance facility reliability by increasing the beam current from 230 µA to 380 µA (a projected 65% increase in production yields). Also, they afford the ability to dynamically make beam energy, current, profile, and emittance measurements in real time. The active adjustable collimator provides the ability to expand or narrow down the beam, improving R&D capabilities and efficiency.

DOE Works to Re-establish Americium-241 production. Americium-241 (Am-241) was once produced by DOE’s Isotope Program to support a number of commercial and industrial uses. Most notably, domestic oil and gas production is heavily reliant upon using Am-241 sealed sources to take crucial measurements of rock porosity in new oil wells in the United States. Since 2004, the petroleum industry has been reliant upon Am-241 imported from foreign countries to meet this critical need. In FY 2017, Los Alamos National Laboratory completed construction of a new Am-241 production line and the DOE/NNSA field office granted safety authorization to begin operations. In 2018, DOE’s objective is to deliver the first 200 grams of newly produced Am-241 to its customers.

Highlights of the FY 2019 Budget Request

For FY 2019, the Department foresees growth in isotope demand, with particular interest in alpha-emitters for cancer therapy and stable isotopes to exploit the newly established domestic production capabilities. The portfolio of the isotope program continues to grow as isotope availability is increased by the program. Revolving fund resources will be used to support efforts to produce isotopes and increase radioisotope production capabilities and availability to meet demand. SC is requesting continued funding in the FY 2019 Nuclear Physics budget for the SIPF MIE, with planned completion of the facility in FY 2023 based on a technically-driven schedule. Initiated in 2017, SIPF will provide increased domestic capability for cost-effective production of critically needed enriched stable isotopes and reduce the nation's dependence on foreign suppliers. NP will make investments in aging isotope production infrastructure to maintain productivity and to provide enhanced facility infrastructure for increased production of Ac-225, a promising cancer therapeutic.

Science Crosscuts
Facilities Maintenance and Repair

The Department's Facilities Maintenance and Repair activities are tied to its programmatic missions, goals, and objectives. The Facilities Maintenance and Repair activities funded by the budget and displayed below and are intended to ensure that the scientific community has the facilities required to conduct cutting edge scientific research now and in the future to meet Department of Energy (DOE) goals and objectives.

Costs for Direct-Funded Maintenance and Repair (including Deferred Maintenance Reduction) ($K)

	FY 2017 Planned Cost	FY 2017 Actual Cost	FY 2018 Planned Cost	FY 2019 Planned Cost
Argonne National Laboratory	0	0	11,900	4,000
Brookhaven National Laboratory	5,791	5,511	5,908	4,272
Lawrence Berkeley National Laboratory	9,000	2,001	18,500	12,950
Notre Dame Radiation Laboratory	175	120	175	125
Oak Ridge National Laboratory	14,853	13,700	15,298	15,260
Oak Ridge Office	9,079	4,059	6,324	4,223
Office of Scientific and Technical Information	402	366	412	381
SLAC National Accelerator Laboratory	3,740	2,742	4,878	4,761
Thomas Jefferson National Accelerator Facility	73	223	75	232
Total, Direct-Funded Maintenance and Repair	**43,113**	**28,722**	**63,470**	**46,204**

General purpose infrastructure includes multiprogram research laboratories, administrative and support buildings, as well as cafeterias, power plants, fire stations, utilities, roads, and other structures. Together, the Office of Science (SC) laboratories have over 1,400 operational buildings and real property trailers, with nearly 20 million gross square feet of space.

Generally, facilities maintenance and repair expenses are funded through an indirect overhead charge. In some cases, however, a laboratory may charge maintenance directly to a specific program. One example would be when maintenance is performed in a building used only by a single program. Such direct-funded charges are not directly budgeted.

Costs for Indirect-Funded Maintenance and Repair (including Deferred Maintenance Reduction) ($K)

	FY 2017 Planned Cost	FY 2017 Actual Cost	FY 2018 Planned Cost	FY 2019 Planned Cost
Ames Laboratory	2,600	2,248	2,900	2,600
Argonne National Laboratory	57,200	57,825	59,500	70,950
Brookhaven National Laboratory	44,971	33,663	45,918	37,146
Fermi National Accelerator Laboratory	19,126	16,556	19,238	20,801
Lawrence Berkeley National Laboratory	27,860	29,431	28,103	29,318
Lawrence Livermore National Laboratory	2,926	2,926	2,984	3,044
Los Alamos National Laboratory	623	623	635	648
Oak Ridge Institute for Science and Education	489	567	490	499
Oak Ridge National Laboratory and Y-12	62,376	65,940	64,202	79,260
Pacific Northwest National Laboratory	6,805	8,134	8,137	8,635
Princeton Plasma Physics Laboratory	8,000	6,016	8,200	6,577
Sandia National Laboratories	2,998	2,998	3,058	3,119
SLAC National Accelerator Laboratory	10,120	11,947	10,835	15,809
Thomas Jefferson National Accelerator Facility	6,360	5,165	6,550	5,374
Total, Indirect-Funded Maintenance and Repair	**252,454**	**244,039**	**260,750**	**283,780**

Facilities maintenance and repair activities funded indirectly through overhead charges at SC laboratories are displayed. Since this funding is allocated to all work done at each laboratory, the cost of these activities charged to funding from SC and other DOE organizations, as well as other Federal agencies and other entities doing work at SC laboratories. Maintenance reported to SC for non-SC laboratories is also shown. The figures are total projected expenditures across all SC laboratories.

Report on FY 2017 Expenditures for Maintenance and Repair

This report responds to the requirements established in Conference Report (H.Rep. 108-10) accompanying Public Law 108-7 (pages 886-887), which requires the Department of Energy to provide an annual year-end report on maintenance expenditures to the Committees on Appropriations. This report compares the actual maintenance expenditures in FY 2017 to the amount planned for FY 2017, including Congressionally directed changes.

Science
Total Costs for Maintenance and Repair ($K)

	FY 2017 Planned Costs	FY 2017 Actual Costs
Ames Laboratory	2,600	2,248
Argonne National Laboratory	57,200	57,825
Brookhaven National Laboratory	50,762	39,174
Fermi National Accelerator Laboratory	19,126	16,556
Lawrence Berkeley National Laboratory	36,860	31,432
Lawrence Livermore National Laboratory	2,926	2,926
Los Alamos National Laboratory	623	623
Notre Dame Radiation Laboratory	175	120
Oak Ridge Institute for Science and Education	489	567
Oak Ridge National Laboratory and Y-12	77,229	79,640
Oak Ridge Office	9,079	4,059
Office of Scientific and Technical Information	402	366
Pacific Northwest National Laboratory	6,805	8,134
Princeton Plasma Physics Laboratory	8,000	6,016
Sandia National Laboratories	2,998	2,998
SLAC National Accelerator Laboratory	13,860	14,689
Thomas Jefferson National Accelerator Facility	6,433	5,388
Total, Maintenance and Repair	**295,567**	**272,761**

Science
Research and Development ($K)

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Basic	4,429,054	4,459,276	4,301,848	-127,206
Applied	0	0	0	0
Subtotal, R&D	4,429,054	4,459,276	4,301,848	-127,206
Equipment	186,796	141,029	171,937	-14,859
Construction	726,624	707,184	861,212	+134,588
Total, R&D	**5,342,474**	**5,307,489**	**5,334,997**	**-7,477**

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

Science

Small Business Innovative Research/Small Business Technology Transfer (SBIR/STTR) ($K)

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Office of Science				
Advanced Scientific Computing Research				
SBIR	19,675	—	21,162	+1,487
STTR	2,766	—	2,976	+210
Basic Energy Sciences				
SBIR	51,189	—	51,175	-14
STTR	7,198	—	7,196	-2
Biological and Environmental Research				
SBIR	19,440	—	15,313	-4,127
STTR	2,734	—	2,153	-581
Fusion Energy Sciences				
SBIR	8,814	—	8,323	-491
STTR	1,239	—	1,170	-69
High Energy Physics				
SBIR	19,532	—	16,363	-3,169
STTR	2,747	—	2,301	-446
Nuclear Physics				
SBIR	15,366	—	15,747	+381
STTR	2,161	—	2,300	+139
Total, Office of Science SBIR	**134,016**	—	**128,083**	**-5,933**
Total, Office of Science STTR	**18,845**	—	**18,096**	**-749**
Other DOE[b]	TBD	—	TBD	TBD
Total, DOE SBIR	**134,016**	—	**128,083**	**-5,933**
Total, DOE STTR	**18,845**	—	**18,096**	**-749**

[a]A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).

[b] The other DOE programs SBIR/STTR funding amounts are listed in the other DOE budget volumes.

Science
Safeguards and Security Crosscut ($K)

	FY 2017 Enacted	FY 2018 Annualized CR[a]	FY 2019 Request	FY 2019 Request vs FY 2017 Enacted
Protective Forces	39,638	–	41,559	+1,921
Security Systems	10,357	–	10,370	+13
Information Security	4,467	–	4,356	-111
Cyber Security[b]	33,236	–	35,332	+2,096
Personnel Security	6,086	–	5,444	-642
Material Control and Accountability	2,458	–	2,431	-27
Program Management	6,758	–	6,618	-140
Total, Safeguards and Security	**103,000**	**102,301**	**106,110**	**+3,110**

[a] A full-year 2018 appropriation for this account was not enacted at the time the budget was prepared; therefore, the budget assumes this account is operating under the Continuing Appropriations Act, 2018 (Division D of P.L. 115-56, as amended). The amounts included for 2018 reflect the annualized level provided by the continuing resolution. (These amounts are shown only at the Congressional control level and above; below that level, a dash (—) is shown).
[b] The Cyber Security amount includes $6,039,000 in FY 2017 and $6,435,000 in FY 2019 for CyberOne through the Working Capital Fund (WCF).

Department of Energy

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Funding by Appropriation by Site

($K)

Science	FY 2017 Enacted	FY 2018 Annualized CR	FY 2019 Request
Ames Laboratory			
Basic Energy Sciences			
Basic Energy Sciences	20,064	15,790	15,479
Biological and Environmental Research			
Biological and Environmental Research	1,200	1,000	0
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	537	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	2,000	0	0
Safeguards and Security			
Safeguards and Security	1,231	1,231	1,231
Total, Ames Laboratory	**25,032**	**18,021**	**16,710**
Ames Site Office			
Program Direction			
Program Direction	649	477	642
Total, Ames Site Office	**649**	**477**	**642**
Argonne National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	83,956	112,272	149,196
Basic Energy Sciences			
Basic Energy Sciences	267,871	221,300	274,509
Biological and Environmental Research			
Biological and Environmental Research	31,823	28,234	21,461
High Energy Physics			
High Energy Physics	15,765	14,839	11,700
Nuclear Physics			
Nuclear Physics	30,791	30,608	30,270
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	1,420	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	21,993	24,839	59,224
Safeguards and Security			
Safeguards and Security	9,240	9,259	9,284
Total, Argonne National Laboratory	**462,859**	**441,351**	**555,644**
Argonne Site Office			
Program Direction			
Program Direction	3,897	4,699	4,435
Total, Argonne Site Office	**3,897**	**4,699**	**4,435**

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Funding by Appropriation by Site

($K)

Science	**FY 2017 Enacted**	**FY 2018 Annualized CR**	**FY 2019 Request**
Berkeley Site Office			
Program Direction			
Program Direction	3,419	3,565	3,945
Total, Berkeley Site Office	**3,419**	**3,565**	**3,945**
Brookhaven National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	1,180	1,116	732
Basic Energy Sciences			
Basic Energy Sciences	179,634	169,433	162,837
Biological and Environmental Research			
Biological and Environmental Research	10,657	9,301	9,106
High Energy Physics			
High Energy Physics	69,736	63,300	68,221
Nuclear Physics			
Nuclear Physics	195,089	191,827	189,095
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	1,763	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	1,800	1,788	15,632
Safeguards and Security			
Safeguards and Security	12,369	12,347	12,659
Total, Brookhaven National Laboratory	**472,228**	**449,112**	**458,282**
Brookhaven Site Office			
Program Direction			
Program Direction	4,806	4,755	4,772
Total, Brookhaven Site Office	**4,806**	**4,755**	**4,772**

Department of Energy

FY 2019 Congressional Budget

Funding by Appropriation by Site

($K)

Science	**FY 2017 Enacted**	**FY 2018 Annualized CR**	**FY 2019 Request**
Chicago Operations Office			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	31,158	27,190	28,400
Basic Energy Sciences			
Basic Energy Sciences	269,867	178,058	325,748
Biological and Environmental Research			
Biological and Environmental Research	115,488	89,550	91,133
Fusion Energy Sciences			
Fusion Energy Sciences	156,622	108,877	95,978
High Energy Physics			
High Energy Physics	106,215	97,873	68,410
Nuclear Physics			
Nuclear Physics	182,072	177,766	153,502
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	1,764	1,752	1,513
Safeguards and Security			
Safeguards and Security	45	50	50
Program Direction			
Program Direction	23,614	22,835	23,721
Total, Chicago Operations Office	**886,845**	**703,951**	**788,455**
Fermi National Accelerator Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	530	341	174
Basic Energy Sciences			
Basic Energy Sciences	1,424	390	1,424
High Energy Physics			
High Energy Physics	398,992	389,513	430,311
Nuclear Physics			
Nuclear Physics	455	30	30
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	210	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	2,500	2,483	8,000
Safeguards and Security			
Safeguards and Security	5,281	5,362	5,388
Total, Fermi National Accelerator Laboratory	**409,392**	**398,119**	**445,327**
Fermi Site Office			
Program Direction			
Program Direction	2,663	2,535	2,390
Total, Fermi Site Office	**2,663**	**2,535**	**2,390**

Department of Energy

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Funding by Appropriation by Site

($K)

Science	**FY 2017 Enacted**	**FY 2018 Annualized CR**	**FY 2019 Request**
Idaho National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	0	70	70
Basic Energy Sciences			
Basic Energy Sciences	900	900	900
Fusion Energy Sciences			
Fusion Energy Sciences	1,300	1,350	2,400
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	344	0	0
Total, Idaho National Laboratory	**2,544**	**2,320**	**3,370**
Lawrence Berkeley National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	147,542	149,833	146,015
Basic Energy Sciences			
Basic Energy Sciences	168,617	148,912	164,458
Biological and Environmental Research			
Biological and Environmental Research	149,272	138,789	125,698
High Energy Physics			
High Energy Physics	67,319	76,449	64,874
Nuclear Physics			
Nuclear Physics	22,030	21,418	21,465
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	1,298	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	28,561	19,428	22,049
Safeguards and Security			
Safeguards and Security	7,169	7,209	7,134
Total, Lawrence Berkeley National Laboratory	**591,808**	**562,038**	**551,693**

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($K)

Science	FY 2017 Enacted	FY 2018 Annualized CR	FY 2019 Request
Lawrence Livermore National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	3,171	5,249	4,445
Basic Energy Sciences			
Basic Energy Sciences	2,094	926	926
Biological and Environmental Research			
Biological and Environmental Research	26,968	23,214	14,733
Fusion Energy Sciences			
Fusion Energy Sciences	6,800	8,222	7,734
High Energy Physics			
High Energy Physics	1,150	3,440	1,205
Nuclear Physics			
Nuclear Physics	1,687	843	1,453
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	414	0	0
Total, Lawrence Livermore National Laboratory	**42,284**	**41,894**	**30,496**
Los Alamos National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	1,620	3,003	2,518
Basic Energy Sciences			
Basic Energy Sciences	23,635	17,513	17,005
Biological and Environmental Research			
Biological and Environmental Research	28,182	23,634	17,254
Fusion Energy Sciences			
Fusion Energy Sciences	3,121	3,390	3,090
High Energy Physics			
High Energy Physics	2,100	1,930	1,400
Nuclear Physics			
Nuclear Physics	10,979	9,066	9,292
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	448	0	0
Total, Los Alamos National Laboratory	**70,085**	**58,536**	**50,559**
National Energy Technology Lab			
Basic Energy Sciences			
Basic Energy Sciences	200	0	0
Total, National Energy Technology Lab	**200**	**0**	**0**

Department of Energy
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Funding by Appropriation by Site
($K)

Science	FY 2017 Enacted	FY 2018 Annualized CR	FY 2019 Request
National Renewable Energy Laboratory			
Basic Energy Sciences			
Basic Energy Sciences	12,459	7,632	6,947
Biological and Environmental Research			
Biological and Environmental Research	500	604	580
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	1,208	0	0
Total, National Renewable Energy Laboratory	**14,167**	**8,236**	**7,527**
Nevada Operations Office			
Basic Energy Sciences			
Basic Energy Sciences	145	0	0
Total, Nevada Operations Office	**145**	**0**	**0**
New Brunswick Laboratory Program Office			
Program Direction			
Program Direction	2,493	1,511	0
Total, New Brunswick Laboratory Program Office	**2,493**	**1,511**	**0**
Oak Ridge Institute for Science & Education			
Basic Energy Sciences			
Basic Energy Sciences	3,176	0	0
Biological and Environmental Research			
Biological and Environmental Research	3,478	1,968	1,043
Fusion Energy Sciences			
Fusion Energy Sciences	574	50	544
High Energy Physics			
High Energy Physics	0	1,523	0
Nuclear Physics			
Nuclear Physics	927	467	353
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	9,663	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	1,000	0	0
Safeguards and Security			
Safeguards and Security	1,925	1,885	1,892
Total, Oak Ridge Institute for Science & Education	**20,743**	**5,893**	**3,832**

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($K)

Science	**FY 2017 Enacted**	**FY 2018 Annualized CR**	**FY 2019 Request**
Oak Ridge National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	278,220	286,935	442,747
Basic Energy Sciences			
Basic Energy Sciences	332,146	317,176	321,062
Biological and Environmental Research			
Biological and Environmental Research	78,371	69,500	61,637
Fusion Energy Sciences			
Fusion Energy Sciences	61,845	61,563	94,793
High Energy Physics			
High Energy Physics	0	500	0
Nuclear Physics			
Nuclear Physics	14,356	16,751	19,223
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	26,000	25,823	10,000
Safeguards and Security			
Safeguards and Security	12,374	13,064	12,864
Total, Oak Ridge National Laboratory	**803,312**	**791,312**	**962,326**
Oak Ridge National Laboratory Site Office			
Program Direction			
Program Direction	6,186	5,766	5,465
Total, Oak Ridge National Laboratory Site Office	**6,186**	**5,766**	**5,465**
Oak Ridge Office			
Basic Energy Sciences			
Basic Energy Sciences	85	85	0
Nuclear Physics			
Nuclear Physics	108	4	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	6,182	6,140	6,434
Safeguards and Security			
Safeguards and Security	21,740	19,701	22,227
Program Direction			
Program Direction	23,639	23,367	24,011
Total, Oak Ridge Office	**51,754**	**49,297**	**52,672**

Department of Energy

FY 2019 Congressional Budget

Funding by Appropriation by Site

($K)

Science	**FY 2017 Enacted**	**FY 2018 Annualized CR**	**FY 2019 Request**
Office of Scientific & Technical Information			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	214	148	0
Basic Energy Sciences			
Basic Energy Sciences	569	148	0
Biological and Environmental Research			
Biological and Environmental Research	190	0	148
Fusion Energy Sciences			
Fusion Energy Sciences	145	0	145
Nuclear Physics			
Nuclear Physics	334	211	108
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	80	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	200	0	0
Safeguards and Security			
Safeguards and Security	784	759	759
Program Direction			
Program Direction	8,557	8,850	8,647
Total, Office of Scientific & Technical Information	**11,073**	**10,116**	**9,807**
Pacific Northwest National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	1,483	2,981	1,162
Basic Energy Sciences			
Basic Energy Sciences	31,527	20,926	27,137
Biological and Environmental Research			
Biological and Environmental Research	110,179	95,028	90,987
Fusion Energy Sciences			
Fusion Energy Sciences	663	863	1,400
High Energy Physics			
High Energy Physics	3,375	2,725	1,465
Nuclear Physics			
Nuclear Physics	520	500	500
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	1,076	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	0	0	4,000
Safeguards and Security			
Safeguards and Security	12,839	12,392	12,349
Total, Pacific Northwest National Laboratory	**161,662**	**135,415**	**139,000**

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($K)

Science	FY 2017 Enacted	FY 2018 Annualized CR	FY 2019 Request
Pacific Northwest Site Office			
Program Direction			
Program Direction	5,105	4,894	5,170
Total, Pacific Northwest Site Office	**5,105**	**4,894**	**5,170**
Princeton Plasma Physics Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	0	385	385
Basic Energy Sciences			
Basic Energy Sciences	1,300	0	0
Fusion Energy Sciences			
Fusion Energy Sciences	76,000	57,151	73,591
High Energy Physics			
High Energy Physics	200	0	0
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	360	0	0
Safeguards and Security			
Safeguards and Security	2,535	2,691	2,732
Total, Princeton Plasma Physics Laboratory	**80,395**	**60,227**	**76,708**
Princeton Site Office			
Program Direction			
Program Direction	1,647	1,794	1,978
Total, Princeton Site Office	**1,647**	**1,794**	**1,978**
Sandia National Laboratories			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	2,829	9,579	7,604
Basic Energy Sciences			
Basic Energy Sciences	33,577	24,038	26,532
Biological and Environmental Research			
Biological and Environmental Research	13,522	9,306	10,100
Fusion Energy Sciences			
Fusion Energy Sciences	2,952	2,741	2,238
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	100	0	0
Total, Sandia National Laboratories	**52,980**	**45,664**	**46,474**

Department of Energy

FY 2019 Congressional Budget

Funding by Appropriation by Site

($K)

Science	**FY 2017 Enacted**	**FY 2018 Annualized CR**	**FY 2019 Request**
Savannah River National Laboratory			
Basic Energy Sciences			
Basic Energy Sciences	827	0	0
Biological and Environmental Research			
Biological and Environmental Research	50	50	0
Fusion Energy Sciences			
Fusion Energy Sciences	0	50	0
Total, Savannah River National Laboratory	**877**	**100**	**0**
SLAC National Accelerator Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	125	428	420
Basic Energy Sciences			
Basic Energy Sciences	401,195	401,111	361,600
Biological and Environmental Research			
Biological and Environmental Research	4,211	4,100	3,100
Fusion Energy Sciences			
Fusion Energy Sciences	4,450	5,550	4,542
High Energy Physics			
High Energy Physics	100,733	61,190	44,788
Nuclear Physics			
Nuclear Physics	1,089	1,009	810
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	429	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	30,000	0	0
Safeguards and Security			
Safeguards and Security	4,255	4,269	4,304
Total, SLAC National Accelerator Laboratory	**546,487**	**477,657**	**419,564**
Stanford Site Office			
Program Direction			
Program Direction	2,442	2,638	2,623
Total, Stanford Site Office	**2,442**	**2,638**	**2,623**

Department of Energy

FY 2019 Congressional Budget

Funding by Appropriation by Site

($K)

Science	FY 2017 Enacted	FY 2018 Annualized CR	FY 2019 Request
Thomas Jefferson National Accelerator Facility			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	0	273	387
High Energy Physics			
High Energy Physics	0	25	0
Nuclear Physics			
Nuclear Physics	112,211	108,244	109,267
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	150	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	8,000	0	0
Safeguards and Security			
Safeguards and Security	2,709	2,728	2,758
Total, Thomas Jefferson National Accelerator Facility	**123,070**	**111,270**	**112,412**
Thomas Jefferson Site Office			
Program Direction			
Program Direction	1,905	1,921	2,088
Total, Thomas Jefferson Site Office	**1,905**	**1,921**	**2,088**
Washington Headquarters			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	94,972	42,803	114,755
Basic Energy Sciences			
Basic Energy Sciences	120,188	334,453	143,436
Biological and Environmental Research			
Biological and Environmental Research	37,909	113,566	53,020
Fusion Energy Sciences			
Fusion Energy Sciences	65,528	127,612	53,545
High Energy Physics			
High Energy Physics	59,415	106,090	77,626
Nuclear Physics			
Nuclear Physics	49,352	59,032	64,632
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	0	19,368	19,000
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	0	46,864	0
Safeguards and Security			
Safeguards and Security	8,504	9,354	10,479
Program Direction			
Program Direction	90,978	91,157	90,113
Total, Washington Headquarters	**526,846**	**950,299**	**626,606**
Total, Science	**5,392,000**	**5,355,383**	**5,390,972**

General Provisions—Department of Energy
(including transfer of funds)

Sec. 301. (a) No appropriation, funds, or authority made available by this title for the Department of Energy shall be used to initiate or resume any program, project, or activity or to prepare or initiate Requests For Proposals or similar arrangements (including Requests for Quotations, Requests for Information, and Funding Opportunity Announcements) for a program, project, or activity if the program, project, or activity has not been funded by Congress.

(b) (1) Unless the Secretary of Energy notifies the Committees on Appropriations of both Houses of Congress at least 3 full business days in advance, none of the funds made available in this title may be used to—

(A) make a grant allocation or discretionary grant award totaling $1,000,000 or more;

(B) make a discretionary contract award or Other Transaction Agreement totaling $1,000,000 or more, including contract covered by the Federal Acquisition Regulation;

(C) issue a letter of intent to make an allocation, award, or Agreement in excess

(D) of the limits in subparagraph (A) or (B); or announce publicly the intention to make an allocation, award, or Agreement in excess of the limits in subparagraph (A) or (B).

(2) The Secretary of Energy shall submit to the Committees on Appropriations of both Houses of Congress within 15 days of the conclusion of each quarter a report detailing each grant allocation or discretionary grant award totaling less than $1,000,000 provided during the previous quarter.

(3) The notification required by paragraph (1) and the report required by paragraph (2) shall include the recipient of the award, the amount of the award, the fiscal year for which the funds for the award were appropriated, the account and program, project, or activity from which the funds are being drawn, the title of the award, and a brief description of the activity for which the award is made.

(c) The Department of Energy may not, with respect to any program, project, or activity that uses budget authority made available in this title under the heading "Department of Energy—Energy Programs", enter into a multiyear contract, award a multiyear grant, or enter into a multiyear cooperative agreement unless—

(1) the contract, grant, or cooperative agreement is funded for the full period of performance as anticipated at the time of award; or

(2) the contract, grant, or cooperative agreement includes a clause conditioning the Federal Government's obligation on the availability of future year budget authority and the Secretary notifies the Committees on Appropriations of both Houses of Congress at least 3 days in advance.

(d) Except as provided in subsections (e), (f), and (g), the amounts made available by this title shall be expended as authorized by law for the programs, projects, and activities specified in the "Final Bill" column in the "Department of Energy" table included under the heading "Title III—Department of Energy" in the explanatory statement accompanying this Act.

(e) The amounts made available by this title may be reprogrammed for any program, project, or activity, and the Department shall notify the Committees on Appropriations of both Houses of Congress at least 30 days prior to the use of any proposed reprogramming that would cause any program, project, or activity funding level to increase or decrease by more than $5,000,000 or 10 percent, whichever is less, during the time period covered by this Act.

(f) None of the funds provided in this title shall be available for obligation or expenditure through a reprogramming of funds that—

(1) creates, initiates, or eliminates a program, project, or activity;

(2) increases funds or personnel for any program, project, or activity for which funds are denied or restricted by this Act; or

(3) reduces funds that are directed to be used for a specific program, project, or activity by this Act.

(g) (1) The Secretary of Energy may waive any requirement or restriction in this section that applies to the use of funds made available for the Department of Energy if compliance with such requirement or restriction would pose a substantial risk to human health, the environment, welfare, or national security.

(2) The Secretary of Energy shall notify the Committees on Appropriations of both Houses of Congress of any waiver under paragraph (1) as soon as practicable, but not later than 3 days after the date of the activity to which a requirement or restriction would otherwise have applied. Such notice shall include an explanation of the substantial risk under paragraph (1) that permitted such waiver.

SEC. 302. The unexpended balances of prior appropriations provided for activities in this Act may be available to the same appropriation accounts for such activities established pursuant to this title. Available balances may be merged with funds in the applicable established accounts and thereafter may be accounted for as one fund for the same time period as originally enacted.

SEC. 303. Funds appropriated by this or any other Act, or made available by the transfer of funds in this Act, for intelligence activities are deemed to be specifically authorized by the Congress for purposes of section 504 of the National Security Act of 1947 (50 U.S.C. 3094) during fiscal year 2019 until the enactment of the Intelligence Authorization Act for fiscal year 2019.

SEC. 304. None of the funds made available in this title shall be used for the construction of facilities classified as high-hazard nuclear facilities under 10 CFR Part 830 unless independent oversight is conducted by the Office of Enterprise Assessments to ensure the project is in compliance with nuclear safety requirements.

SEC. 305. None of the funds made available in this title may be used to approve critical decision–2 or critical decision–3 under Department of Energy Order 413.3B, or any successive departmental guidance, for construction projects where the total project cost exceeds $100,000,000, until a separate independent cost estimate has been developed for the project for that critical decision.

SEC. 306. Notwithstanding section 301(c) of this Act, none of the funds made available under the heading "Department of Energy—Energy Programs—Science" in this or any subsequent Energy and Water Development and Related Agencies appropriations Act for any fiscal year may be used for a multiyear contract, grant, cooperative agreement, or Other Transaction Agreement of $1,000,000 or less unless the contract, grant, cooperative agreement, or Other Transaction Agreement is funded for the full period of performance as anticipated at the time of award.

SEC. 307. (a) NEW REGIONAL RESERVES.—The Secretary of Energy may not establish any new regional petroleum product reserve unless funding for the proposed regional petroleum product reserve is explicitly requested in advance in an annual budget submission and approved by the Congress in an appropriations Act.

(b) The budget request or notification shall include—

(1) the justification for the new reserve;

(2) a cost estimate for the establishment, operation, and maintenance of the reserve, including funding sources;

(3) a detailed plan for operation of the reserve, including the conditions upon which the products may be released;

(4) the location of the reserve; and

(5) the estimate of the total inventory of the reserve.

SEC. 308. Treatment of Lobbying and Political Activity Costs as Allowable Costs under Department of Energy Contracts.

(a) Allowable Costs.—

(1) Section 4801(b) of the Atomic Energy Defense Act (50 U.S.C. 2781(b)) is amended—

(A) by striking "(1)" and all that follows through "the Secretary" and inserting The Secretary"; and

(B) by striking paragraph (2).

(2) Section 305 of the Energy and Water Development Appropriation Act, 1988, as contained in section 101(d) of Public Law 100–202 (101 Stat. 1329–125), is repealed.

(b) Regulations Revised.—The Secretary of Energy shall revise existing regulations consistent with the repeal of 50 U.S.C. 2781(b)(2) and section 305 of Public Law 100–202 and shall issue regulations to implement 50 U.S.C. 2781(b), as amended by subsection (a), no later than 150 days after the date of the enactment of this Act. Such regulations shall be consistent with the Federal Acquisition Regulation 48 C.F.R. 31.205–22.

SEC. 309. Not to exceed 5 percent of any appropriation made available for Department of Energy activities funded in this Act may be transferred between such appropriations, but no such appropriation, except as otherwise provided, shall be increased or decreased by more than 5 percent by any such transfers, and notification of any such transfers shall be submitted promptly to the Committees on Appropriations of the House of Representatives and the Senate.

SEC. 310. Notwithstanding section 161 of the Energy Policy and Conservation Act (42 U.S.C. 6241), the Secretary of Energy shall draw down and sell one million barrels of refined petroleum product from the Strategic Petroleum Reserve during fiscal year 2019. Proceeds from sales under this section shall be deposited into the general fund of the Treasury during fiscal year 2019.

SEC. 311. The Secretary of Energy may draw down and sell up to 1 million barrels of crude oil from the Strategic Petroleum Reserves during fiscal year 2019. The proceeds of such sale shall be deposited into the SPR Petroleum Account and shall remain available until expended.

TITLE V—GENERAL PROVISIONS

SEC. 501. None of the funds appropriated by this Act may be used in any way, directly or indirectly, to influence congressional action on any legislation or appropriation matters pending before Congress, other than to communicate to Members of Congress as described in 18 U.S.C. 1913.

SEC. 502. None of the funds made available by this Act may be used in contravention of Executive Order No. 12898 of February 11, 1994 (Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations).