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Volume 4

Department of Energy
FY 2020 Congressional Budget Request

Science

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Table of Contents

FUNDING BY APPROPRIATION

($K)

Department of Energy Budget by Appropriation	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted $	FY 2020 Request vs FY 2019 Enacted %
Energy and Water Development, and Related Agencies					
Energy Programs					
Energy Efficiency and Renewable Energy	2,321,778	2,379,000	343,000	-2,036,000	-85.6%
Electricity Delivery and Energy Reliability	261,329	0	0	0	N/A
Electricity	0	156,000	182,500	+26,500	+17.0%
Cybersecurity, Energy Security, and Emergency Response	0	120,000	156,500	+36,500	+30.4%
Nuclear Energy	1,205,056	1,326,090	824,000	-502,090	-37.9%
Fossil Energy Programs					
Fossil Energy Research and Development	726,817	740,000	562,000	-178,000	-24.1%
Naval Petroleum and Oil Shale Reserves	4,900	10,000	14,000	+4,000	+40.0%
Strategic Petroleum Reserve	260,716	235,000	174,000	-61,000	-26.0%
Strategic Petroleum Account	8,400	10,000	27,000	+17,000	+170.0%
Northeast Home Heating Oil Reserve	6,500	10,000	0	-10,000	-100.0%
Total, Fossil Energy Programs	**1,007,333**	**1,005,000**	**777,000**	**-228,000**	**-22.7%**
Uranium Enrichment Decontamination and Decommissioning (D&D) Fund	840,000	841,129	715,112	-126,017	-15.0%
Energy Information Administration	125,000	125,000	118,000	-7,000	-5.6%
Non-Defense Environmental Cleanup	298,400	310,000	247,480	-62,520	-20.2%
Science	6,259,903	6,585,000	5,545,972	-1,039,028	-15.8%
Advanced Research Projects Agency - Energy	353,314	366,000	-287,000	-653,000	-178.4%
Nuclear Waste Disposal (26M in DNWF 050)	0	0	90,000	+90,000	N/A
Departmental Administration	189,652	165,858	117,545	-48,313	-29.1%
Indian Energy Policy and Programs	0	18,000	8,000	-10,000	-55.6%
Inspector General	49,000	51,330	54,215	+2,885	+5.6%
International Affairs	0	0	36,100	+36,100	N/A
Title 17 - Innovative Technology Loan Guarantee Program	30,892	13,000	-160,659	-173,659	-1,335.8%
Advanced Technology Vehicles Manufacturing Loan Program	5,000	5,000	0	-5,000	-100.0%
Tribal Energy Loan Guarantee Program	1,000	1,000	-8,500	-9,500	-950.0%
Total, Energy Programs	**12,947,657**	**13,467,407**	**8,759,265**	**-4,708,142**	**-35.0%**
Atomic Energy Defense Activities					
National Nuclear Security Administration					
Federal Salaries and Expenses	407,595	410,000	434,699	+24,699	+6.0%
Weapons Activities	10,642,138	11,100,000	12,408,603	+1,308,603	+11.8%
Defense Nuclear Nonproliferation	1,999,219	1,930,000	1,993,302	+63,302	+3.3%
Naval Reactors	1,620,000	1,788,618	1,648,396	-140,222	-7.8%
Total, National Nuclear Security Administration	**14,668,952**	**15,228,618**	**16,485,000**	**+1,256,382**	**+8.3%**
Environmental and Other Defense Activities					
Defense Environmental Cleanup	5,988,048	6,024,000	5,506,501	-517,499	-8.6%
Other Defense Activities	840,000	860,292	1,035,339	+175,047	+20.3%
Defense Nuclear Waste Disposal (90M in 270 Energy)	0	0	26,000	+26,000	N/A
Total, Environmental and Other Defense Activities	**6,828,048**	**6,884,292**	**6,567,840**	**-316,452**	**-4.6%**
Total, Atomic Energy Defense Activities	**21,497,000**	**22,112,910**	**23,052,840**	**+939,930**	**+4.3%**
Power Marketing Administrations					
Southeastern Power Administration	0	0	0	0	N/A
Southwestern Power Administration	11,400	10,400	10,400	0	N/A
Western Area Power Administration	93,372	89,372	89,196	-176	-0.2%
Falcon and Amistad Operating and Maintenance Fund	228	228	228	0	N/A
Colorado River Basins Power Marketing Fund	-23,000	-23,000	-21,400	+1,600	+7.0%
Total, Power Marketing Administrations	**82,000**	**77,000**	**78,424**	**+1,424**	**+1.8%**
Federal Energy Regulatory Commission (FERC)	**0**	**0**	**0**	**0**	**N/A**
Subtotal, Energy and Water Development, and Related Agencies	**34,526,657**	**35,657,317**	**31,890,529**	**-3,766,788**	**-10.6%**
Excess Fees and Recoveries, FERC	-9,000	-16,000	-16,000	0	N/A
Title XVII Loan Guarantee Program Section 1703 Negative Credit Subsidy Receipt	0	-107,000	-15,000	+92,000	+86.0%
Sale of Northeast Gas Reserve	0	0	-130,000	-130,000	N/A
Sale of Northeast Home Heating Oil Reserve	0	0	-27,000	-27,000	N/A
Total, Funding by Appropriation	**34,517,657**	**35,534,317**	**31,702,529**	**-3,831,788**	**-10.8%**

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] *33* passenger motor vehicles including one bus, [and one airplane for replacement only, $6,585,000,000] *$5,545,972,000*, to remain available until expended: *Provided*, That of such amount, [$183,000,000] *$183,000,000* shall be available until September 30, [2020]*2021*, for program direction. *(Energy and Water Development and Related Agencies Appropriations Act, 2019.)*

Explanation of Change

Proposed appropriation language updates reflect the funding and replacement of passenger motor vehicle levels and removes the airplane replacement.

Public Law Authorizations

<u>Science:</u>

- 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 108-423, " Department of Energy High-End Computing Revitalization Act of 2004"
- 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"
- Public Law 115-246, "American Super Computing Leadership Act of 2017"
- Public Law 115-246, "Department of Energy Research and Innovation Act", 2018
- Public Law 115-368, "National Quantum Initiative Act", 2018

<u>Nuclear Physics:</u>

- 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

<u>Workforce Development for Teachers and Scientists:</u>

- 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
(dollars in thousands)

FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request
$6,259,903	$6,585,000	$5,545,972

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 27 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 2018 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 2020 Request
The FY 2020 Request for SC is $5,546 million, a decrease of 15.8 percent, below the FY 2019 Enacted level, to implement the Administration's objectives for advancing U.S. science and technology and making the Nation prosperous and strong[a]. The FY 2020 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 includes investments in a coordinated, multidisciplinary research effort in quantum information sciences (QIS) in support of the National Quantum Initiative, data-driven science enabled by artificial intelligence (AI) and machine learning (ML), next-generation microelectronics, genomic sciences to inform biosecurity research, and critical scientific infrastructure needs at DOE laboratories. 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 2020, SC's suite of 27 scientific user facilities will continue to provide unmatched tools and capabilities for over 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 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.

[a] M-18-22, OMB/OSTP Memo: *FY 2020 Administration R&D Budget Priorities* (American Leadership in Artificial Intelligence, Quantum Information Sciences, and Strategic Computing, American Energy Dominance, Security of the American People, Managing and Modernizing R&D Infrastructure, and Training a Workforce for the 21st Century.)

Highlights of the FY 2020 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 $920.9 million, is a decrease of $14.6 million, or 1.6 percent, below the FY 2019 Enacted level. The Request supports the Department's Exascale Computing Initiative (ECI) and will enable delivery of at least one exascale-capable system in calendar year 2021—reasserting U.S. leadership in this critical area. Within ASCR, ECI consists of two components, Office of Science Exascale Computing 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 calendar year 2021. To ensure continued progress during and after the ECI, this Request prioritizes basic research for ML/AI with a focus on foundational research and data intensive science and on future computing technologies. The Request maintains support for ASCR's Computational Partnerships with a focus on developing strategic partnerships in quantum computing. ASCR will partner with the Offices of Basic Energy Sciences and High Energy Physics to establish at least one multi-disciplinary QIS center to promote basic research and early stage development to accelerate the advancement of QIS through vertical integration between systems and theory and hardware and software. The Request also provides strong support for ASCR user facilities operations to ensure the availability of high performance computing and networking to the scientific community and upgrades to maintain U.S. leadership in these essential areas. Funding for the LCF's is increased to continue site preparations and non-recurring engineering activities to deploy an exascale system at the Argonne Leadership Computing Facility (ALCF) in calendar year 2021 and for a second architecturally distinct exascale system at the Oak Ridge Leadership Computing Facility (OLCF) to be deployed in the calendar year 2021–2022 timeframe. Both facilities will provide testbed resources to the SC-ECP to test and scale application codes and continuously test and deploy software technologies. The FY 2020 Request also supports the operations of the 200 petaflop (pf) Summit system at OLCF, and the 8.5 pf Theta system 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, and funding will support the final site and early application preparations for NERSC-9. Increased funds will support continued operations of the Energy Sciences Network (ESnet) and the ESnet-6 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 $1,858.3 million is a decrease of $307.7 million, or 14.2 percent, below the FY 2019 Enacted level. The FY 2020 Request focuses resources toward early-stage fundamental research, the operation and maintenance of a complementary suite of scientific user facilities, and the highest priority facility upgrades. The highest priorities in core research are QIS, next-generation microelectronics, and data analytics and machine learning for data-driven science. BES will partner with the ASCR and High Energy Physics programs to establish at least one multi-disciplinary QIS center to promote basic research and early stage development to accelerate the advancement of QIS through vertical integration between systems and theory and hardware and software. The Request increases funding for the Energy Frontier Research Centers (EFRCs) with a planned solicitation in FY 2020 to expand the EFRC portfolio in topical areas of the highest priority to the Department, including QIS and microelectronics, and recompeting funding for science relevant to the Department's environmental management mission. The Request continues support for computational materials and chemical sciences to deliver shared software infrastructure to the research communities as part of the ECI, and supports the Batteries and Energy Storage Energy Innovation Hub. The Fuels from Sunlight Energy Innovation Hub will complete its second five-year term with FY 2019 funding. FY 2020 funding is requested for continued support of early-stage fundamental research on solar fuels generation that builds on the Hub's unique capabilities and accomplishments to date. An open competition will solicit research to address emerging new directions as well as long-standing challenges in this transformational area of energy science. The Request also provides funds for the DOE Established Program to Stimulate Competitive Research (EPSCoR). BES maintains a balanced suite of complementary tools, including supporting Linac Coherent Light Source (LCLS) operations, which will resume in the second quarter of FY 2020 after completion of installation of LCLS-II accelerator components. The Request supports about 87 percent of optimal operations in FY 2020 at the four remaining x-ray facilities, both BES-supported neutron sources, and five nanoscale science research centers (NSRC). Funding for the Advanced Photon Source Upgrade project continues per the project plan. The Request includes funds for the Advanced Light Source Upgrade project, the Linac Coherent Light Source-II High Energy (LCLS-II-HE) project, and the Proton Power Upgrade and the Second Target Station projects at the

Spallation Neutron Source. The FY 2020 Request includes two new Major Item of Equipment projects: the NSLS-II Experimental Tools-II (NEXT-II) project to continue the phased build-out of beamlines at NSLS-II and the NSRC Recapitalization 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 $494.4 million is a decrease of $210.6 million, or 29.9 percent, below the FY 2019 Enacted level. The FY 2020 Request implements Administration priorities for early-stage fundamental research focused on biological and earth and environmental systems that will contribute to a future of stable, reliable, and secure sources of American energy and advance transformative science for economic prosperity. The FY 2020 Request for Biological Systems Science supports core research areas of Genomic Sciences, including new efforts in secure biosystems design, particularly genome-scale engineering tools, ongoing activities in systems biology and environmental genomics, and fully supports the third year of the recompeted four DOE Bioenergy Research Centers (BRCs). The BRCs continue to perform 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. Extended secure biosystems design activities will test the fundamental engineering principles that control plant and microbial systems, with a specific goal of enhancing the stability, resilience, and controlled performance of engineered biological systems. 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 QIS imaging and sensing approaches will expand experimental observation capabilities to advance systems-level predictive understanding of biological processes. 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 and associated data management. The Request supports operations of BER's three scientific user facilities: the DOE Joint Genome Institute (JGI), the Environmental Molecular Sciences Laboratory, and the Atmospheric Radiation Measurement Research Facility (ARM). JGI operations are reduced to accommodate the FY 2020 move into the Integrative Genomics Building on the Lawrence Berkeley National Laboratory campus. The ARM user facility will continue to develop the aerial capability acquired in FY 2019.

- *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 needed to develop a fusion energy source. The FES FY 2020 Request of $402.8 million is a decrease of $161.3 million, or 28.6 percent, below the FY 2019 Enacted level. The FY 2020 Request prioritizes keeping SC fusion user facilities world-leading, investing in FES related high performance computing and preparing for exascale, exploring the potential of QIS and ML, supporting high-impact research in fusion materials, strengthening collaborations that enable access to international facilities with unique capabilities, learning how to predict and control transient events in fusion plasmas, continuing stewardship of discovery plasma science, and increasing partnership opportunities with the private sector. FES investments in DIII-D facility operations focus on utilizing the facility enhancements implemented during the FY 2018 – FY 2019 Long Torus Opening; the Request supports 13 weeks of research operations, which is 65 percent of optimal operations, along with machine improvements needed for new research capabilities. In FY 2020, the NSTX-U facility is down for recovery and repair; the Request for NSTX-U Operations will support high-priority activities to implement repairs and corrective actions required to achieve research operations, as well as to increase machine reliability. In addition, the Request includes funding for enhanced collaborative research at other facilities to support NSTX-U research program priorities. In FY 2020, the FES SciDAC portfolio, in partnership with ASCR, will continue to address challenges in burning plasma science, with emphasis on integration and whole-device modeling capability, as well as strengthening readiness for the Exascale era. In addition, research efforts focusing on emerging technologies with transformational potential, such as ML/AI and computing aspects of QIS, will be enhanced. The FY 2020 Request will continue support for leveraged research opportunities by U.S. scientists on international superconducting tokamaks, stellarators, and other facilities with unique capabilities, and core discovery plasma science experiments on intermediate-scale collaborative facilities. Funding is requested for the Materials-Plasma Exposure eXperiment MIE project, which is expected to be baselined in FY 2020 and will be a world-leading facility for steady-state, high-heat-flux testing of fusion materials. The Request supports the initiation of a line-item construction project for a significant upgrade to the Matter in Extreme Conditions instrument at the LCLS facility at SLAC National Accelerator Laboratory to support research in high energy density laboratory plasmas. The Request also supports research conducted on medium-scale laser facilities through the new LaserNetUS network, and explores research opportunities of high energy density science for QIS. The FY 2020 Request includes funding for continued design and fabrication of the highest priority “in-kind” hardware systems for ITER.

- *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 2020 Request of $768.0 million is a decrease of $212 million, or 21.6 percent, below the FY 2019 Enacted level. The FY 2020 Request will focus support on the highest priority elements identified in the 2014 High Energy Physics Advisory Panel Particle Physics Project Prioritization Panel (P5) Report. Support for Research will prioritize efforts that address the science drivers of particle physics, as identified in the P5 report, and enable early and visible science results from HEP project investments. R&D that requires long-term investments, including Advanced Technology R&D, Accelerator Stewardship, and cross-cutting efforts in QIS and AI/ML to accelerate discovery in particle physics, will also be given higher priority in order to sustain world-leading efforts and support Office of Science priorities. HEP will partner with ASCR and BES to establish at least one multi-disciplinary QIS center to promote basic research and early stage development to accelerate the advancement of QIS through vertical integration between systems and theory and hardware and software. 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 2020 Request will support these high-priority projects. The Request continues support for LBNF/DUNE, including upgrades to the Sanford Underground Research Facility (SURF) to meet DOE expectations of reliable, efficient, and safe operations during the construction of LBNF/DUNE and its subsequent data-taking phase. The Request supports R&D to reduce technical risk for the planned Proton Improvement Plan II (PIP-II) construction project. Eight HEP projects will be completely funded by FY 2020: the Dark Energy Spectrographic Instrument (DESI), Facility for Advanced Accelerator Experimental Tests II (FACET-II), LHC ATLAS Detector Upgrade, LHC CMS Detector Upgrade, Large Synoptic Survey Telescope camera (LSSTcam), Large Underground Xenon (LUX)-ZonEd Proportional scintillation in LIquid Noble gases (ZEPLIN) experiment (LZ), Muon to Electron Conversion Experiment (Mu2e), and the Super Cryogenic Dark Matter Search at Sudbury Neutrino Observatory Laboratory (SuperCDMS-SNOLAB). DESI, FACET-II, LZ, Mu2e, and SuperCDMS-SNOLAB projects received final project funds in FY 2019. The FY 2020 Request will support technology R&D and pre-conceptual design studies for the next generation Cosmic Microwave Background (CMB-S4) experiment, recommended by P5. The Request will also support the operation of the Fermi National Accelerator Laboratory Accelerator Complex at 88 percent of optimal, and will support the new Fermilab Kautz Road Sub-Station Radial Feed Electrical Upgrade General Plant Project, which will upgrade or replace existing electrical feeders to improve reliability, increase system capacity, and bring the service up to modern standards.

- *Nuclear Physics (NP)* supports experimental and theoretical research to discover, explore, and understand all forms of nuclear matter. The FY 2020 Request of $624.9 million is a decrease of $65.1 million, or 9.4 percent, below the FY 2019 Enacted level. The FY 2020 Request will support the highest priority research and scientific user facilities to maintain U.S. leadership in nuclear science. The FY 2020 Request supports operations of the Relativistic Heavy Ion Collider (RHIC) to confirm the origin of intriguing new phenomena observed in quark gluon plasma formation, and continues support for the Strongly Pioneering High Energy Nuclear Interaction eXperiment (sPHENIX) MIE, which will further explore the properties of the quark gluon plasma. Operations support for the recently updated 12 GeV Continuous Electron Beam Accelerator Facility (CEBAF) will enable the highly anticipated science program to make progress towards unraveling the mechanism of quark confinement. The Request supports a new General Purpose Plant project to build and install the critically needed End Station Refrigerator to mitigate end-of-life risk of current equipment and provide required additional capacity for future experiments. At Argonne National Lab, the Request also supports the 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, and continues support for the Gamma-Ray Energy Tracking Array (GRETA) detector for FRIB. In FY 2020, three additional MIEs are initiated: the High Rigidity Spectrometer (HRS) for FRIB, which will maximize FRIB’s ability to study heavy, neutron-rich nuclei thought to be central to the production of heavy elements in the cosmos, the Measurement of a Lepton-Lepton Electroweak Reaction (MOLLER) experiment, which will search for physics beyond our present understanding by measuring parity-violation in electron-electron scattering with the 12 GeV CEBAF machine; and the Ton-Scale Neutrino-less Double Beta Decay (NLDBD) Experiment, which will determine whether the neutrino is its own antiparticle. Funding is requested in FY 2020 for the start of R&D and conceptual design for a proposed U.S.-based Electron Ion Collider. The FY 2020 Request increases support for the DOE Isotope Program to produce, and develop cutting-edge approaches for producing, critical isotopes in short supply. The Request also continues the Stable Isotope Production Facility (SIPF) MIE project and initiates an AIP project for the harvesting of isotopes at FRIB. The FY 2020 Request initiates a new construction project for the U.S. Stable Isotope Production and Research Center to produce critical enriched stable isotopes in short supply and mitigate U.S. dependence on foreign supply. The Request for Research supports university and laboratory researchers to nurture critical core competencies and enable the highest priority theoretical and experimental activities to target compelling scientific opportunities at the frontier of nuclear science, including investments in QIS efforts in collaboration with other SC programs, the development of quantum sensors based on atomic-nuclear interactions and quantum control techniques, and the production of stable isotopes for next generation quantum information systems.

Reorganization and Restructure Initiative

SC continues to review its functions and the organizational structure to maximize efficiencies across all programs in an attempt to reduce and streamline 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. SC has begun the implementation of a restructuring of the Field and mission support components following approval by the Secretary of Energy in November 2018. This restructuring merges two geographical separate service centers (Chicago and Oak Ridge) into a functionally consolidated center and consolidates corporate functions to improve consistency in operations, and pilots the merging of two SC federal site offices at national laboratories in the same geographic area (Lawrence Berkeley National Laboratory Site Office and the SLAC Site Office), both located in the San Francisco Bay area. This reorganization maximizes efficiencies across all SC field components programs and will reduce and streamline the Federal footprint. Through workforce analysis and restructuring, SC reviewed, analyzed and prioritized mission requirements and identified 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, SC has focused on functional consolidation, elimination of positions, and hiring limitations to achieve necessary results.

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 National 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 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., *Basic Research Needs for Microelectronics*, joint BES, ASCR, and HEP workshop (2018); *Basic Research Needs for Scientific Machine Learning; Core Technologies for Artificial Intelligence*, ASCR workshop (2018)[b]; *Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global* Context, by the High Energy Physics

[a] In compliance with the reporting requirements in the America COMPETES Act of 2007 (P.L. 110-69, section 1008)
[b] https://science.energy.gov/ascr/community-resources/program-documents/

Advisory Panel (2014)[a]; *Quantum Computing Testbed for Science,* ASCR workshop report (2017)[b]; *Basic Energy Science Roundtable: Opportunities for Basic Research for Quantum Computing in Chemical and Materials Sciences*, Basic Energy Sciences workshop report (2017); *Basic Energy Science Roundtable: Opportunities for Basic Research for Next-Generation Quantum Systems*, Basic Energy Sciences workshop report (2017)[c]; *Challenges at the Frontiers of Matter and Energy: Transformative Opportunities for Discovery Science*, by BES Advisory Committee (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 (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

For more than 60 years SC and its predecessors have fostered the training of a highly skilled scientific workforce. In addition to the undergraduate and graduate research opportunities provided through SC's Office of Workforce Development for Teachers and Scientists, 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. To help attract critical talent, 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]. To retain highly skilled researchers by rewarding scientific excellence and leadership, SC initiated the Distinguished Scientist Fellows opportunity to recognize innovative and accomplished DOE laboratory staff and sponsoring their efforts to develop, sustain, and promote scientific and academic excellence in SC research through collaborations between institutions of higher education and national laboratories. 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. SC supports the Cybersecurity Departmental Crosscut, which includes 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.

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[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/reports/2018/Quantum_computing.pdf;
https://science.energy.gov/~/media/bes/pdf/reports/2018/Quantum_systems.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

(dollars in thousands)

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Advanced Scientific Computing Research				
Research	605,000	702,794	732,153	+29,359
17-SC-20, Office of Science Exascale Computing Project (SC-ECP)	205,000	232,706	188,735	-43,971
Total, Advanced Scientific Computing Research	**810,000**	**935,500**	**920,888**	**-14,612**
Basic Energy Sciences				
Research	1,744,900	1,757,700	1,675,285	-82,415
Construction				
19-SC-14, Second Target Station (STS), ORNL	—	1,000	1,000	—
18-SC-10, Advanced Photon Source Upgrade (APS-U), ANL	93,000	130,000	150,000	+20,000
18-SC-11, Spallation Neutron Source Proton Power Upgrade (PPU), ORNL	36,000	60,000	5,000	-55,000
18-SC-12, Advanced Light Source Upgrade (ALS-U), LBNL *(19-SC-10)*	16,000	60,000	13,000	-47,000
18-SC-13, Linac Coherent Light Source-II-High Energy (LCLS-II-HE), SLAC *(19-SC-11)*	8,000	28,000	14,000	-14,000
13-SC-10, Linac Coherent Light Source-II (LCLS-II), SLAC	192,100	129,300	—	-129,300
Total, Construction	**345,100**	**408,300**	**183,000**	**-225,300**
Total, Basic Energy Sciences	**2,090,000**	**2,166,000**	**1,858,285**	**-307,715**
Biological and Environmental Research	**673,000**	**705,000**	**494,434**	**-210,566**
Fusion Energy Sciences				
Research	410,111	432,000	294,750	-137,250
Construction				
20-SC-61, Matter in Extreme Conditions (MEC) Petawatt Upgrade	—	—	1,000	+1,000
14-SC-60, U.S. Contributions to ITER	122,000	132,000	107,000	-25,000
Total, Construction	**122,000**	**132,000**	**108,000**	**-24,000**
Total, Fusion Energy Sciences	**532,111**	**564,000**	**402,750**	**-161,250**

	(dollars in thousands)			
	FY 2018 Enacted	**FY 2019 Enacted**	**FY 2020 Request**	**FY 2020 Request vs FY 2019 Enacted**
High Energy Physics				
Research	767,600	800,000	648,038	-151,962
Construction				
18-SC-42, Proton Improvement Plan II (PIP-II), FNAL	1,000	20,000	20,000	—
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment (LBNF/DUNE), FNAL	95,000	130,000	100,000	-30,000
11-SC-41, Muon to Electron Conversion Experiment, FNAL	44,400	30,000	—	-30,000
Total, Construction	**140,400**	**180,000**	**120,000**	**-60,000**
Total, High Energy Physics	**908,000**	**980,000**	**768,038**	**-211,962**
Nuclear Physics				
Operation and Maintenance	586,800	615,000	579,854	-35,146
Construction				
20-SC-51, U.S. Stable Isotope Production and Research Center, ORNL	—	—	5,000	+5,000
14-SC-50, Facility for Rare Isotope Beams, MSU	97,200	75,000	40,000	-35,000
Total, Construction	**97,200**	**75,000**	**45,000**	**-30,000**
Total, Nuclear Physics	**684,000**	**690,000**	**624,854**	**-65,146**
Workforce Development for Teachers and Scientists	**19,500**	**22,500**	**19,500**	**-3,000**
Science Laboratories Infrastructure				
Infrastructure Support				
Payment in Lieu of Taxes	1,713	1,713	4,540	+2,827
Oak Ridge Landlord	6,382	6,434	5,610	-824
Facilities and Infrastructure	70,347	45,543	25,050	-20,493
Oak Ridge Nuclear Operations	26,000	26,000	10,000	-16,000
Total, Infrastructure Support	**104,442**	**79,690**	**45,200**	**-35,490**
Construction				
20-SC-71, Critical Utilities Rehabilitation Project, BNL	—	—	12,000	+12,000
20-SC-72, Seismic and Safety Modernization, LBNL	—	—	5,000	+5,000
20-SC-75, CEBAF Renovation and Expansion, TJNAF *(19-SC-75)*	—	—	2,000	+2,000
20-SC-76, Craft Resources Support Facility, ORNL *(19-SC-76)*	—	—	20,000	+20,000
20-SC-77, Large Scale Collaboration Center, SLAC *(19-SC-77)*	—	—	3,000	+3,000
19-SC-71, Science User Support Center, BNL	—	7,000	6,400	-600
19-SC-72, Electrical Capacity and Distribution Capability, ANL	—	30,000	30,000	—

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
	(dollars in thousands)			
19-SC-73, Translational Research Capacity, ORNL	—	25,000	15,000	-10,000
19-SC-74, BioEPIC, LBNL	—	5,000	6,000	+1,000
18-SC-71, Energy Sciences Capability, PNNL	20,000	24,000	9,000	-15,000
17-SC-71, Integrated Engineering Research Center, FNAL	20,000	20,000	10,000	-10,000
17-SC-73, Core Facility Revitalization, BNL	30,000	42,200	—	-42,200
15-SC-76, Materials Design Laboratory, ANL	44,500	—	—	—
15-SC-78, Integrative Genomics Building, LBNL	38,350	—	—	—
Total, Construction	**152,850**	**153,200**	**118,400**	**-34,800**
Total, Science Laboratories Infrastructure	**257,292**	**232,890**	**163,600**	**-69,290**
Safeguards and Security	**103,000**	**106,110**	**110,623**	**+4,513**
Program Direction	**183,000**	**183,000**	**183,000**	**—**
Total, Science	**6,259,903**	**6,585,000**	**5,545,972**	**-1,039,028**
Federal FTEs	**825**	**810**	**797**	**-13**

SBIR/STTR funding:

- FY 2018 Enacted: SBIR $143,935,000 and STTR $20,240,000 (SC only)
- FY 2019 Enacted: SBIR $148,264,000 and STTR $20,851,000 (SC only)
- FY 2020 Request: SBIR $132,747,000 and STTR $18,667,000 (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 sophisticated 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. ASCR supports state-of-the-art capabilities that enable scientific discovery through computation. The Computer Science and Applied Mathematics activities in ASCR provide the foundation for increasing the capability of the national high performance computing (HPC) ecosystem by focusing on long-term research to develop software, algorithms, and methods that anticipate future hardware challenges and opportunities as well as science application needs. ASCR's partnerships and coordination with industry are essential to these efforts. At the same time, ASCR partners with disciplinary sciences to deliver some of the most advanced scientific computing applications in areas of strategic importance to the Office of Science (SC) and the Department of Energy (DOE). ASCR also supports world-class, open access high performance computing facilities and high performance networks for scientific research.

For over half a century, the U.S. has 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. Leadership in HPC has also played a crucial role in sustaining America's competitiveness internationally. 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] While this continues to be true, there is also a growing recognition that the nation that leads in machine learning (ML) and artificial intelligence (AI) will lead the world in developing new technologies, medicines, industries, and military capabilities. Most of the modeling and prediction necessary to produce the next generation of breakthroughs in science, energy, medicine, and national security will come not from applying traditional theory, but from employing data-driven methods at extreme scale. Today, significant investments in Asia and Europe are challenging U.S. dominance in computing and nations around the globe are enthusiastically investing in AI. The U.S. must invest in these fields that are critical to American prosperity. Public-private partnerships remain vital as we push our state-of-the-art fabrication techniques to their limit to develop an exascale-capable (one billion billion operations per second) system while simultaneously preparing for the artificial intelligence-big data surge and what follows at the end of the current technology roadmap. 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. DOE has a long history of making fundamental contributions to applied mathematics and computer science associated with strategic computing and a similar set of contributions is foreseen for ML and AI in the science domain and related investments in advanced architectures and hardware. ASCR's proposed activities are in line with the Nation's Research and Development (R&D) priority for American Leadership in AI, Quantum Information Science (QIS), and Strategic Computing.

ASCR-supported activities are entering a new paradigm driven by sharp increases in the heterogeneity and complexity of computing systems and the need to seamlessly and intelligently integrate simulation, AI, data analysis, and other tasks into coherent and usable workflows. HPC has become an essential tool for understanding complex systems in unprecedented detail; exploring systems of systems through ensembles of simulations; learning from extreme scale, complex data; and carrying out data analyses, especially when time is of the essence. These changes are being driven by enormous increases in the volume and complexity of data generated by SC user facilities–from simulations, experiments, and observations–and these new opportunities are propelled by advances already achieved through the DOE Exascale Computing Initiative (ECI). The convergence of AI technologies with these existing investments creates a powerful accelerator for progress and gives the U.S. a distinct advantage over nations with less integrated investments.

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

AI and ML are critical technologies in this new paradigm that are expected to be deployed at multiple stages of the scientific process using a variety of techniques. Many popular machine learning methods lack mathematical approaches to provide robustness, reliability, and transparency and so require significant domain knowledge to be effectively applied. In addition, ML/AI applications and tools are needed to extract knowledge and discovery of patterns and classification in data from large scientific datasets that span SC programs, for example, automate data collection and advanced control and supervision of experiments at light sources, neutron sources, microscopes and telescopes; predict and avoid plasma disruptions in fusion reactors; control and optimize particle accelerators and improve the detection of events; and predict bio-design and the design of complex communities. Due to its tradition of partnering with other SC programs, its history of supporting world-leading mathematics and computer science for computation and data analysis, and its support of open access HPC facilities, which are now powerful tools for data analysis, ML, as well as simulation, ASCR is uniquely positioned to support long-term research for scientific AI and ML.

Moore's Law—the historical pace of microchip innovation whereby feature sizes reduce by a factor of two approximately every two years—is nearing an end due to limits imposed by fundamental physics; feature sizes cannot shrink smaller than the size of atoms. The emerging fields of QIS—the ability to exploit intricate quantum mechanical phenomena to create fundamentally new ways of obtaining and processing information—are opening new vistas of science discovery and technology innovation. QIS is currently at the threshold of a revolution, creating opportunities and challenges for the Nation, as growing international interest and investments are starting a global quantum race. DOE envisions a future in which the cross-cutting field of QIS increasingly drives scientific frontiers and innovations toward realizing the full potential of quantum-based applications, from computing, to communication, to sensing. This will require a detailed understanding of how quantum systems behave, accurate knowledge of how to integrate the components into complex systems, and precise control of the structures and functionalities. The traditional linear model of discovery science leading to design development and commercial deployment will not meet these goals alone within an acceptable time, due to the urgency and scale of our mission. Rather, there is a need for bold approaches that better couple all elements of the technology innovation chain and combine the talents of the program offices in SC, universities, national labs, and the private sector in concerted efforts to define and construct an internationally competitive U.S. economy. In support of the National Quantum Initiative, one or more SC QIS Centers,[a] coupled with a robust core research portfolio stewarded by the individual SC programs including ASCR, will create the ecosystem across universities, national labs, and industry that is needed to foster these developments with benefits in national security, economic competitiveness, and leadership in scientific discovery.

SC and the DOE National Nuclear Security Administration (NNSA) continue to partner on the Department's ECI to overcome key exascale challenges in parallelism, energy efficiency, and reliability, leading to deployment of a diverse set of exascale systems in the calendar year 2021-2022 timeframe. The ECI's goal for an exascale-capable system is a five-fold increase in sustained performance over the Summit HPC 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, emphasizing sustained performance in science and national security mission applications and increased convergence between exascale and large-data analytic computing.

Highlights of the FY 2020 Request

The FY 2020 Request of $920,888,000 for ASCR will strengthen U.S. leadership in strategic computing, the foundations of AI, and QIS. 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 ML/AI, and future computing technologies, and maintains support for ASCR's Computational Partnerships with a focus on developing strategic partnerships in quantum computing and data intensive applications. The Request also provides strong support for ASCR user facilities operations to ensure the availability of high performance computing and networking to the scientific community and upgrades to maintain U.S. leadership in these essential areas. Increased funding supports upgrades at 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). The Request provides robust support for ECI which includes the SC-Exascale Computing Project (SC-ECP) and site preparations, testbeds, and non-recurring engineering (NRE) activities at the LCFs in support of the delivery of at least one exascale computing system in calendar year 2021.

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[a] Recently authorized by Section 402 of the National Quantum Initiative Act, PL 115-368.

The Request provides funding to meet the baseline schedules for the OLCF-5, NERSC-9 and ALCF-3 upgrades. In addition, to ensure the rapid and agile adoption of Big Data and AI solutions, ASCR will also support the seamless integration of data and computing resources through the ESnet-6 upgrade.

Mathematical, Computational, and Computer Sciences Research

When combined with the advances of exascale computing, ML/AI can significantly improve productivity by managing complex simulations and augmenting first principle simulations with data driven predictive models. The FY 2020 Request supports foundational research to improve the robustness, reliability, and transparency of Big Data and AI technologies, uncertainty quantification, and development of software tools to tightly couple simulation, data analysis, and AI for DOE mission applications. Investments focus on areas unique to science such as the transparency and interpretability of AI and ML, uncertainty quantification, and the computer science and software infrastructure for AI and ML applications, including tools for data management. The Request also supports partnerships among computer scientists, applied mathematicians, and domain scientists to develop hybrid models where current DOE applications, which are characterized by complex, multi-scale physics as well as large-scale, multi-faceted data, are merged with AI and ML techniques - providing the combined benefits of both techniques.

Recognizing the limits of Moore's Law, ASCR began activities in FY 2017 to explore future computing technologies, such as quantum information science (QIS) and neuromorphic computing, that are not based on silicon microelectronics. In the FY 2020 Request, QIS remains a principal emphasis. ASCR will partner with SC's Basic Energy Sciences (BES) and High Energy Physics (HEP) programs to establish at least one multi-disciplinary QIS Center to promote basic research and early stage development to accelerate the advancement of QIS through vertical integration between systems and theory and hardware and software. ASCR's Quantum Testbeds activities, which provide researchers with access to novel, early-stage quantum computing resources and services, will be expanded to support partnerships with the BES Nanoscale Science Research Centers. In addition, research in quantum information networks focuses on the opportunities and challenges of transporting and storing quantum information over interconnects and networks.

The Computer Science and Applied Mathematics activities in ASCR provide the foundation for increasing the capability of the national HPC ecosystem by focusing on long-term research to develop software, algorithms, and methods that anticipate future hardware challenges and opportunities as well as science application needs. In FY 2020, these activities will continue to address the combined challenges of increasingly heterogeneous computer architectures, and the changing ways in which HPC systems are used—incorporating more data-intensive applications and greater connectivity with distributed systems and resources, such as other SC user facilities. AI and ML are key technologies in this portfolio.

The Computational Partnerships activity is primarily focused on the Scientific Discovery through Advanced Computing (SciDAC) computational partnerships, which were re-competed in FY 2017, and 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 SciDAC portfolio will continue to focus on advancing the mission critical applications of the other SC programs. The research results emerging from the ECI inform SciDAC investments, which will, whenever possible, incorporate the software, methods, and tools developed by that initiative.

The current and predicted computing needs for DOE research and applications aggregate to a need for ubiquitous computing. Computational Partnerships also supports partnerships with other SC programs to ensure the seamless integration of Big Data and AI with computing resources to support the large-scale computing and data requirements from SC user facilities as well as to prepare for future technology through investments in QIS algorithms and applications.

High Performance Computing and Network Facilities

In FY 2020, ASCR's high performance computing and high performance networking user facilities will continue to advance scientific discovery through optimal operations. The Leadership Computing Facilities (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. NERSC will provide an innovative platform to advance SC mission research. ESnet will continue to expand capacity to meet the Department's exponential growth in scientific data traffic while executing a major upgrade to the core network.

In 2020, the ALCF will finalize site preparations and complete NRE investments with the vendor in preparations for the delivery of an exascale system (the ALCF-3 upgrade) in calendar year 2021. In addition, the ALCF will continue to operate the Theta system and provide additional testbeds for testing SC-ECP applications and software technologies at scale.

The OLCF Summit system became the world's fastest supercomputer in June 2018 and will be in full operation in FY 2020. In addition to scientific modeling and simulation, Summit offers unparalleled opportunities for the integration of AI and scientific discovery, enabling researchers to apply techniques like machine learning and deep learning to problems in high energy physics, materials discovery, and other areas. ORNL will continue site preparations, such as increased power and cooling capacity, testbeds, and NRE investments for an exascale upgrade (OLCF-5) in the calendar year 2021-2022 timeframe that will be architecturally diverse from the ALCF-3 system.

NERSC will continue operations of the 30 petaflop (pf) NERSC-8 supercomputer, named Cori. To address growing demand for capacity computing to meet mission needs, the FY 2020 Request supports activities for the delivery of NERSC-9, which will have approximately three times the capacity of NERSC-8, in late calendar year 2020. The Request also supports completion of site preparation activities for the NERSC-9 upgrade, such as increased power and cooling capacity, and investments to ensure that the diverse NERSC user community is prepared to fully utilize the new computing system.

In FY 2020, ESnet will continue to provide networking connectivity for large-scale scientific data flows while modernizing the network to meet the future needs of the DOE community. The last significant upgrade of the ESnet was in calendar year 2010, and the current optical and routing equipment is at or near the end of its operational effectiveness. The forthcoming delivery of exascale machines and the dramatically accelerating data rates from many SC user facilities and research projects demand not only ever-greater network capacity and security but also new flexibility to deliver on-demand data movement. The ESnet-6 upgrade is designed to achieve these capabilities and provide DOE with a fully integrated network backbone completely under DOE control with enhanced cyber resiliency. Funding for the upgrade continues in FY 2020.

The Department recognizes the significant and sustained competition among employers for trained computational data/network professionals, and the impact of workforce needs on achievement of the accelerated timeline for the delivery of an exascale system. The Research and Evaluation Prototypes (REP) activity will continue to support, in partnership with the NNSA, the Computational Sciences Graduate Fellowship at $10,000,000. Experienced computational scientists who assist a wide range of users in taking effective advantage of DOE's 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 at the ASCR user facilities for high end computational science and engineering through facilities operations funding. In addition, the three ASCR HPC user facilities will continue to prepare their users for future architectures through the deployment of experimental testbeds.

<u>Exascale Computing</u>

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 2020 Request includes $463,735,000 towards SC's contribution to DOE's ECI 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 calendar year 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 and help sustain U.S. leadership in information technology.

The results of Exascale's previous investments with vendors in the Hardware and Integration focus area were evident in the vendor's responses to the CORAL (Collaboration of Oak Ridge, Argonne and Livermore) II request for proposals for the second and third exascale systems to be sited at Oak Ridge and Lawrence Livermore National Laboratories respectively. Once the exascale system vendors have been selected, the LCFs will fund NRE activities to fully realize the potential of Exascale's vendor investments.

Investments in ECI follow the project funding plan and will help to maintain U.S. leadership in HPC into the next generation of exascale computing, which is of critical strategic importance to science, engineering, and national security. The ASCR FY 2020 Request funds two components of the ECI: planning, site preparations, and NRE at the Leadership Computing Facilities (LCF) to prepare for deployment of at least one exascale system in calendar year 2021, and the ASCR-supported Office of Science Exascale Computing Project (SC-ECP), first proposed in the FY 2017 Request, which includes the related R&D activities required to develop exascale-capable computers. The SC-ECP focuses on three areas aimed at increasing the convergence of big compute and big data, which then creates a holistic exascale HPC ecosystem:

- *Hardware and Integration:* The goal of the Hardware and Integration focus area is to integrate the delivery of SC-ECP products on targeted systems at leading DOE computing facilities.
- *Software Technology:* The goal of the 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 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 the mission of DOE, which 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, and scaling to larger systems.

Funding for ECI ($463,735,000) continues 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 calendar year 2021 at ANL, followed by a second exascale system with a different advanced architecture at ORNL:

- A total of $188,735,000 for the ECP project for the continued preparation of applications, to develop a software stack for both exascale platforms, and to support co-design centers in preparation for exascale system deployment in calendar year 2021. The final PathForward milestones were funded in FY 2019.
- A total of $275,000,000 in LCFs activity to support operations of the ALCF's Theta system and testbeds, NRE and site preparation investments at both LCFs to prepare for the deployment of an exascale system. The first exascale system will be delivered to the ALCF in calendar year 2021 and an additional exascale system, with a different architecture, will be delivered to the OLCF in the calendar year 2021-2022 timeframe. The deployment of exascale systems to these two LCFs will occur as part of their usual upgrade processes.

This approach will reduce the project risk.

ASCR supports the following FY 2020 Administration priorities.

FY 2020 Administration Priorities

	(dollars in thousands)		
	Exascale Computing Initiative (ECI)	**Artificial Intelligence (AI)**	**Quantum Information Science (QIS)**
Advanced Scientific Computing Research	463,735	36,000	51,161

Advanced Scientific Computing Research
Funding

(dollars in thousands)

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Mathematical, Computational, and Computer Sciences Research				
Applied Mathematics	34,104	28,206	41,500	+13,294
Computer Science	29,508	22,000	38,700	+16,700
Computational Partnerships	49,910	75,667	60,959	-14,708
SBIR/STTR	4,301	4,768	5,347	+579
Total, Mathematical, Computational, and Computer Sciences Research	**117,823**	**130,641**	**146,506**	**+15,865**
High Performance Computing and Network Facilities				
High Performance Production Computing	94,000	104,000	85,000	-19,000
Leadership Computing Facilities	272,500	339,000	360,000	+21,000
Research and Evaluation Prototypes	24,260	24,452	39,453	+15,001
High Performance Network Facilities and Testbeds	79,000	84,000	80,000	-4,000
SBIR/STTR	17,417	20,701	21,194	+493
Total, High Performance Computing and Network Facilities	**487,177**	**572,153**	**585,647**	**+13,494**
Subtotal, Advanced Scientific Computing Research	**605,000**	**702,794**	**732,153**	**+29,359**
Exascale Computing				
17-SC-20 Office of Science Exascale Computing Project (SC-ECP)	205,000	232,706	188,735	-43,971
Total, Advanced Scientific Computing Research	**810,000**	**935,500**	**920,888**	**-14,612**

SBIR/STTR funding:

- FY 2018 Enacted: SBIR $19,040,000 and STTR $2,678,000
- FY 2019 Enacted: SBIR $22,329,000 and STTR $3,140,000
- FY 2020 Request: SBIR $23,269,000 and STTR $3,272,000

Advanced Scientific Computing Research
Explanation of Major Changes

	(dollars in thousands) FY 2020 Request vs FY 2019 Enacted
Mathematical, Computational, and Computer Sciences Research The Computer Science and Applied Mathematics activities will continue to increase their emphasis on the combined challenges of increasingly heterogeneous architectures, and the changing ways in which HPC systems are used—incorporating machine learning (ML) and artificial intelligence (AI) into simulations and data intensive applications while increasing greater connectivity with distributed systems and resources including other SC user facilities. The Computational Partnerships activity will continue to infuse the latest developments in applied math and computer science, particularly in the areas of AI and ML, into the strategic applications of the SC to get the most out of the leadership computing systems. These efforts will be forward funded for two years in FY 2019. In addition, the Computational Partnerships activity will continue investments in new algorithms and applications focused on both artificial intelligence and on future computing technologies such as QIS, in partnership with BES, Biological and Environmental Research (BER), High Energy Physics (HEP), and Nuclear Physics (NP). Increases in Computer Science for quantum information networks will focus on addressing new opportunities and challenges of transporting and storing quantum information.	**+15,865**
High Performance Computing and Network Facilities Increased facilities funding continues site preparations and NRE activities to deploy an exascale system at the ALCF in calendar year 2021 and for an exascale system at the OLCF, that is architecturally distinct from the ALCF system, to be deployed in the calendar year 2021-2022 timeframe. Both facilities will provide testbed resources to the SC-ECP to test and scale application codes and continuously test and deploy software technologies. In addition, funding supports the final site and early application preparations for NERSC-9 and supports the ESnet-6 upgrade to significantly increase capacity and security at all DOE sites. Funding also supports operations, including increased power costs, equipment, staffing, planning, and long lead site preparations at ASCR's facilities.	**+13,494**
Exascale Computing The FY 2020 Request will support efforts in the SC-ECP for the continuation of co-design efforts in application and software development for both planned exascale architectures and partnerships with the ASCR facilities that are providing resources for continuous integration and testing of exascale-ready software. The decrease represents completion of ASCR supported vendor partnerships with the six computer vendors to develop critical technologies, such as interconnects, processors and memory, needed for the exascale system.	**-43,971**
Total, Advanced Scientific Computing Research	**-14,612**

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 other SC Programs have been established in QIS; and the DOE activities in AI and QIS are coordinated with other agencies through the National Science and Technology Council (NSTC). There are growing areas of collaboration in the area of data-intensive science, AI, 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 R&D Subcommittee of the 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 2020, cross-agency interactions and collaborations will continue in coordination with the Office of Science and Technology Policy.

Program Accomplishments

Re-establishing U.S. pre-eminence in High Performance Computing. In June 2018, the Oak Ridge Leadership Computing Facility's Summit system reclaimed the top spot for the U.S. in the global "Top 500" list of high performance computing systems and held the top spot in the November list, which included five DOE systems among the top ten. Two DOE teams shared the prestigious Gordon Bell prize in 2018 for outstanding achievement in high-performance computing using the Summit system—a seven-member team affiliated with ORNL was recognized for their paper "Attacking the Opioid Epidemic: Determining the Epistatic and Pleiotropic Genetic Architectures for Chronic Pain and Opioid Addiction," and a 12-member team affiliated with the LBNL was recognized for their paper "Exascale Deep Learning for Climate Analytics."

ECP PathForward Element Drives Translational U.S. HPC Vendor Research into Exascale Platform Offerings. As evidenced by CORAL II vendor platform offerings, ECP is successfully influencing leading U.S. computing companies to maintain focus on designing and building far more powerful and balanced computers for DOE simulation workloads in spite of a strong market pull away from serving simulation workloads. This was achieved through sustained investments and management by DOE through a partnership between NNSA/ASC and SC/ASCR in processor, memory system, and interconnect R&D (FastForward, DesignForward, and now ECP's PathForward). ECP provides a path for continued American leadership in simulation even in the face of substantial market and technical challenges.

Launching the Exascale area. ORNL researchers broke the Exascale barrier, achieving a peak throughput of 1.88 exaops with mixed precision—faster than any previously reported science application—while analyzing genomic data on the recently launched Summit supercomputer. The ORNL team achieved the feat, the equivalent to carrying out nearly two billion billion calculations per second, by using a mixture of numerical precisions. Traditionally, scientific computing has relied on double-precision floating point operations. However, interest in reduced numerical precision has grown in recent years due to breakthroughs in artificial intelligence and machine learning. The ORNL researchers were able to implement high-speed single- and half-precision operations with the comparative genomics application Combinatorial Metrics (CoMet) on Summit's state-of-the-art architecture. Doing so allowed the team to achieve more than a 25-fold code speedup compared to runs conducted on the OLCF's previous leadership-class supercomputer Titan. Exascale-level performance allowed the researchers to analyze datasets composed of millions of genomes—a size that was previously impossible—and study variations between all possible combinations of two or three alleles at a time. Scientists can use this information to uncover hidden networks of genes in plants and animals that contribute to observable traits, such as biomarkers for drought-resistance in plants or disease in humans. In this demonstration, the ORNL team was able to discover key regulatory genes in plant cell walls that could be manipulated to enhance biofuels and other bioproducts. This team is also contributing to a human health application, in partnership with Department of Veteran Affairs (VA) researchers, which is a finalist for the 2018 Gordon Bell prize.

Leveraging HPCs to advance Scientific Machine Learning. Scientific data often looks very different from the data used in artificial intelligence applications. Developing the right artificial neural network can take months of handcrafting for experts and can feel like an impossible guessing game for non-experts. To expand the benefits of deep learning for science, researchers need new tools to build high-performing neural networks that don't require specialized knowledge. By leveraging the GPU computing power of the OLCF, an ORNL team has developed an evolutionary algorithm capable of auto-generating networks quickly, in a matter of hours as opposed to the months needed using conventional methods. The research team's algorithm, called MENNDL (Multinode Evolutionary Neural Networks for Deep Learning), is designed to evaluate, evolve, and optimize neural networks for unique datasets. Scaled across the OLCF Titan's 18,688 GPUs, MENNDL can test and train thousands of potential networks for a science problem simultaneously, eliminating poor performers and averaging high performers until an optimal network emerges. The process eliminates much of the time-intensive, trial-and-error tuning traditionally required of machine learning experts. One science domain in which MENNDL is already proving its value is neutrino physics. Neutrinos, ghost-like particles that pass through your body at a rate of trillions per second, could play a major role in explaining the formation of the early universe and the nature of matter—if only scientists knew more about them. The MENNDL team is working with scientists from DOE's Fermi National Accelerator Laboratory (Fermilab) to integrate neural networks into the classification and analysis of detector data. The work could improve the efficiency of some measurements, help physicists understand how certain they can be about their analyses, and lead to new avenues of inquiry. In addition to improved physics measurements, the results could provide insight into how and why machines learn–accelerating the pace of progress in scientific applications of artificial intelligence.

First simulation of an atomic nucleus using a quantum computer. Quantum computing, in which computations are carried out using uniquely quantum mechanical properties of matter, has great promise for simulating physical systems that are not accessible to conventional supercomputers. A multidisciplinary team led by scientists at ORNL took a significant step towards realizing that promise by performing the first successful simulation of an atomic nucleus using a quantum computer. The team developed a new quantum algorithm to simulate the deuteron–a proton bound to a neutron –and ran the algorithm on two different quantum computers, performing over 700,000 quantum measurements in the process. The algorithm is expected to scale up to larger and more complex atomic nuclei. This exciting new result was achieved by a collaboration between the Quantum Algorithms and Quantum Testbeds teams funded by ASCR in FY 2017 as well as the NUCLEI Scientific Discovery through Advanced Computing (SciDAC)-4 team, and leverages decades of built-up expertise in nuclear physics at ORNL and the University of Washington.

Accelerating Discovery of New Materials for dye-sensitized solar cells. Buildings consume an estimated 40 percent of energy used in the United States—a burden that also represents a renewable energy opportunity. Solar-powered windows, equipped with dye-sensitized solar cells, provide an innovative technology for generating electricity in a sustainable, environmentally friendly fashion. This type of solar cell is a promising alternative to today's solar cells made with rare earth metals that are scarce, cost prohibitive, and not environmentally sustainable. A research team from the University of Cambridge and Argonne National Laboratory is using supercomputers at the Argonne Leadership Computing Facility to combine advanced data mining techniques with machine learning and computational modeling to identify new materials with optimal properties for dye-sensitized solar cells. This approach has allowed the researchers to narrow a list of 9,000 potential materials down to six promising candidates. The team has collaborated with chemists from around the world to synthesize the six dye materials. The researchers are now working to optimize experimental conditions for solar cell device fabrication and testing. Initial experiments with the synthesized materials have yielded promising photovoltaic properties.

Convergence of big data with big compute to understand how the universe operates. NOvA, the world's longest-baseline neutrino experiment, was designed to discover more about neutrinos, ghostly yet abundant particles that travel through matter mostly without leaving a trace, to answer questions about how the universe operates. NOvA, in partnership with SciDAC, HEPcloud, and the National Energy Research Scientific Computing Center (NERSC) used over 35 million computing cores, or CPUs over approximately 54 hours to conduct the largest-scale analysis ever to support the recent evidence of antineutrino oscillation, a phenomenon that may hold clues to how our universe evolved. Although NERSC is located over 2,000 miles away from the NOvA experimental facility, researchers were able to enable near-real time analysis of time-sensitive science at rates 50 times faster than what was previously possible. Without the NERSC resources and SciDAC partnership, the NOvA collaboration could not have turned around results as quickly.

Data-driven visualization of large power grids. Driven by the emerging industry needs, electric utilities and grid coordination organizations are eager to seek advanced tools to assist grid operators and analysts to perform mission-critical tasks and enable them to make quick and accurate decisions. Traditionally, visualization of power grids heavily relies on human designers. Building and maintaining the visualization displays, however, is a very labor-intensive and error-prone process. Furthermore, the legacy approach restricts the visualization process to follow a limited number of pre-defined patterns created by human designers, thus hindering users' ability to discover. To overcome these shortcomings, researchers at Power Info LLC have developed a data-driven approach for visualization of large power grids with funding provided through the Small Business Innovation Research (SBIR) program. The developed data-driven visualization algorithm uses empirically or mathematically derived data to formulate visualizations on-the-fly. The resulting visual presentations emphasize what the data is rather than how the data should be presented, thus fostering comprehension and discovery. The software tool resulting from this research is now being leveraged by more than 70 utility organizations in North America and Europe. For example, Dominion Virginia Power used the tool, combining artificial intelligence and human's natural intelligence, to auto-generate a large number of high-quality visualization displays at a fraction of the traditional cost. Work that used to consume more than six months for two full-time employees was completed by a college intern within a month with no errors. The end-users concluded that the delivered solution saved operational costs and reduced human errors.

Most Detailed 3-D Map of Earth's Interior. Using advanced modeling and simulation, seismic data generated by earthquakes, and OLCF's Titan, a team led by Princeton University has created the most detailed 3-D picture of Earth's interior showing the entire globe from the surface to the core–mantle boundary, a depth of 1,800 miles. This first global seismic model where no approximations were used to simulate how seismic waves travel through the Earth marked a milestone for the seismology community. The model was created using seismic tomography, which is based on combining many seismograms. In the past, seismic tomography techniques have been limited in the amount of seismic data they could use. Traditional methods forced researchers to make approximations in their wave simulations and restrict observational data. The novel approach used in this study allowed researchers to use the entire dataset. Getting the most out of this data required a robust automated workflow. To improve data movement and flexibility on large-scale parallel computing resources, in collaboration with the OLCF staff, the team developed a superior file format called the Adaptable Seismic Data Format (ASDF) that leverages the Adaptable I/O System (ADIOS) parallel library, long supported by ASCR's computer science and SciDAC programs. As part of the OLCF's Center for Accelerated Application Readiness, the team is currently preparing to run further simulations on Summit to be able to image the entire globe from crust all the way down to Earth's center, including the core.

Description

The Mathematical, Computational, and Computer Sciences Research subprogram supports research activities to effectively meet the Office of Science high performance computing (HPC) mission needs, including both data intensive and computationally intensive science. Computational science is central to progress at the frontiers of science and to our most challenging engineering problems. The Computer Science and Applied Mathematics activities in ASCR provide the foundation for increasing the capability of the national HPC ecosystem by focusing on long-term research to develop software, algorithms, and methods that anticipate future hardware challenges and opportunities as well as science application needs. ASCR partnerships and coordination with industry are essential to these efforts. ASCR partnerships with disciplinary science deliver some of the most advanced scientific computing applications in areas of strategic importance to SC. Scientific software often has a lifecycle that spans decades—much longer than the average HPC system. Research efforts must therefore anticipate changes in hardware as well as application needs over the long term. ASCR's partnerships with vendors and discipline sciences are critical to these efforts. Accordingly, the subprogram delivers:

- new mathematics and algorithms required to more accurately model systems involving processes taking place across a wide range of time and length scales and incorporate machine learning techniques into computational simulations;
- the software needed to support DOE mission applications, including new paradigms of data-intensive applications and machine learning, on current and increasingly more heterogeneous future systems;
- insights about computing systems and workflow performance and usability leading to more efficient and productive use of computing, storage and networking resources;
- collaboration tools and partnerships to make scientific resources readily available to scientists in university, national laboratory, and industrial settings; and
- long-term, basic research on future computing technologies with relevance to the DOE mission.

<u>Applied Mathematics</u>

The Applied Mathematics activity supports basic research leading to fundamental mathematical advances and computational breakthroughs across DOE and SC missions. Basic research in scalable algorithms, multiscale modeling, artificial intelligence, 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 machine learning, and for enabling greater capabilities for scientific discovery, design, and decision-support.

<u>Computer Science</u>

The Computer Science research program supports basic research that enables computing and networking at extreme scales and the understanding of extreme scale, or complex data from both simulations and experiments. Through the development of adaptive software tools, it aims to make high performance scientific computers and networks highly productive and efficient to solve scientific challenges while attempting to reduce domain science application complexity as much as possible. ASCR-supported activities are entering a new paradigm driven by sharp increases in the heterogeneity and complexity of computing systems and the need to seamlessly and intelligently integrate simulation, data analysis, and other tasks into coherent and usable workflows.

The Computer Science activity supports long-term, basic research on 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 does 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.

Computational Partnerships

The Computational Partnerships activity primarily 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.

The Computational Partnerships activity also supports critical partnerships in the areas of data analysis and future computing. Collaboratory and data analysis partnerships enable large distributed research teams to share data and develop tools for real-time analysis of the massive data flows from SC scientific user facilities, as well as the R&D of software to support a distributed data and computing environment. Interdisciplinary teams in partnership with BES, BER, HEP, and NP enable development of new algorithms and applications targeted for future computing platforms, including quantum information systems.

Activities and Explanation of Changes

FY 2019 Enacted	FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Mathematical, Computational, and Computer Sciences Research $130,641,000	**$146,506,000**	**+$15,865,000**
Applied Mathematics $28,206,000	$41,500,000	+$13,294,000
Applied Mathematics continues its core programs in new algorithmic techniques and strategies that extract scientific advances and engineering insights from massive data for DOE missions. Applied Mathematics also continues to focus on the development of adaptive algorithms and machine learning in recognition of the increased interest in these technologies across SC application areas.	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 increase investments in research to develop foundational capabilities in scientific AI and ML.	Support for the core programs continues with an increased focus on investments in the mathematical foundational of AI, such as uncertainty quantification and optimization needed to develop reliable predictive models.
Computer Science $22,000,000	$38,700,000	+$16,700,000
Computer Science continues efforts to develop software, new programming models, new operating systems, and continued efforts to promote ease of use. In addition, efforts in quantum networking, transferred from the Next Generation Networking for Science activity, continue, sustained at FY 2018 levels. In addition, there is also an emphasis on preparing for the "extremely heterogeneous" post-exascale era.	Computer Science will continue to address the combined challenges of increasingly heterogeneous architecture, and the changing ways in which HPC systems are used—incorporating more data intensive applications and greater connectivity with distributed systems and resources including other Office of Science user facilities. The Request expands efforts in quantum networking.	Support for the core program continues with an increased focus on incorporating AI and ML learning into data analytics software from networking to HPCs. Increases also support expansion of the quantum networking activity.
Computational Partnerships $75,667,000	$60,959,000	-$14,708,000
In addition to continued support for the SciDAC institutes and partnerships awarded in FY 2017-FY 2018, this activity increases efforts in QIS in partnership with the other SC programs, and efforts to bring the power of HPC to data intensive science.	In addition to continued support for the SciDAC institutes and partnerships awarded in FY 2017-18, this activity will maintain efforts in QIS in partnership with the other SC programs, and efforts to bring the power of HPC to data intensive science.	Two year AI partnerships with other Office of Science programs were forward funded in FY 2019; therefore, funding is not needed for this effort in FY 2020. The SciDAC Institutes will be recompeted and refocused on introducing new AI and ML algorithms and tools. Quantum algorithm partnerships will be re-competed as part of the proposed QIS Centers.

FY 2019 Enacted		FY 2020 Request		Explanation of Changes FY 2020 Request vs FY 2019 Enacted	
SBIR/STTR	$4,768,000		$5,347,000		+$579,000
In FY 2019, SBIR/STTR funding is set at 3.65% of non-capital funding.		In FY 2020, SBIR/STTR funding is set at 3.65% of non-capital funding.		Funding changes are the direct result of increases in the non-capital budget request.	

Description
The High Performance Computing and Network Facilities subprogram supports the operations of forefront computational and networking user facilities to meet critical mission needs. ASCR operates three high performance computing (HPC) user facilities: the National Energy Research Scientific Computing Center (NERSC) at Lawrence Berkeley National Laboratory (LBNL) provides high performance computing resources and large-scale storage to a broad range of SC researchers; and the two Leadership Computing Facilities (LCFs) at ORNL and ANL provide leading-edge high performance computing capability to the U.S. research and industrial communities. ASCR's high performance network user facility, ESnet, delivers highly reliable data transport capabilities optimized for the requirements of large-scale science. Finally, operations of these facilities also includes investments in upgrades, including electrical and mechanical system enhancements, to ensure each remains state-of-the-art and can install future systems.

The Research and Evaluation Prototypes (REP) activity investigates next-generation computing systems. By actively partnering with the research community, including industry and other Federal agencies, to explore next-generation computing platforms, ASCR ensures they will serve the needs of the scientific community. Conversely, the REP activity prepares researchers to effectively use future computing platforms. Through these efforts the REP activity mitigates strategic risk. In addition, the REP activity supports DOE workforce needs through the Computational Sciences Graduate Fellowship, which prepares the next generation of computational scientists and engineers to work on advanced computing systems.

ASCR regularly gathers requirements from the other SC research programs through formal processes to inform upgrade plans. These requirements activities are also vital to planning for SciDAC and other ASCR research 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 at LBNL to deliver high-end production computing services for the SC research community. Approximately 7,000 computational scientists conducting 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 energy, 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 population ranges from experienced to neophyte. NERSC aids users entering the HPC arena for the first time, as well as those preparing leading-edge codes that harness the full potential of the machine.

NERSC currently operates the 30 pf Intel/Cray system (Cori). 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 REP and ASCR research efforts. Another LCF strength is the staff, who 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. LCF staff experience is critical to the success of industry partnerships to address the challenges of next-generation computing.

The Oak Ridge Leadership Computing Facility (OLCF) at ORNL currently operates testbeds in support of ECI and the 200 pf IBM/NVIDIA system (Summit), which achieved the global number one ranking as the world's fastest system in June 2018.

Early science applications at Summit include: 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. 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 U.S. companies. Also, the OLCF is preparing to deploy an exascale system in the calendar year 2021-2022 timeframe.

The Argonne Leadership Computing Facility (ALCF) at ANL operates an 8.5 pf Intel/Cray system (Theta) and testbeds to prepare their users and SC-ECP applications and software technology for the ALCF-3 upgrade in calendar year 2021. The ALCF-3 system, which will be the Department’s first exascale system when deployed in calendar year 2021, is being designed to support the largest-scale computational simulations possible as well as large-scale analytics and machine learning. The ALCF and OLCF systems are architecturally distinct, consistent with DOE’s strategy to foster diverse capabilities that provide 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 more than a factor of two.

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 emulators.

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 DOE’s national laboratory system, dozens of other DOE sites, and approximately 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).

Activities and Explanation of Changes

FY 2019 Enacted		FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
High Performance Computing and Network Facilities	**$572,153,000**	**$585,647,000**	**+$13,494,000**
High Performance Production Computing	$104,000,000	$85,000,000	-$19,000,000
Support continues for operations and user support at the NERSC facility–including power, space, leases and staff. Funding also supports 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.		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.	Decrease reflects the completion of many site preparation activities for deployment of NERSC-9 in early FY 2021.
Leadership Computing Facilities	$339,000,000	$360,000,000	+$21,000,000
ANL Leadership Computing Facility	*$140,000,000*	*$150,000,000*	*+$10,000,000*
ORNL Leadership Computing Facility	*$199,000,000*	*$210,000,000*	*+$11,000,000*
Support continues for 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, are supported. The OLCF continues the operation and allocation of Summit while decommissioning Titan. In support of ECP, the OLCF provides access to Summit for the application and software projects to scale and test their codes. The OLCF also continues activities to enable deployment of an exascale system in the calendar year 2021-2022 timeframe under the CORAL II.		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 and testbeds, will also be supported. The OLCF will continue operation and allocation of Summit. In support of ECP, the OLCF will provide access to Summit and other testbeds 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 calendar year 2021-2022 timeframe under the CORAL II.	Support is increased for final site preparations inside the computer facilities for the planned deployment of exascale systems and for the final NRE efforts.

FY 2019 Enacted	FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
The ALCF continues the operation of Theta. The ALCF continues 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. In addition, the ALCF is procuring a large developmental testbed to test activities from NRE investments and to provide ECP applications and software technology projects to test their codes.	The ALCF will continue operation of Theta and testbeds that will be deployed in FY 2019 to support SC-ECP. 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 calendar year 2021 timeframe as part of ECI, while decommissioning MIRA.	
Research and Evaluation Prototypes $24,452,000	$39,453,000	+$15,001,000
The Enacted budget provides 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 provides continued support for quantum testbed efforts to provide resources for the researchers supported through the quantum information science partnerships with the other SC programs.	The Request will maintain 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.	Increase supports new at least one new QIS center in partnership with BES and HEP.
High Performance Network Facilities and Testbeds (ESnet) $84,000,000	$80,000,000	-$4,000,000
The Enacted budget supports operations of the ESnet at 99.999% reliability. In addition, funding supports the ESnet-6 upgrade to increase network capacity and modernize the network architecture.	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 decrease reflects the execution of several significant long-lead procurement contracts for the ESnet-6 upgrade in FY 2019 and therefore fewer funding requirements in FY 2020.
SBIR/STTR $20,701,000	$21,194,000	+$493,000
In FY 2019, SBIR/STTR funding is set at 3.65% of non-capital funding.	In FY 2020, SBIR/STTR funding is set at 3.65% of non-capital funding.	Funding changes are the direct result of increases in the non-capital budget request.

Advanced Scientific Computing Research
Exascale Computing

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 Office of Science Exascale Computing Project (SC-ECP) captures the research aspects of ASCR's participation in the ECI, to ensure the hardware and software R&D, including applications software, for an exascale system is completed in time to meet the scientific and national security mission needs of DOE in calendar year 2021. The deployment of these systems, funded under ECI, includes necessary site preparations and NRE at the Leadership Computing Facilities that will ultimately house and operate the exascale systems. The ECI will execute a program, jointly 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, 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 ANL and ORNL and NERSC at LBNL.

Overall project management for the 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 projects, such as the Spallation Neutron Source project. A Memorandum of Agreement is in place between the six DOE national laboratories participating in the SC-ECP: LBNL, ORNL, ANL, Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL) and Sandia National Laboratories (SNL). The Project Office at ORNL is executing the project and coordinating among partners.

The FY 2020 Request includes $188,735,000 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. Funding for the final vendor PathForward milestones ended in FY 2019. The results of the PathForward investments were evident in the vendor's responses to the CORAL II request for proposals. Once the exascale system vendors have been selected, the LCFs will increase investments through NRE funding to fully realize the potential of the PathForward investments. Thus, the PathForward investments will no longer be needed. Deployment of exascale systems will be through the LCFs as part of their usual upgrade processes.

Activities and Explanation of Changes

FY 2019 Enacted		FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Construction	**$232,706,000**[a]	**$188,735,000**	**-$43,971,000**
17-SC-20 Office of Science Exascale Computing Project (SC-ECP)	$232,706,000	$188,735,000	-$43,971,000
Funding continues the acceleration of application and software stack development in preparation for delivery of an exascale system in 2021.		The Request will provide funding for the acceleration of application and software stack development in preparation for delivery of the first exascale system in calendar year 2021.	Decreases in funding represent completion of ASCR supported vendor partnerships while continuing investments in applications and partnerships with ASCR's facilities to continuously develop, integrate and test the ECI software stack in preparation for the delivery of the two exascale systems in the calendar year 2021–2022 timeframe.

[a] In addition, $240,000,000 of ECI funding is provided within the Leadership Computing Facilities activity in FY 2019 and $275,000,000 is requested in FY 2020 to begin planning, non-recurring engineering, and site preparations for at least one exascale system to be delivered in calendar year 2021.

Advanced Scientific Computing Research
Capital Summary

(dollars in thousands)

	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Capital Operating Expenses Summary						
Capital equipment	N/A	N/A	10,000	5,000	5,000	—
Total, Capital Operating Expenses	**N/A**	**N/A**	**10,000**	**5,000**	**5,000**	**—**

Capital Equipment

(dollars in thousands)

	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Capital Equipment						
Total, Non-MIE Capital Equipment	N/A	N/A	10,000	5,000	5,000	—
Total, Capital Equipment	**N/A**	**N/A**	**10,000**	**5,000**	**5,000**	**—**

Funding Summary

(dollars in thousands)

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Research	364,500	408,500	395,888	-12,612
Facility operations	445,500	527,000	525,000	-2,000
Total, Advanced Scientific Computing Research	**810,000**	**935,500**	**920,888**	**-14,612**

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

Definitions for TYPE A facilities:
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.

(dollars in thousands)

	FY 2018 Enacted	FY 2018 Current	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
TYPE A FACILITIES					
NERSC	**$94,000**	**$94,000**	**$104,000**	**$85,000**	**-$19,000**
Number of Users	6,000	7,449	7,500	7,500	—
Achieved operating hours	N/A	8,485	N/A	N/A	N/A
Planned operating hours	8,585	8,585	8,585	8,585	—
Optimal hours	8,585	8,585	8,585	8,585	—
Percent optimal hours	99%	99%	N/A	N/A	N/A
Unscheduled downtime hours	1%	1%	N/A	N/A	N/A

	(dollars in thousands)				
	FY 2018 Enacted	FY 2018 Current	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
OLCF	**$162,500**	**$162,500**	**$199,000**	**$210,000**	**+$11,000**
Number of Users	1,064	1,444	1,450	1,450	—
Achieved operating hours	N/A	6,896	N/A	N/A	N/A
Planned operating hours	7,008	7,008	7,008	7,008	—
Optimal hours	7,008	7,008	7,008	7,008	—
Percent optimal hours	>99%	98%	N/A	N/A	N/A
Unscheduled downtime hours	<1%	2%	N/A	N/A	N/A
ALCF	**$110,000**	**$110,000**	**$140,000**	**$150,000**	**+$10,000**
Number of Users	1,434	954	950	950	—
Achieved operating hours	N/A	6,980	N/A	N/A	N/A
Planned operating hours	7,008	7,008	7,008	7,008	—
Optimal hours	7,008	7,008	7,008	7,008	—
Percent optimal hours	>99%	99%	N/A	N/A	N/A
Unscheduled downtime hours	<1%	1%	N/A	N/A	N/A
ESnet	**$79,000**	**$79,000**	**$84,000**	**$80,000**	**-$4,000**
Number of users[a]	N/A	N/A	N/A	N/A	N/A
Achieved operating hours	N/A	N/A	N/A	N/A	N/A
Planned operating hours	8,760	8,760	8,760	8,760	—
Optimal hours	8,760	8,760	8,760	8,760	—
Percent optimal hours	100%	100%	N/A	N/A	N/A
Unscheduled downtime hours	0%	0%	N/A	N/A	N/A
Total Facilities	**$445,500**	**$445,500**	**$527,000**	**$525,000**	**-$2,000**
Number of Users[b]	8,498	9,847	9,900	9,900	—
Achieved operating hours	N/A	31,121	N/A	N/A	N/A
Planned operating hours	31,361	31,361	31,361	31,361	—
Optimal hours	31,361	31,361	31,361	31,361	—
Percent of optimal hours[a]	99%	99%	N/A	N/A	N/A
Unscheduled downtime hours	1%	1%	N/A	N/A	N/A

[a] ESnet is a high performance scientific network connecting DOE facilities to researchers around the world; user statistics are not collected.
[b] Total users only for NERSC, OLCF, and ALCF.

Advanced Scientific Computing Research
Scientific Employment

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Number of permanent Ph.D.'s (FTEs)	620	611	615	+4
Number of postdoctoral associates (FTEs)	205	198	202	+4
Number of graduate students (FTEs)	516	487	495	+8
Other scientific employment (FTEs)[b]	268	256	263	+7

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

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

1. Summary, Significant Changes, and Schedule and Cost History

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 an exascale ecosystem as part of the ECI. Other activities included in the ECI but not the SC-ECP include $275,000,000 in FY 2020 to support the initiation of planning, site preparations, and non-recurring engineering (NRE) 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 the calendar year 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 SC-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 2020, SC-ECP funding will support project management; co-design activities between application, software, and hardware technologies; investments on critical hardware technologies with vendors, R&D of exascale systems, software, and tools needed for exascale programming; increased engagement and integration between SC-ECP and the LCF's upgrades to provide continuous integration and testing of the ECP funded applications and software; and completion of the milestones of the vendor partnerships which received final funding in FY 2019.

Significant Changes

This Project Data Sheet (PDS) is an update of the FY 2019 PDS and does not include a new start for FY 2020.

The FY 2020 Request for SC-ECP is $188,735,000 and is a decrease of $43,971,000 from the FY 2019 Enacted. The FY 2020 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 the calendar year 2021 timeframe. The project is expected to achieve CD-2 in early FY 2020 and the decrease is a result of ASCR funding in FY 2019 its share of the vendor partnerships to initiate their final milestones

Following the Independent Project Review in January 2018, a Baseline Change Proposal (BCP) was executed and approved in March 2018, to officially move the responsibility for the exascale systems' NRE and development testbeds from ECP scope to the Exascale Computing Initiative (ECI) through the DOE high performance computing facilities. This effectively eliminated the need for CD-3A.

The current preliminary estimate for the SC-ECP total project cost was revised from $1,233,965 to $1,256,385, an increase of $22,420, which is based on updated cost information from the remaining 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, which was approved on January 3, 2017. Even with the BCP, the estimated Total Project Cost (TPC) range of the SC-ECP is $1.0 billion to $2.7 billion.

A Federal Project Director with the appropriate certification level was assigned to this project.

Critical Milestone History

Fiscal Year	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
FY 2020	07/28/2016	2Q FY 2019	01/03/2017	1Q FY 2020	3Q FY 2019	1Q FY 2020	N/A	4Q FY 2023

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 or will be 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-3A – Approve Long Lead Time Procurements
CD-3B– Approve Start of Construction
D&D Complete – Completion of D&D work
CD-4 – Approve Start of Operations or Project Closeout

Fiscal Year	Performance Baseline Validation
FY 2017	TBD
FY 2018	4Q FY 2019
FY 2019	4Q FY 2019
FY 2020	1Q FY 2020

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.

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D	OPC, D&D	OPC, Total	Total
FY 2017	N/A	TBD	TBD	TBD	N/A	TBD	TBD
FY 2018	N/A	390,000	390,000	763,524	N/A	763,524	1,153,524
FY 2019	N/A	426,735	426,735	807,230	N/A	807,230	1,233,965
FY 2020	N/A	426,735	426,735	829,650	N/A	829,650	1,256,385

2. 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.

[a] http://science.energy.gov/ascr/research/scidac/exascale-challenges

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 calendar year timeframe under ECI.

Justification

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 the National Energy Research Scientific Computing Center (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 system design), and these costs will be reported as Other Project Costs. Once the project is baselined in FY 2020, 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.

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.

Performance Measure	Threshold	Objective
Performance on scientific and national security applications relative to today's performance	Greater than 50x improvement in performance[a] by at least 50% of the subset of ECP applications selected for measurement under KPP-1.	Greater than 50x improvement in performance by 100% of subset of ECP applications selected for measurement under KPP-1.
Broaden the reach of exascale science and mission capability	50% of the subset of ECP applications selected for measurement under KPP-2 s can execute their exascale challenge problem[b]	100% of the subset of ECP applications selected for measurement under KPP-2 can execute their exascale challenge problem

[a] Performance is measured by a Figure of Metric that represents the rate of "science work" defined specific to each scientific application and takes into consideration the increased complexity and precision in addition to the speed of solution.

[b] This KPP assesses the successful creation of new exascale science and mission capability. An exascale challenge problem is defined for every scientific application in the project. The challenge problem is reviewed annually to ensure it remains both scientifically impactful to the nation and requires exascale-level resources to execute.

Performance Measure	Threshold	Objective
Productive and Sustainable High-Performance Computing (HPC) software ecosystem	Software teams meet 75% of their impact goals[a]	Software teams meet 100% of their impact goals
Enrich the HPC Hardware Ecosystem	Vendors meet 80% of all the PathForward milestones	Vendors meet 100% of all the PathForward milestones

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
(Hardening of Applications Development System Software Technology, Hardware Technology)			
FY 2020	174,735	174,735	174,735
Outyears	252,000	252,000	252,000
Total, TEC	**426,735**	**426,735**	**426,735**
Other Project Costs (OPC)			
(Research for Application Development, System Software Technology, and Hardware Technology)			
FY 2016[b]	157,944	157,944	8,338
FY 2017	164,000	164,000	89,058
FY 2018	205,000	205,000	180,453
FY 2019	232,706	232,706	230,066
FY 2020	14,000	14,000	250,000
Outyears	56,000	56,000	71,735
Total, OPC	**829,650**	**829,650**	**829,650**
Total Project Costs (TPC)			
FY 2016[c]	157,944	157,944	8,338
FY 2017	164,000	164,000	89,058
FY 2018	205,000	205,000	180,453
FY 2019	232,706	232,706	230,066
FY 2020	188,735	188,735	424,735
Outyears	308,000	308,000	323,735
Total, TPC	**1,256,385**	**1,256,385**	**1,256,385**

4. Details of 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.

[a] This KPP measures progress on the goal to develop a software ecosystem where high-performance applications can be efficiently and effectively designed, developed, tuned, and executed on exascale systems. Each software effort in the project defines 2-4 impact goals, which must be measurable and provide tangible value to the HPC ecosystem.

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

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Application Development	211,800	255,125	N/A
Production Ready Software	147,190	157,870	N/A
Hardware Partnerships	67,745	13,740	N/A
Total, TEC	**426,735**	**426,735**	**N/A**
Other Project Costs (OPC) (Research)			
Planning/Project Mgmt	123,715	109,715	N/A
Application Development	298,824	295,062	N/A
Software Research	167,970	179,303	N/A
Hardware Research	239,141	223,150	N/A
Total, OPC	**829,650**	**807,230**	**N/A**
Total Project Cost (TPC)	**1,256,385**	**1,233,965**	**N/A**

5. Schedule of Appropriation Requests

(dollars in thousands)

Request Year	Type	FY 2016[a]	FY 2017	FY 2018	FY 2019	FY 2020	Outyears	Total
FY 2017	TEC	—	—	TBD	TBD	TBD	TBD	TBD
	OPC	157,894	154,000	TBD	TBD	TBD	TBD	TBD
	TPC	157,894	154,000	TBD	TBD	TBD	TBD	TBD
FY 2018	TEC	—	—	—	—	175,000	215,000	390,000
	OPC	157,944	164,000	196,580	189,000	14,000	42,000	763,524
	TPC	157,944	164,000	196,580	189,000	189,000	257,000	1,153,524
FY 2019	TEC	—	—	—	—	174,735	252,000	426,735
	OPC	157,944	164,000	196,580	232,706	14,000	42,000	807,230
	TPC	157,944	164,000	196,580	232,706	188,735	294,000	1,233,965
FY 2020	TEC	—	—	—	—	174,735	252,000	426,735
	OPC	157,944	164,000	205,000	232,706	14,000	56,000	829,650
	TPC	157,944	164,000	205,000	232,706	188,735	308,000	1,256,385

6. 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 or research program's budget. A BCP was executed in March, 2018 to reflect this change. In the FY 2020 Budget Request, $275,000,000 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 (fiscal quarter or date)	2022
Expected Useful Life (number of years)	5
Expected Future start of D&D for new construction (fiscal quarter)	4Q 2030

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

7. D&D Information

N/A, no construction.

8. 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.

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. BES accomplishes its mission through excellence in scientific discovery in the energy sciences, and through stewardship of world-class scientific user facilities that enable cutting-edge research and development.

The research disciplines that BES supports—condensed matter and materials physics, chemistry, geosciences, and aspects of biosciences—touch virtually every important aspect of energy resources, production, conversion, transmission, storage, efficiency, and waste mitigation, providing a knowledge base for achieving a secure and sustainable energy future. The 2018 Basic Energy Sciences Advisory Committee (BESAC) report, "A Remarkable Return on Investment in Fundamental Research",[a] provides key examples of major technological, commercial, and national security impacts directly traceable to BES-supported basic research. This mission-relevance of BES research results from a long-standing established strategic planning process, which encompasses BESAC reports, topical in-depth community workshops and reports, and rigorous program reviews.

BES scientific user facilities consist 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 science questions. The above-noted BESAC report recounts the central role of these shared resources as a key to U.S. scientific and industrial leadership. BES has a long history of delivering major construction projects on time and on budget, and of providing reliable availability and support to users for operating facilities. This record follows from rigorous community-based processes for conceptualization, planning, and execution of projects, and from performance assessment of operating facilities.

Key to exploiting scientific discoveries for future energy systems 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 and conversions of energy from one form to another. Such materials will need to be more functional than today's energy materials. These new chemical processes will require ever-increasing control to the levels of electrons. These advances are not found in nature; they must be designed and fabricated to exacting standards using principles revealed by basic science. Today, 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. Collectively, these new tools and capabilities convey a significant strategic advantage for the Nation to advance the scientific frontiers while laying the foundation for future innovations and economic prosperity.

DOE envisions a future in which the cross-cutting field of quantum information science (QIS) increasingly drives these scientific frontiers and innovations toward realizing the full potential of quantum-based applications, from computing, to communication, to sensing. This will require precise control at the atomic and molecular levels for the understanding, design, prediction, synthesis, fabrication, and integration of quantum systems. In support of the National Quantum Initiative[b], SC QIS Centers, coupled with a robust core research portfolio stewarded by the individual Office of Science (SC) programs including BES, will create the ecosystem across universities, national labs, and industry that is needed to foster these developments.

The Office of Science has been an important facilitator and sponsor of research at the cutting edge of microelectronics. Its programs have made major contributions to the scientific understanding and advanced instrumentation that enabled Moore's law scaling, and have driven transformative advances in microelectronics in response to the challenging demands of DOE's high performance computing and science facilities. Sustained and rapid progress in microelectronics science and

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[a] All reports are available at https://science.energy.gov/bes/community-resources/reports/.
[b] Section 402 of the National Quantum Initiative Act, PL 115-368

technology is essential if DOE is to continue pushing the boundaries of science and, more significantly, continue to lead the global information technology revolution.

Highlights of the FY 2020 Request

The BES FY 2020 Request of $1,858,285,000 focuses resources toward the highest priorities in early-stage fundamental research, in operation and maintenance of scientific user facilities, and in facility upgrades.

Key elements in the FY 2020 Request include:

Research

Core research priorities in the FY 2020 Request include QIS, next-generation microelectronics, and data analytics and machine learning for data-driven science. BES will partner with SC's Offices of Advanced Scientific Computing Research (ASCR) and High Energy Physics (HEP) to establish at least one multi-disciplinary QIS center to promote basic research and early stage development to accelerate the advancement of QIS through vertical integration between systems and theory and hardware and software. The Request increases funding for the Energy Frontier Research Centers (EFRCs) with a planned solicitation in FY 2020 to expand the EFRC portfolio in topical areas of the highest priority to the Department, including QIS, microelectronics, and other program priorities. This EFRC solicitation will also recompete funding for science relevant to the Department's environmental management mission. The Request continues support for computational materials and chemical sciences to deliver shared software infrastructure to the research communities as part of the Exascale Computing Initiative. The BES-supported Batteries and Energy Storage Energy Innovation Hub continues. The Fuels from Sunlight Energy Innovation Hub will complete its second five-year term with FY 2019 funding. FY 2020 funding is requested to continue support of early-stage fundamental research on solar fuels generation that builds on the Hub's unique capabilities and accomplishments to date. BES will issue an open competition in FY 2020 for new multi-investigator, cross-disciplinary solar fuels research to address emerging new directions as well as long-standing challenges in this transformational area of energy science.

Facility Operations

In the Scientific User Facilities subprogram, BES maintains a balanced suite of complementary tools. Linac Coherent Light Source (LCLS) operations will resume in the second quarter of FY 2020 on completion of installation of LCLS-II accelerator components. The Advanced Light Source (ALS), Advanced Photon Source (APS), National Synchrotron Light Source-II (NSLS-II), and the Stanford Synchrotron Radiation Lightsource (SSRL) will continue operations and are supported at approximately 87% of optimum. Both BES-supported neutron sources, the Spallation Neutron Source (SNS) and the High Flux Isotope Reactor (HFIR), will be operational in FY 2020 and funded at approximately 87% of optimum. All five Nanoscale Science Research Centers (NSRCs) will be supported with funding designated for nanoscience as well as QIS research and related tools development.

Projects

In the Construction subprogram, the LCLS-II project received its last year of funding in FY 2019, per the project plan. The FY 2020 Request provides continued support for the Advanced Photon Source Upgrade (APS-U) project, the Advanced Light Source Upgrade (ALS-U) project, the Linac Coherent Light Source-II High Energy (LCLS-II-HE) project, the Proton Power Upgrade (PPU) project, and the Second Target Station (STS) project at SNS. The FY 2020 Request includes two new Major Item of Equipment projects: the NSLS-II Experimental Tools-II (NEXT-II) project to continue the phased build-out of beamlines at NSLS-II, and the NSRC Recapitalization project.

The Basic Energy Sciences program supports the following FY 2020 Administration Priorities:

FY 2020 Administration Priorities

	(dollars in thousands)			
	Exascale Computing Initiative (ECI)	**Artificial Intelligence (AI)**	**Quantum Information Science (QIS)**	**Microelectronics**
Basic Energy Sciences	26,000	10,000	52,503	25,000

Basic Energy Sciences
Funding

	(dollars in thousands)			
	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Materials Sciences and Engineering				
Scattering and Instrumentation Sciences Research	73,569	71,235	65,205	-6,030
Condensed Matter and Materials Physics Research	127,984	132,463	140,625	+8,162
Materials Discovery, Design, and Synthesis Research	67,588	65,443	59,989	-5,454
Established Program to Stimulate Competitive Research (EPSCoR)	19,270	19,270	7,323	-11,947
Energy Frontier Research Centers (EFRCs)	55,800	55,800	65,000	+9,200
Energy Innovation Hubs—Batteries and Energy Storage	24,088	24,088	24,088	—
Computational Materials Sciences	13,000	13,000	13,000	—
SBIR/STTR	14,445	14,445	14,215	-230
Total, Materials Sciences and Engineering	**395,744**	**395,744**	**389,445**	**-6,299**
Chemical Sciences, Geosciences, and Biosciences				
Fundamental Interactions Research	86,053	89,067	84,111	-4,956
Chemical Transformations Research	99,886	97,836	83,635	-14,201
Photochemistry and Biochemistry Research	76,688	75,724	64,163	-11,561
Energy Frontier Research Centers (EFRCs)	54,200	54,200	65,000	+10,800
Energy Innovation Hubs—Fuels from Sunlight	15,000	15,000	20,000	+5,000
Computational Chemical Sciences (CCS)	13,000	13,000	13,000	—
General Plant Projects (GPP)	1,000	1,000	1,000	—
SBIR/STTR	13,063	13,063	12,498	-565
Total, Chemical Sciences, Geosciences, and Biosciences	**358,890**	**358,890**	**343,407**	**-15,483**

(dollars in thousands)

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Scientific User Facilities				
X-Ray Light Sources	488,903	505,000	484,514	-20,486
High-Flux Neutron Sources	279,768	282,000	254,665	-27,335
Nanoscale Science Research Centers (NSRCs)	129,926	135,000	127,229	-7,771
Other Project Costs	23,900	19,100	6,000	-13,100
Major Items of Equipment	—	—	2,000	+2,000
Research	34,080	29,457	36,118	+6,661
SBIR/STTR	33,689	32,509	31,907	-602
Total, Scientific User Facilities	**990,266**	**1,003,066**	**942,433**	**-60,633**
Subtotal, Basic Energy Sciences	**1,744,900**	**1,757,700**	**1,675,285**	**-82,415**
Construction				
19-SC-14 Second Target Station (STS), ORNL	—	1,000	1,000	—
18-SC-10 Advanced Photon Source Upgrade (APS-U), ANL	93,000	130,000	150,000	+20,000
18-SC-11 Spallation Neutron Source Proton Power Upgrade (PPU), ORNL	36,000	60,000	5,000	-55,000
18-SC-12 Advanced Light Source Upgrade (ALS-U), LBNL (19-SC-10 in FY 2019 President's Request)	16,000	60,000	13,000	-47,000
18-SC-13 Linac Coherent Light Source-II-High Energy (LCLS-II-HE), SLAC (19-SC-11 in FY 2019 President's Request)	8,000	28,000	14,000	-14,000
13-SC-10 Linac Coherent Light Source-II (LCLS-II), SLAC	192,100	129,300	—	-129,300
Total, Construction	**345,100**	**408,300**	**183,000**	**-225,300**
Total, Basic Energy Sciences	**2,090,000**	**2,166,000**	**1,858,285**	**-307,715**

SBIR/STTR Funding:

- FY 2018 Enacted: SBIR $53,652,000 and STTR $7,545,000
- FY 2019 Enacted: SBIR $52,617,000 and STTR $7,400,000
- FY 2020 Request: SBIR $51,393,000 and STTR $7,227,000

Basic Energy Sciences
Explanation of Major Changes

	(dollars in thousands) FY 2020 Request vs FY 2019 Enacted
Materials Sciences and Engineering Research will continue to support fundamental scientific opportunities, including those identified as high priorities in recent BESAC and Basic Research Needs workshop reports. Research priorities include increased support for novel materials and theory for QIS and next-generation microelectronics, continued emphasis on materials science theory for computational applications that take full advantage of exascale computing, and new directions in the use of data analytics and machine learning for data-driven materials science. The Request increases funding for the EFRCs with a planned solicitation in FY 2020 to expand the EFRC portfolio in topical areas of the highest priority to the Department and to recompete funding for science relevant to the Department's environmental management mission. The Request also includes funding for continued support of the Batteries and Energy Storage Energy Innovation Hub.	**-6,299**
Chemical Sciences, Geosciences, and Biosciences Research will continue to support fundamental science, including grand challenge science and opportunities identified in recent BESAC and Basic Research Needs workshop reports. Priority research areas include QIS research to understand the quantum nature of atomic and molecular systems and to exploit advances in quantum computing for solutions to currently intractable problems; next-generation microelectronics; chemical science theory for computational applications that take full advantage of exascale computing; chemical conversion of increasingly complex chemical systems such as polymers; and the use of data analytics and machine learning for data-driven science. The Request increases funding for the EFRCs with a planned solicitation in FY 2020 to expand the EFRC portfolio in topical areas of the highest priority to the Department and to recompete funding for science relevant to the Department's environmental management mission. The Fuels from Sunlight Energy Innovation Hub will complete its second five-year term with FY 2019 funding. An open competition in FY 2020 will solicit early-stage fundamental research on solar fuels generation that builds on the Hub's unique capabilities and accomplishments to date.	**-15,483**
Scientific User Facilities Linac Coherent Light Source (LCLS) operations will resume in the second quarter of FY 2020 on completion of installation activities for the LCLS-II construction project. All remaining scientific user facilities will operate at a reduced level, approximately 87% of optimum. Funding for the Nanoscale Science Research Centers will include support for nanoscience and QIS research and related tools development. Research priorities include applications of artificial intelligence methods and machine learning techniques to accelerator optimization, control, prognostics, and data analysis. The Request includes funds to initiate two major items of equipment: the NEXT-II beamline project for NSLS-II and the NSRC recapitalization project.	**-60,633**
Construction The Request continues support for the Advanced Photon Source-Upgrade (APS-U) project, the Advanced Light Source Upgrade (ALS-U) project, the Linac Coherent Light Source-II High Energy (LCLS-II-HE) project, the Proton Power Upgrade (PPU) project at the Spallation Neutron Source (SNS), and the Second Target Station (STS) project at SNS.	**-225,300**
Total, Basic Energy Sciences	**-307,715**

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. BES coordinates with 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, including solar fuels; 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

Control of Chemical Reaction Pathways. Catalytic conversion of feedstocks to fuels; extraction of energy from fuels such as in combustion; and capture, conversion, and storage of energy in biological organisms involve complex, multistep chemical reaction mechanisms. The specific reaction pathways determine what is produced and vary widely depending on the reaction environment. New computational tools and experimental approaches allow understanding of how diverse reaction environments provide control of chemical reaction pathways.

- Plants and algae adjust photosynthetic rates to prevent damage under environmental stresses like cold and limited nutrients. Researchers discovered that, when exposed to environmental stress, an algal enzyme was activated and reduced the amount of a major lipid in the membranes that house the photosynthetic machinery. This structural change altered the arrangement of photosynthetic proteins in the membranes and contributed to regulating the amount of sunlight captured and used for photosynthesis to mitigate damage.
- A mechanistic understanding of the electrochemical reduction of CO_2 is needed to enable efficient production of solar fuels and other chemicals. Using sophisticated X-ray spectroscopy and high-resolution microscopy, researchers analyzed the oxidation state and surface structure of metal catalysts under reaction conditions. Building on these molecular-level details, multiscale computational techniques were developed to understand the complex influence of electrolyte composition on catalyst surface chemistry.
- The dry reforming of propane, derived from shale gas, with CO_2 may follow two pathways leading to valuable products, one that produces propylene and another yielding CO and H_2 (syngas). Both pathways are catalyzed by nickel alloys. Researchers predicted the mechanisms and successfully showed, via experiments, the atomic-level detail of the structures, compositions, and oxidation states of the iron-nickel alloy that exclusively produces propylene and the platinum-nickel alloy that produces syngas.

Energy Storage. Advances in energy storage are essential for a wide range of energy technologies, notably improvements to the stability of the electrical grid and increased lifetimes and safety for future batteries. Understanding the fundamentals of electrochemistry and the interactions of the materials used in batteries are key enablers for next generation technologies.

- Batteries could dramatically increase their capacity, the amount of energy they can deliver, if they could use two electrons, rather than just the one electron in current devices. For the first time, researchers reversibly inserted and extracted two lithium ions from a multi-electron lithium ion battery cathode (ε-$VOPO_4$), with full recovery upon recharging. The key was low temperature synthesis of nanoparticles, which preserved their crystallinity, and a conductive graphene coating.

- Lithium metal electrodes hold great promise for next-generation battery systems due to its superior energy density, but dendrites can form during charging and short circuit the battery, leading to premature failure. Researchers added very high molecular weight polymers that suppressed localized instabilities near the electrode surfaces, which reduced the formation of dendrites and also extended the range of operating voltages. This advance opens a new approach for utilizing high-energy metal anodes such as lithium and aluminum without forming dendrites.
- Lithium-sulfur (Li-S) batteries are one of the most promising alternatives to today's lithium ion batteries; however, the sluggish and partially irreversible formation of new phases when the batteries discharge during use has been identified as a critical hurdle for attaining high energy capacity and long cycle life. A new discharge pathway has been discovered that forms stable and inherently self-healing phases (Li_2S_2) in micropores, opening the door to the design of higher capacity, more reversible Li-S batteries.

Computational Materials and Chemical Sciences. BES supports basic research to develop open-source, experimentally validated software and the associated databases required to predictively design materials and chemical processes and assemblies with specific functionality. Software is targeted for today's leadership class computing facilities but is broadly applicable on smaller machines. Software is also being developed for exascale computing facilities as these become available.

- The Materials Project provides a unique collection of computed properties of materials for more than 80,000 compounds plus downloadable software for data analysis. The site has more than 38,000 registered users. Online properties include electrochemical and electronic structure, mechanical properties, phase stability and corrosion resistance. Data has been used to explore performance of novel battery designs, among other energy applications.
- A new mechanism has been discovered for generation of current in organic photovoltaic materials that could lead to greatly improved performance and lower cost solar cell technology. Software developed for these studies has performed well on pre-exascale computers with up to 500,000 processor cores.
- Understanding charge transfer processes in complex molecular systems is challenging because they depend on multiple factors including local environment and molecular structure. Computational chemical scientists employed a multiscale approach to a photosynthetic reaction center mimic to show how the solvent environment modifies the propensity of a molecule to bend, causing the quantum analog of an electrical short circuit. These insights will enhance knowledge of Nature's light-harvesting systems that, in turn, will enable predictions of novel artificial solar energy systems.

Science for Environmental Management. The cleanup and long term storage of large quantities of highly complex nuclear waste remains one of DOE's greatest challenges. Studies of the fundamental chemical and physical properties of radioactive and other elements present in the waste, as well as the creation of novel storage materials, will enable more efficient, cost-effective, and safer solutions.

- Dissolution and precipitation of gibbsite (an aluminum-based compound) is important in radioactive waste treatment and industrial aluminum production. Real-time experiments revealed that the aluminum does not transition between a 4-coordinate species in solution to a 6-coordinate species as a solid, but involves an intermediate 5-coordinate species that depends on the composition of the solution. Such studies support the development of new methods for processing high level radioactive wastes at Hanford and Savannah River, and provide potentially less energy-intensive routes for aluminum production.
- Cerium is often used as an analog for plutonium in experiments that explore the selective binding of actinides for recycling used nuclear fuels. Experiments showed that both plutonium and cerium complexes exhibit the same coordination and structure, but the plutonium complex was more stable and only the plutonium complex exhibited quasi-reversible redox behavior. This work exposes the limits of using cerium as a surrogate for plutonium in future research.
- Separating cesium and chlorine from liquid waste streams is important, the former for its radioactivity and the latter for its incompatibility with borosilicate glasses, the leading nuclear waste form. Researchers showed that spark plasma sintering can be used to form dense pellets of a perovskite material with 23% mass cesium and 38% mass chlorine without decomposition. The leading alternate waste form only incorporates about 11% chlorine. This work could enable a simpler and more efficient treatment of nuclear waste streams that contain chlorine.

BES user facilities contribute to world leading science. Researchers from U.S. industries and academia use the unique capabilities at the BES scientific user facilities to advance science and technology frontiers.

- Intense x-rays delivered from the newly developed helical superconducting undulator at the Advanced Photon Source can image the fuel spray process from an injector with unprecedented resolution without x-ray optics. The auto industry can use this information to gain detailed insights into the relationship between the fuel distribution and mechanical movement of the fuel injector inside a combustion engine. This knowledge will help the industry to develop cleaner and more fuel-efficient engines.
- Center for Integrated Nanotechnologies researchers successfully integrated donor atoms and quantum dots to create quantum bits, or qubits, for quantum computers. For almost two decades, scientists have created theoretical proposals of such a hybrid qubit architecture. Researchers have now made an important step toward the practical realization of silicon qubits. Silicon matters because the qubit manufacturing process could fit within today's manufacturing and computing technologies.
- The VULCAN instrument at the Spallation Neutron Source can measure atomic level details of defects in large engineered components at extreme conditions. Its ability to spatially resolve residual stress enabled researchers from the United States Steel Corporation to perform experiments on how lightweight advanced high-strength steels formed by hydroforming behave at realistic operating conditions. These unique experimental capabilities enable U.S. industries to design and engineer automotive and other components that are lighter, stronger, and more durable.

New capabilities for users at BES facilities. Researchers developed new capabilities and instrumentation at the BES scientific user facilities to enable cutting-edge user experiments.

- A new beamline instrument at the Linac Coherent Light Source was used to split x-ray pulses, creating femtosecond to nanosecond time delays between the pulses. Using this new capability, scientists measured the nanosecond equilibrium dynamics of nanoparticles, allowing the examination of heterogeneous dynamics associated with cooling a liquid. Such dynamics are important in complex synthesis and fabrication of energy-relevant materials.
- The Full Field X-ray Imaging beamline, one of the newest beamlines at NSLS-II, can complete a 3D nanotomography measurement with unprecedented time and spatial resolution. This advanced scientific research tool provides the researchers the ability to examine nanostructures in details and to study the reaction of forming new nanomaterials in real time.
- Center for Nanophase Materials Sciences researchers developed a technique that creates tiny, precise metallic shapes. They rastered a beam from a helium-ion microscope through a liquid precursor to induce chemical reactions. The reactions locally deposit high purity platinum in ribbons only 15 nanometers in diameter. The new high-precision, additive direct ion beam writing capability opens nanofabrication opportunities to improve electronics, drug delivery, chemical separations, and other applications.

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 BESAC report on transformative opportunities for discovery science, coupled with the Basic Research Needs workshop reports on energy technologies and roundtable reports on quantum information and ultrafast science, 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. Growing research activities in quantum materials highlight the importance and challenges for materials science in understanding and guiding the development of systems that realize unique properties for QIS and can contribute to SC QIS Centers. Materials science for next generation microelectronics will provide the needed advances for future computing, sensors, and detectors that are critical for national priorities in energy and for leadership in advanced research over a wide range of fields. Research priorities in this field will be guided by a Basic Research Needs workshop and reports. Another increasingly important aspect of materials research is the growing use of data analytics and machine learning for data-driven science to enhance the utility of both theoretical and experimental data for predictive design and discovery of materials.

In addition to single-investigator and small-group research, this subprogram supports Computational Materials Sciences, EFRCs, and the Batteries and Energy Storage Hub, and in FY 2020 will become a partner in support of at least one SC QIS Center. 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. In support of the National Quantum Initiative, SC QIS Centers will push the current state-of-the-art science and technology toward realizing the full potential of quantum-based applications, from computing to communication to sensing.

The Materials Sciences and Engineering subprogram also includes the DOE Established Program to Stimulate Competitive Research (EPSCoR). The DOE EPSCoR program strengthens investments in early stage energy research for states and U.S. territories that do not historically have large federally-supported 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 techniques and instrumentation development for advanced materials science research with scattering, spectroscopy, and imaging using electrons, neutrons, and x-rays, including development of science to understand ultrafast dynamics. These techniques provide precise and complementary information on the relationship among structure, dynamics, and properties. The major advances in materials sciences from DOE's world-leading electron, neutron, and x-ray scattering facilities provide 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 future transformational advances. 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."[a] 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 and support the work of SC QIS Centers.

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 and techniques for scattering, spectroscopy, and imaging needed to correlate the microscopic and macroscopic properties of energy materials. The use of multiscale and multimodal techniques to extract heretofore unattainable information on multiple length and time scales is a growing aspect of this research. For example, to design transformational new materials for energy-related applications, operando experiments contribute to understanding the atomic and nanoscale changes that lead to materials failure in non-equilibrium and extreme environments (temperature, pressure, stress, radiation, magnetic fields, and electrochemical potentials). 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.

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

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

experimental and theoretical research to advance the 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. New techniques for data analytics and machine learning for data-driven science are seeing increasing applications in materials science research to extract value from large databases of theoretical calculations and experimental measurements.

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. These advances will be key components of the activities of SC QIS Centers. Related to quantum materials is materials research for next-generation microelectronics, critical for competitiveness for future computers, sensors, and related technologies.

This activity includes the SC QIS Centers which will promote basic research and early stage development to accelerate the advancement of QIS through vertical integration between systems and theory and hardware and software. As identified by BES strategic planning reports including the Basic Research Needs Workshop on Quantum Materials and the Roundtable on Opportunities for Basic Research for Next-Generation Quantum Systems, key materials-related technical areas will include fundamental theory of materials and molecular systems for quantum applications; research leading to materials and molecular systems that meet quantum communication, computation, and sensor requirements; fundamental research on device physics for next generation QIS systems, including interface science and modeling of materials performance; and synthesis and fabrication research for quantum materials and processes, including integration in novel device architectures. In FY 2020, BES will partner with ASCR and HEP to establish at least one multi-disciplinary multi-institutional QIS center, which will be selected through a merit reviewed process conducted early in FY 2020. The scope of the SC QIS center will be on a set of QIS applications or cross-cutting topics that collectively cover the development space that may impact ASCR, BES and HEP and include work on sensors, quantum emulators/simulators and enabling technologies that will pave the path to exploit quantum computing in the longer term.

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 low energy synthesis approaches of biology to produce materials; 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 and self-regulating 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.

Annual EPSCoR funding opportunities alternate between a focus on research performed in collaboration with the DOE national laboratories and a focus on implementation awards that facilitate larger team awards for the development of research infrastructure. The program supports a small cadre of early career scientists from EPSCoR jurisdictions on an annual basis and provides complementary support for research grants to eligible institutions.

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. They allow experts from a variety of disciplines to collaborate on shared challenges, combining their strengths to uncover new and innovative solutions to the most difficult problems in materials sciences. The EFRCs also support numerous graduate students and postdoctoral researchers, educating and training a scientific workforce for the 21st century economy. The EFRCs supported in this subprogram focus on the following topics: 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; future nuclear energy; and quantum materials that can optimize the transmission, utilization, and control of energy and information. After nine years of research activity, the program has produced an impressive breadth of scientific accomplishments, including over 10,500 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 early stage research to tackle forefront, basic scientific challenges for next-generation electrochemical energy storage. JCESR is a multi-institutional research team led by Argonne National Laboratory (ANL) in collaboration with four other national laboratories, eleven universities, the Army Research Laboratory, and industry. In the initial five-year award (2013-2018), 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 in lithium-sulfur batteries to greatly improve cycle life; and computational screening of over 16,000 potential electrolyte compounds using the Electrolyte Genome protocols.

For the current award (2018-2023, pending annual progress reviews and appropriations), JCESR used its past research to identify a number of critical scientific gaps to serve as a foundation for the proposed research. The research directions are consistent with the priorities established in the recent BES workshop report *Basic Research Needs for Next Generation Electrical Energy Storage,*[a] 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. In the current research, prototypes will be used to demonstrate the impact of materials advances for specific battery architectures and designs.

Based on established best practices for managing large awards, BES will continue to require quarterly reports, frequent teleconferences, and annual progress reports and peer reviews to communicate progress, provide input on the technical directions, and ensure high quality research.

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,

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

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, appropriate data analytics tools for materials research, 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 2019 Enacted		FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Materials Sciences and Engineering	**$395,744,000**	**$389,445,000**	**-$6,299,000**
Scattering and Instrumentation Sciences Research	$71,235,000	$65,205,000	-$6,030,000
The FY 2019 Enacted budget emphasizes the development and use of forefront characterization tools to address challenges in materials science including understanding of quantum phenomena, with a continued emphasis on ultrafast techniques. In addition to high spatial resolution, the research emphasizes 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 emphasizes hypothesis-driven research with x-ray free electron laser sources, tailored excitations with pumped laser control, and coherent x-ray imaging. Neutron scattering research emphasizes research in emergent quantum phenomena, especially research involving interfaces. Electron scattering research focuses on innovative techniques to assess quantum phenomena, especially with ultrafast techniques.		The Request will continue to emphasize the development and use of forefront characterization tools to address challenges in materials science including understanding of quantum phenomena. The research will explore dynamics across many orders of magnitude in length and time scales to understand the evolution of emergent phenomena and in materials and their properties. Research includes complex quantum behavior and performance in the environments experienced by materials used in energy generation and use. Investments in x-ray science will emphasize hypothesis-driven research using x-ray free electron laser (XFEL) sources, exploiting tailored excitations, and imaging with coherent x-rays. Neutron scattering research will focus on emergent quantum phenomena and soft materials, especially at interfaces. Electron scattering research will focus on innovative techniques to assess quantum phenomena.	Emphasis will be on characterization of quantum phenomena using new developments in XFELs, neutron instrumentation, and scanning probes; and combining techniques to produce novel multi-modal approaches to understanding structure and excitations at the quantum level of matter. This activity will de-emphasize conventional and heavy fermion superconductivity, lower time resolution dynamic electron scattering, and x-ray scattering for bulk material systems, steady state analysis, and equilibrium systems. Conventional materials systems and research focused on well-established tools and techniques will be phased out.
Condensed Matter and Materials Physics Research	$132,463,000	$140,625,000	+$8,162,000
The FY 2019 Enacted budget continues to focus on fundamental experimental and theoretical research on the properties of materials, emphasizing quantum phenomena, continues. Experimental and theoretical condensed matter physics research emphasizes quantum materials, focusing on new and emergent behavior for QIS, including spintronics, topological		The Request will continue to focus on forefront experimental and theoretical condensed matter research, emphasizing quantum phenomena including new and emergent behavior for QIS such as spintronics, topological states and novel 2D materials. Physical behavior research will emphasize innovative science to understand coherent light-matter interactions. Related activities will advance	Research on quantum materials will continue to increase, including a focus on innovation for new materials systems and use of quantum computing platforms for materials science research. Additionally, the increased funding will support research to provide the scientific foundations for future microelectronics. Also highlighted is

FY 2019 Enacted	FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
states and novel 2D materials. Physical behavior research emphasizes innovative science to understand optical and electronic phenomena. Mechanical behavior and radiation effects research continues 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.	the underlying physical science understanding for next generation electronics. 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. BES will partner with ASCR and HEP to establish at least one multi-disciplinary multi-institutional QIS center, which will be selected through a merit reviewed process conducted early in FY 2020. The scope of the SC QIS center will be on a set of QIS applications or cross-cutting topics that collectively cover the development space that may impact ASCR, BES and HEP and include work on sensors, quantum emulators/ simulators and enabling technologies that will pave the path to exploit quantum computing in the longer term.	development and use of advanced computational tools for materials sciences, including data mining. Radiation effects research to address the challenges for next generation nuclear reactors will be emphasized. Topics to be deemphasized include conventional superconductivity, fractional quantum Hall physics, and theory of granular materials. Topics to be phased out include mechanics and theory of soft matter and ionic liquids.
Materials Discovery, Design, and Synthesis Research $65,443,000	$59,989,000	-$5,454,000
The FY 2019 Enacted budget continues 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 is emphasized, as is 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 is stressed for complex materials including quantum materials, organic systems, nanomaterials, electrochemical materials, polymers, and high fidelity mesoscale systems.	The Request will continue to focus on understanding the fundamentals of predictive design and synthesis of materials across multiple length scales using chemical, physical and bio-inspired techniques. Development of insights on the dynamics of materials structure and chemistry during the early stages of materials synthesis will be stressed, as will research that incorporates both experiment and theory. For complex materials and materials systems, research will focus on the fundamentals of growth kinetics, self-assembly, directed and dissipative assembly, and the role of interfaces and defect management. Discovery of new functional materials and new synthesis and computational techniques to create complex materials with targeted structure and properties will be emphasized.	Emphasis will be on forefront research for the synthesis of complex materials for novel functionalities, especially for quantum materials and systems in which interfaces are critical. Topics to be de-emphasized include control of synthesis to direct materials properties, molecular materials chemistry, and aspects of biocentric/biohybrid research approaches. Topics to be phased out include traditional synthesis research for conventional materials systems and optimization of synthetic processes.

FY 2019 Enacted	FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Established Program to Stimulate Competitive Research (EPSCoR) $19,270,000	$7,323,000	-$11,947,000
The FY 2019 Enacted budget continues to span science in support of the DOE mission, with emphasis on early stage science that underpins DOE energy technology programs. Research emphasizes EPSCoR jurisdiction implementation awards and investment in early career research faculty from EPSCoR designated jurisdictions.	The Request will continue to span science in support of the DOE mission, with emphasis on early stage science that underpins DOE energy technology programs. Following the prior year focus on implementation award investments, the focus for this year will be on broadening EPSCoR jurisdiction-laboratory partnerships, leveraging the DOE national laboratory energy research expertise and user facilities. Investment will continue in early career research faculty from EPSCoR designated jurisdictions and in co-investment with other programs for awards to eligible institutions.	FY 2020 funding will focus on research that involves collaboration among researchers in EPSCoR jurisdictions with the DOE national laboratories.
Energy Frontier Research Centers (EFRCs) $55,800,000	$65,000,000	+$9,200,000
The FY 2019 Enacted budget continues to support EFRC awards that were made in FY 2016 and FY 2018.	The Request will continue to support four-year EFRC awards that were made in FY 2018. In addition, FY 2020 funds will support a recompetition of the four-year EFRC awards made in FY 2016, which focused on science relevant to DOE's environmental management mission. Finally, the request will support a solicitation for new EFRCs that are responsive to recent BES strategic planning workshop reports, including use-inspired science relevant to advanced microelectronics and QIS.	Additional funds in FY 2020 will be used to expand the EFRC portfolio in topical areas of the highest priority to DOE, including microelectronics and QIS.
Energy Innovation Hubs—Batteries and Energy Storage $24,088,000	$24,088,000	$—
The FY 2019 Enacted budget continues to focus on early stage research to tackle forefront, basic scientific challenges for next-generation electrochemical energy storage. The research emphasizes discovery science, elucidation of cross-cutting scientific principles for electrical energy storage, and integration of theory,	The Request will continue to focus on early stage research for next generation electrical energy storage for the grid and vehicles. Research will emphasize understanding the fundamentals of electrochemistry (transport, solvation, evolution of chemistries and materials during charge/ discharge) and discovery science, including close coupling of theory, simulation, and experimentation, to elucidate	The funding continues at the same level. Annual peer reviews will be used to fine tune research directions based on annual progress, input from the JCESR team, and peer review.

FY 2019 Enacted		FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
experiment, and computational approaches to accelerate progress.		the impact of coupled phenomena and for predictive design of new materials for batteries.	
Computational Materials Sciences	$13,000,000	$13,000,000	$—
The FY 2019 Enacted budget continues research on the Computational Materials Sciences (CMS) 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 is developed that utilizes leadership class computers, and made available to the broad research community. In addition, the codes incorporate frameworks that are suited for future exascale computer systems. Awards that complete their fourth year of research are considered for renewal in a solicitation that also considers new applications.		The Request will continue research on current CMS awards that focus on development of research-oriented, open-source, experimentally validated software and the associated databases required to predictively design materials with specific functionality. Software will utilize leadership class computers, and be made available to the broad research community. The codes will also incorporate frameworks 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 FY 2020 solicitation will incorporate materials science research priorities from the most recent BES workshop and roundtable reports on basic research needs related to specific energy technologies, QIS, and next generation electronics, as well as consideration of data analytics and machine learning for data-driven science.
SBIR/STTR	$14,445,000	$14,215,000	-$230,000
In FY 2019, SBIR/STTR funding is set at 3.65% of non-capital funding.		In FY 2020, SBIR/STTR funding will be set at 3.65% of non-capital funding.	Funding changes are the direct result of decreases in 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 multi-investigator, cross-disciplinary teams—through EFRCs, the Energy Innovation Hub for solar fuels, and Computational Chemical Sciences—to focus on forefront scientific challenges that relate to the DOE energy mission. In FY 2020, the subprogram will become a partner in support of at least one SC QIS Center.

The FY 2020 Request continues to focus resources toward the highest priorities in early-stage fundamental research. High priority areas include ultrafast science to probe the dynamics of electrons, atoms, and molecules that underlie photochemical processes, chemical transformations, and energy flow; QIS research 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; photo and electrochemical processes associated with the capture of solar energy and conversion to fuels; chemical conversion of increasingly complex chemical systems such as polymers; the use of data analytics and machine learning for data-driven science; 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. The goal, which will be fundamental to the work of SC QIS Centers, 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 and x-ray free electron laser sources such as the Linac Coherent Light Source (LCLS) are used to image the dynamics of electrons and charge transport. Chemical physics research builds from the AMOS 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, including solar energy conversion, radiolytic effects, and catalysis. In addition, unraveling complex mechanisms of chemical reactions at interfaces can inform the design and synthesis of new materials relevant to microelectronics and QIS. 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 and combustion. 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, which 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; in the context of SC QIS Centers, this research also lays groundwork for applications of future quantum computers to computational quantum chemistry. Additional emphasis will be placed on codes that contribute to a fundamental understanding of how molecules might function as components of quantum computers.

This activity includes the SC QIS Centers which will promote basic research and early stage development to accelerate the advancement of QIS through vertical integration between systems and theory and hardware and software. As identified by BES strategic planning reports including the Roundtable on Opportunities for Quantum Computing in Chemical and

Materials Sciences and the Roundtable on Opportunities for Basic Research for Next-Generation Quantum Systems, key technical areas will include fundamental theory of materials and molecular systems for quantum applications; research leading to materials and molecular systems that meet quantum communication, computation, and sensor requirements; fundamental research on device physics for next generation QIS systems, including interface science; and synthesis and fabrication research for quantum materials and processes, including integration in novel device architectures. In FY 2020, BES will partner with ASCR and HEP to establish at least one multi-disciplinary multi-institutional QIS center, which will be selected through a merit reviewed process conducted early in FY 2020. The scope of the SC QIS center will be on a set of QIS applications or cross-cutting topics that collectively cover the development space that may impact ASCR, BES and HEP and include work on sensors, quantum emulators/simulators and enabling technologies that will pave the path to exploit quantum computing in the longer term.

Chemical Transformations Research

Fundamentally, Chemical Transformations Research advances 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, experimental tools, and theoretical, computational and data analytics approaches. 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, computational and data analytics methods 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 single 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, for enabling the beneficial chemical conversion of complex materials, such as synthetic polymers, and for guiding synthesis mechanisms of novel molecular systems for microelectronics.

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.

Photochemistry and Biochemistry Research
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. 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.

Supported research on the structural and chemical dynamics of energy absorption, transfer, conversion and storage across multiple spatial and temporal scales provides fundamental knowledge of *Charge Transport and Reactivity*. Efforts target the basic understanding of mechanisms and dynamics of chemical and biochemical processes including water oxidation, charge transfer, and redox interconversion of small molecules (e.g. carbon dioxide/methane, nitrogen/ammonia, and protons/hydrogen). A breadth of approaches and tools, such as those in *Ultrafast Chemistry*, are used to investigate quantum phenomena in natural and artificial systems; studies of the potential role and manipulation of photodriven quantum coherence in natural photosynthesis and artificial molecular systems could not only enhance fundamental understanding of energy transfer but also inspire new methods for quantum information processing, potentially in the portfolio of SC QIS Centers. Crosscutting research underpins a fundamental understanding of the synthesis, dynamics, and function of natural and artificial membranes and nano- to meso-scale structures, increasing knowledge of *Chemistry at Complex Interfaces* as well as *Chemistry in Aqueous Environments*. To understand *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 exemplified by studies of the water oxidation reaction and the nitrogen reduction reaction that are catalyzed by complex and unique metalloclusters of the oxygen evolving complex in natural photosynthesis and the nitrogenase enzyme in microbial systems respectively.

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, quantum coherent energy transfer, 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. The resulting mechanistic understanding of natural photosynthesis provides inspiration in the development of bio-hybrid, biomimetic, and artificial photosynthetic systems for solar fuels production and informs strategies to enhance photosynthetic efficiency in natural systems. Physical science tools 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 in natural systems, including complex multielectron redox reactions, electron transfer and bifurcation, and processes beyond primary photosynthesis such as nitrogen reduction and deposition of reduced carbon into energy-dense carbohydrates and lipids. This knowledge of energy conversion and storage in natural systems will identify principles for the design of highly selective and efficient catalysts, for instance, for ammonia synthesis or chemical conversion of polymers; the control of electron flow to achieve desired metabolic products; and the design of next-generation energy conversion/storage technologies.

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, photodriven generation of quantum coherence in artificial molecular systems, and artificial assemblies for charge separation and transport. These studies provide essential foundational knowledge for the use of solar energy for fuel production and electricity generation.

This activity also supports radiation science, investigating fundamental physical and chemical effects produced by the absorption of energy from ionizing radiation. 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. These studies increase fundamental knowledge of the chemical reactions that occur in radiation fields of nuclear reactors, including in their fuel and coolants, and can provide insights for effective nuclear waste remediation, fuel-cycle separation and design of nuclear reactors.

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. They allow experts from a variety of disciplines to collaborate on shared challenges, combining their strengths to uncover new and innovative solutions to the most difficult problems in chemical sciences, geosciences, and biosciences. The EFRCs also support numerous graduate students and postdoctoral researchers, educating and training a scientific workforce for the 21st century economy. The EFRCs supported in this subprogram focus 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; interdependent energy-water issues; future nuclear energy; 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 10,500 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.

JCAP's fundamental research enabled development of experimental artificial photosynthesis systems using earth-abundant catalysts for efficient solar-to-hydrogen conversion, now up to 19%. Central to these systems is JCAP's research leading to the development of transparent electrically conductive coatings for semiconductors that protect against corrosion in the aqueous electrolytes used for solar-fuels generation. JCAP research is also solving the critical and highly complex puzzle of directing the selectivity of carbon dioxide reduction into specific products. Studies revealed that molecular-level modifications to the reaction electrolyte of an electrocatalyst pre-activated carbon dioxide to promote formation of valuable two- and three-carbon products. JCAP used high throughput experimentation and theory to identify unique light absorbers with desired energetics; the combination of light absorbers and selective electrocatalysis is a crucial tool in defining mechanisms of light-driven carbon dioxide reduction.

With the completion of the second five-year term of JCAP, FY 2020 funding is requested for continued support of early-stage fundamental research on solar fuels generation that builds on JCAP's unique capabilities and accomplishments to date. An open competition will be held to solicit new awards of multi-investigator, cross-disciplinary solar fuels research to address emerging new directions as well as long-standing challenges in this transformational area of energy science.

Computational Chemical Sciences
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 chemical sciences research that focuses on the creation of computational codes and associated experimental/computational databases for the design of chemical processes and assemblies. Additional awards were initiated in FY 2018. 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 DOE-owned facilities and to meet requirements for safe and reliable facilities operation.

Activities and Explanation of Changes

FY 2019 Enacted		FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Chemical Sciences, Geosciences, and Biosciences	**$358,890,000**	**$343,407,000**	**-$15,483,000**
Fundamental Interactions Research	$89,067,000	$84,111,000	-$4,956,000
The FY 2019 Enacted budget continues 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 continues to develop and apply approaches to examine the structure and dynamics of reactive intermediates and how they impact reaction pathways in heterogeneous environments. Research efforts are extended to understand and control chemical processes and dynamics, at the molecular level, in increasingly complex aqueous and interfacial systems. Research expands the use of ultrafast techniques to study gas-phase, condensed phase and interfacial chemical phenomena. The activity develops advanced theoretical methods for electronic structure calculations that can be scaled to operate on exascale computers. Research supports 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 emphasizes efforts to drive advances in the application of quantum computing for molecular calculations.		The Request will continue to develop forefront ultrafast approaches, with emphasis on the use of x-ray free electron lasers, to study and control energy flow and bond rearrangements in gas-phase, condensed phase and interfacial chemical phenomena. Gas-phase research will continue studies of how reactive intermediates in heterogeneous environments impact reaction pathways and expand to examine quantum phenomena such as coherence and entanglement in tailored molecules. Research will extend efforts to understand and control chemical processes and quantum phenomena, at the molecular level, in increasingly complex aqueous and interfacial systems. Understanding interfacial chemical reactions and their control will inform the design and synthesis of new materials relevant to microelectronics. The activity will continue to develop advanced theoretical and computational approaches, including data science approaches such as machine learning that can be scaled to operate on exascale computers and apply the approaches to calculations on progressively complex systems to guide and interpret ultrafast measurements and to develop understanding needed to advance catalysis and solar energy research. The activity will continue to emphasize efforts to drive advances in the	Research will emphasize forefront efforts to image molecular dynamics using, as well as developing, ultrafast capabilities at BES light sources, to understand increasingly complex interfacial systems, and to advance exascale-ready computational tools and data science approaches for molecular systems of increasing complexity. Continuing emphasis will remain on 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. Research will emphasize experimental and computational studies of tailored molecular systems in the gas-phase, solutions, and interfacial systems to understand quantum phenomena underlying quantum systems for QIS. Emphasis continues on understanding the molecular mechanisms of charge transport. New efforts will develop an understanding of interfacial processes that inform the design and synthesis of systems with advanced (opto)electronic and spin properties relevant to microelectronics. The application of quantum computing to calculations of molecular structure and dynamics will continue to be emphasized. This activity will continue to de-emphasize aspects of nanoscience and combustion research.

FY 2019 Enacted	FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
	application of quantum computing for molecular calculations. BES will partner with ASCR and HEP to establish at least one multi-disciplinary multi-institutional QIS center, which will be selected through a merit reviewed process conducted early in FY 2020. The scope of the SC QIS center will be on a set of QIS applications or cross-cutting topics that collectively cover the development space that may impact ASCR, BES and HEP and include work on sensors, quantum emulators/ simulators and enabling technologies that will pave the path to exploit quantum computing in the longer term.	
Chemical Transformations Research $97,836,000	$83,635,000	-$14,201,000
The FY 2019 Enacted budget continues 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, continues to be pursued. Fundamental separation science research continues 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 continues 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 continues to be supported. Heavy element research continues to expand the knowledge of the chemistry of actinide reactivity, bonding, synthesis, and	The Request will continue to support predictive fundamental research on the design and synthesis of novel catalysts to efficiently convert chemical feedstocks, including synthetic polymers, to high-value fuels and chemicals. Fundamental studies will also target the understanding and control of the synthesis and reconstruction of molecular structures with advanced (opto)electronic and spin properties. Fundamental separation science research will continue on innovative approaches for separating chemical mixtures. This activity will emphasize the use of computational approaches, including data science tools and multi-scale methods, to investigate molecular recognition at complex interfaces, predict transport and separation in confined environments, and bonding and dynamics. 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	Research will emphasize efforts in ultrafast spectroscopy for detailed studies of reaction pathways, electronic structure calculations for systems of increasing molecular and solid complexity, and multiscale modeling, simulations, and data science approaches for complex reaction and transport processes. Research will continue to lead the mechanistic understanding of chemical catalysis, synthesis, separations, stabilization and transport required to control chemical processes in diverse environments created by complex atomic architectures, solvents, electric or mechanical field. It will provide new knowledge of reaction processes that integrate multiple steps, such as chemical conversion and chemical separation steps of multiple sources of energy and feedstocks, including polymeric materials. This activity will emphasize fundamental studies of the structure, dynamics, and energetics of coolants and fuels in extreme nuclear environments, and the chemical and physical properties of interfaces and heavy elements in these environments. Efforts will

FY 2019 Enacted	FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
separation, and also support training in nuclear chemistry. Theoretical methods continue to be advanced to accurately describe the chemistry of f-element compounds.	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.	explore molecular mechanisms central to the synthesis of novel molecular systems for microelectronics. This activity will continue to de-emphasize research on chemical analysis, synthesis of nanomaterials, physics of fluids in rock systems, and biocatalytic reactions.
Photochemistry and Biochemistry Research $75,724,000	$64,163,000	-$11,561,000
The FY 2019 Enacted budget continues to support fundamental research on photon 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 continues to be emphasized in both natural and artificial systems. Research of the fundamental mechanisms of photocatalysis and biocatalysis 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 continue to be supported and target a fundamental understanding of ultrafast chemistry and of reactivity across complex interfaces, in aqueous environments, and under dynamic conditions. Research also continues 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 will continue to support fundamental research and innovative approaches to understand physical, chemical, and biochemical processes of light energy capture and conversion in chemical and biological systems. Studies of light absorption, energy transfer, charge transport and separation, and photocatalysis will continue to be emphasized in both natural and artificial systems to advance foundational knowledge of solar energy capture and conversion with an emphasis on solar fuels generation. Understanding of molecular mechanisms of photon capture and electron transfer will advance solar fuels research as well as provide insights into quantum phenomena in energy transfer. Research on biocatalysis will continue to focus on a mechanistic understanding of enzyme structure and function with a particular emphasis on multi-electron redox reactions, electron bifurcation, and co-factor tuning. Efforts to understand processes and reactions on ultrafast timescales for energy conversion in natural and artificial systems will continue as will studies of reactivity across complex interfaces, in aqueous environments, and under dynamic conditions.	Research will emphasize cutting-edge science of charge transport, energy transfer, photo- and bio-catalytic mechanisms, and excited-state dynamics of processes important for energy capture and conversion in chemical and biological systems. Studies will increase focus on quantum phenomena in photochemical and biochemical processes, such as quantum coherence in energy transfer. Studies of biocatalysis and biological energy conversion will emphasize multi-electron reactions and control of electron flow to identify fundamental principles for catalyst and pathway design, for example, for targeted chemical production or for chemical conversion of complex materials such as polymers. Research in fundamental radiation chemistry will continue to be emphasized to provide a foundation for prediction and control of radiation-chemical transformations in complex systems. Emphasis on light capture and charge transfer will include fundamental phenomena important for quantum information science. This activity will continue to de-emphasize efforts in plant cell wall biosynthesis and structure, light signaling in plant development, organismal level studies, and molecular solar thermal energy storage.

FY 2019 Enacted	FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Energy Frontier Research Centers (EFRCs) $54,200,000	$65,000,000	+$10,800,000
The FY 2019 Enacted budget continues to support EFRC awards that were made in FY 2016 and FY 2018.	The Request will continue to support four-year EFRC awards that were made in FY 2018. In addition, FY 2020 funds will support a recompetition of the four-year EFRC awards made in FY 2016, which focused on science relevant to DOE's environmental management mission. Finally, the request will support a solicitation for new EFRCs that are responsive to recent BES strategic planning workshop reports, including use-inspired science relevant to advanced microelectronics and QIS.	Additional funds in FY 2020 will be used to expand the EFRC portfolio in topical areas of the highest priority to DOE, including microelectronics and QIS.
Energy Innovation Hubs—Fuels from Sunlight $15,000,000	$20,000,000	+$5,000,000
The FY 2019 Enacted budget continues to support JCAP's fundamental research on the science of carbon dioxide reduction.	The Request will support early-stage fundamental research on solar fuels generation that builds on JCAP's unique capabilities and accomplishments to date. A competition will be held to solicit new awards of multi-investigator, cross-disciplinary solar fuels research to address emerging new directions as well as long-standing challenges in this transformational area of energy science. Research will focus on tackling forefront, fundamental scientific challenges for generating fuels using only sunlight, carbon dioxide, and water as inputs. Advances in this area will also benefit from consideration of photodriven generation of fuels from molecules other than CO_2. The research will capitalize on unique capabilities and accomplishments developed to date to elucidate scientific principles for light energy capture and conversion into chemical bonds by integrating experiment and theory, including coupling high-throughput experimentation with artificial intelligence to accelerate progress.	The highest priorities in fundamental solar fuels generation research will be supported, building on capabilities and accomplishments developed by the former Fuels from Sunlight Hub, JCAP. Additional funding will expand fundamental research efforts in challenging aspects of solar fuels generation with a particular emphasis on photo-electrocatalysis for CO_2. The focus remains on use of only sunlight, carbon dioxide, and water as inputs for fuel production; however, new insights may be gained from studies of photodriven conversion of other molecules to fuels.

FY 2019 Enacted		FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Computational Chemical Sciences	$13,000,000	$13,000,000	$—
The FY 2019 Enacted budget continues to support Computational Chemical Sciences (CCS) awards that were made in FY 2017 and any new awards in complementary research areas made in FY 2018.		The Request will continue the CCS awards, with ongoing focus on developing public, open source codes for future exascale computer platforms.	No changes.
General Plant Projects	$1,000,000	$1,000,000	$—
The FY 2019 Enacted budget supports minor facility improvements at Ames Laboratory.		The Request will support minor facility improvements at Ames Laboratory.	No changes.
SBIR/STTR	$13,063,000	$12,498,000	-$565,000
In FY 2019, SBIR/STTR funding is set at 3.65% of non-capital funding.		In FY 2020, SBIR/STTR funding will be set at 3.65% of non-capital funding.	Funding changes are the direct result of decreases in non-capital funding.

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.

The twelve BES scientific user facilities provide the nation with the most comprehensive and advanced x-ray, neutron, and electron based experimental tools enabling fundamental discovery science. Hundreds of experiments are conducted simultaneously around the clock generating vast quantities of raw experimental data that must be stored, transported, and then analyzed to convert the raw data into information to unlock the answers to important scientific questions. Managing the collection, transport and analysis of data at the BES facilities is a growing challenge as new facilities come on line with expanded scientific capabilities coupled together with advances in detector technology. Over the next decade, the data volume, and the computational power to process the data, is expected to grow by several orders of magnitude. Artificial intelligence and machine learning will bring new software and hardware advances to help address these data and information challenges.

In FY 2018, the BES scientific facilities were used by more than 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.

X-Ray Light Sources
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 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.

Since completing construction of NSLS-II in FY 2015, BES has invested in the scientific research capabilities at this advanced light source facility by building specialized experimental stations or “beamlines.” The initial suite of 7 beamlines has expanded to the current 28 beamlines with room for at least 30 more. In order to adopt the most up-to-date technologies and to provide the most advanced capabilities, BES plans a phased approach to new beamlines at NSLS-II, as was done for the other light sources in the BES portfolio. The NSLS-II Experimental Tools-II (NEXT-II) major item of equipment (MIE) project proposed in the FY 2020 request will provide three best-in-class beamlines to support the needs of the U.S. research community. These beamlines will focus on the techniques of coherent diffraction imaging, soft x-ray spectromicroscopy, and nanoscale probes of electronic excitations.

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.

The Spallation Neutron Source (SNS) at ORNL uses another approach for generating neutron beams where an accelerator generates protons that strike a heavy-metal target. As a result of the impact, neutrons are produced in a process known as spallation. The SNS 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 comprised of a suite of smaller unique tools and expert scientific staff rather than based on a large accelerator or reactor. 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 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. The NSRCs will continue to develop nanoscience and QIS-related research infrastructure and capabilities for materials synthesis, device 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 and capabilities.

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. As the complexity of accelerators and the performance requirements continue to grow the need for more dynamic and adaptive control systems becomes essential. Particle accelerators are complicated interconnected machines and ideal for applications of artificial intelligence and machine learning algorithms to improve performance optimization, rapid recovery of fault conditions and prognostics to anticipate problems. 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.

Activities and Explanation of Changes

FY 2019 Enacted		FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Scientific User Facilities	**$1,003,066,000**	**$942,433,000**	**-$60,633,000**
X-Ray Light Sources	$505,000,000	$484,514,000	-$20,486,000
The FY 2019 Enacted budget continues LCLS operations 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 continue at 100% of optimum.		The Request supports LCLS operations, which will resume in the second quarter of FY 2020 upon completion of installation of LCLS-II accelerator components. The remaining light source facilities will operate at approximately 87% of optimal.	The funding will support operations at five BES light sources (LCLS, APS, ALS, NSLS-II, and SSRL).
High-Flux Neutron Sources	$282,000,000	$254,665,000	-$27,335,000
The FY 2019 Enacted budget continues support for SNS and HFIR operations at 100% of optimum.		The Request provides funding for SNS and HFIR. These facilities will operate at approximately 87% of optimal.	The funding will support operations for SNS and HFIR.
Nanoscale Science Research Centers	$135,000,000	$127,229,000	-$7,771,000
The FY 2019 Enacted budget supports all five NSRCs, with part of the funding designated for tool development for QIS.		The Request provides funding for five BES Nanoscale Science Research Centers, with funding for nanoscience, QIS research, and related development of synthesis and characterization tools.	The funding will support operations for the five NSRCs.
Other Project Costs	$19,100,000	$6,000,000	-$13,100,000
The FY 2019 Enacted budget supports the LCLS-II project at SLAC National Accelerator Laboratory, ALS-U at Lawrence Berkeley National Laboratory, LCLS-II-HE at SLAC, and the Second Target Station at ORNL.		The Request will support Other Project Costs for the LCLS-II-HE project at SLAC National Accelerator Laboratory and ALS-U at Lawrence Berkeley National Laboratory.	Other Project Costs decrease in FY 2020 according to the project plans for LCLS-II and ALS-U.

FY 2019 Enacted	FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Major Items of Equipment $—	$2,000,000	+$2,000,000
No MIE funds were appropriated in FY 2019.	The Request includes funds to initiate a beamline project for NSLS-II (NEXT-II) at Brookhaven National Laboratory and will support conceptual designs of new beamlines. The Request also includes MIE funds to initiate a recapitalization project for the NSRCs and will support planning and design activities in preparation for CD-1, along with possible procurements.	The Request initiates two new MIEs: NEXT-II and NSRC Recapitalization project.
Research $29,457,000	$36,118,000	+$6,661,000
The FY 2019 Enacted budget supports 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 was appropriated for these activities in FY 2019.	The Request will support high-priority research activities for detectors and optics instrumentation and applications of machine learning techniques to accelerator optimization, control, prognostics, and data analysis.	The research increase will be used to explore artificial intelligence methods and machine learning techniques for application to accelerator improvements.
SBIR/STTR $32,509,000	$31,907,000	-$602,000
In FY 2019, SBIR/STTR funding is set at 3.65% of non-capital funding.	In FY 2020, SBIR/STTR funding will be set at 3.65% of non-capital funding.	Funding changes are the direct result of decreases in 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. The project received approval for CD-2, Approve Performance Baseline, on December 9, 2018, establishing a Total Project Cost (TPC) of $815,000,000 and a CD-4, Project Completion date of March 31, 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. The project received CD-1, Approve Alternative Selection and Cost Range, on September 21, 2018, establishing a cost range of $330,000,000 - $495,000,000 based on a point estimate of $368,000,000 and projected project finish in 2028.

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. The project received CD-1, Approve Alternative Selection and Cost Range, on September 21, 2018, establishing a cost range of $290,000,000 - $480,000,000 based on a point estimate of $368,000,000 and projected project finish in 2028.

The **Proton Power Upgrade (PPU)** project will double the proton beam power capability of the Spallation Neutron Source (SNS) from 1.4 MW to 2.8 MW, upgrade the first target station to accommodate beam power up to 2 MW, and deliver a 2 MW qualified target. PPU will fabricate and install seven new superconducting radio frequency (RF) cryomodules, with supporting RF equipment, in the existing linac tunnel and klystron gallery respectively. Equipment will be upgraded to handle the higher beam current. The ring will be upgraded with minor modifications to the injection and extraction areas. The increased beam power of 2 MW to be provided to the first target station will be enabled by the additional cryomodules, and improved target performance will be enabled by the addition of a new target gas injection system and a redesigned mercury target vessel. The project received approval for CD-1, Approve Alternative Selection and Cost Range, on April 4, 2018. The current TPC range is $184,000,000 - $320,000,000 based on a point estimate of $250,000,000 and a projected project finish in 2027. The project received CD-3A, Approve Long Lead Procurements, approval on October 5, 2018, authorizing long lead and advanced procurements for accelerator components and associated systems.

The **Second Target Station (STS)** project will expand SNS capabilities for neutron scattering research by exploiting part of the higher SNS accelerator proton power (2.8 MW) enabled by the PPU project. The STS will be a complementary pulsed source with a narrow proton beam which increases the proton power density by up to 4.5 times compared to the first target station (FTS). This dense beam of protons, when deposited on a compact, rotating, water-cooled tungsten target will create neutrons through spallation and direct them to high efficiency coupled moderators to produce an order of magnitude higher brightness cold neutrons than were previously achievable. By optimizing the design of the instruments with advanced neutron optics, optimized geometry for 10 Hz operation, and advanced detectors, the detection resolution will be up to two orders of magnitude higher, enabling new research opportunities. The most recent DOE O 413.3B approved CD is CD-0 (Approve Mission Need), approved on January 7, 2009. The current TPC range is $800,000,000 - $1,500,000,000.

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 CD-2, Approve Performance Baseline, which are reproduced in the construction project data sheet.

Activities and Explanation of Changes

FY 2019 Enacted		FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Construction	**$408,300,000**	**$183,000,000**	**-$225,300,000**
19-SC-14, Second Target Station (STS), ORNL	$1,000,000	$1,000,000	$—
The FY 2019 Enacted budget supports planning, targeted R&D and engineering design, and other activities required to advance the STS project.		The Request will support continued planning, targeted R&D and engineering design, and other activities required to advance the STS project using Other Project Costs funds appropriated in prior years. Construction funds will be executed after the appropriate critical decision approvals are received.	The Request continues funding for the STS project.
18-SC-10, Advanced Photon Source Upgrade (APS-U), ANL	$130,000,000	$150,000,000	+$20,000,000
The FY 2019 Enacted budget supports targeted R&D, engineering design, equipment prototyping, testing, fabrication, site preparation, installation, and long lead and advance procurements.		The Request will support targeted R&D, engineering design, equipment prototyping, testing, fabrication, site preparation, installation, long lead and advanced procurements, and other activities required to advance the APS-U project.	The Request continues funding for the APS-U project.
18-SC-11, Spallation Neutron Source Proton Power Upgrade (PPU), ORNL	$60,000,000	$5,000,000	-$55,000,000
The FY 2019 Enacted budget supports R&D, engineering, prototyping, preliminary and final design, long-lead procurement, and other activities required to advance the PPU project.		The Request will support R&D, engineering, prototyping, preliminary and final design, long-lead procurement, and other activities required to advance the PPU project.	The Request continues funding for the PPU project.
18-SC-12, Advanced Light Source Upgrade (ALS-U), LBNL	$60,000,000	$13,000,000	-$47,000,000
The FY 2019 Enacted budget supports R&D, engineering design, equipment prototyping, testing, and other activities required to advance the ALS-U project.		The Request will support planning, engineering design, R&D, equipment prototyping, testing, and other activities to advance the ALS-U project.	The Request continues funding for the ALS-U project.

FY 2019 Enacted	FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
18-SC-13, Linac Coherent Light Source-II High Energy (LCLS-II-HE), SLAC $28,000,000	$14,000,000	-$14,000,000
The FY 2019 Enacted budget supports R&D, engineering design, equipment prototyping, testing, and other activities required to advance the LCLS-II-HE project.	The Request will support planning, engineering design, R&D, equipment prototyping, testing, and other activities required to advance the LCLS-II-HE project.	The Request continues funding for the LCLS-II-HE project.
13-SC-10, Linac Coherent Light Source-II (LCLS-II), SLAC $129,300,000	$—	-$129,300,000
The FY 2019 Enacted budget supports 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.	No funding is requested for FY 2020. FY 2019 was the last year of funding for LCLS-II. The project will continue with construction activities towards an early completion in FY 2020 – FY 2021.	Final funding was provided in FY 2019.

Basic Energy Sciences
Capital Summary

	(dollars in thousands)					
	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Capital Operating Expenses Summary						
Capital Equipment	N/A	N/A	48,831	76,610	38,755	-37,855
Minor Construction Activities						
General Plant Projects (GPP)	N/A	N/A	1,000	3,000	1,000	-2,000
Accelerator Improvement Projects (AIP)	N/A	N/A	9,950	33,800	29,500	-4,300
Total, Capital Operating Expenses	**N/A**	**N/A**	**59,781**	**113,410**	**69,255**	**-44,155**

Capital Equipment

	(dollars in thousands)					
	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Capital Equipment						
Major Items of Equipment (MIE)						
NSLS-II Experimental Tools-II (NEXT-II), BNL	60,000	—	—	—	1,000	+1,000
NSRC Recapitalization	60,000	—	—	—	1,000	+1,000
Total MIEs	N/A	N/A	—	—	2,000	+2,000
Total Non-MIE Capital Equipment	N/A	N/A	48,831	76,610	36,755	-39,855
Total, Capital Equipment	**N/A**	**N/A**	**48,831**	**76,610**	**38,755**	**-37,855**

Minor Construction Activities

	(dollars in thousands)					
	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
General Plant Projects (GPP)						
GPP less than $5M[a]	N/A	N/A	1,000	3,000	1,000	-2,000
Total, GPP	**N/A**	**N/A**	**1,000**	**3,000**	**1,000**	**-2,000**

[a] GPP activities less than $5M include design and construction for additions and/or improvements to land, buildings, replacements or additions to roads, and general area improvements.

	(dollars in thousands)					
	Total	**Prior Years**	**FY 2018 Enacted**	**FY 2019 Enacted**	**FY 2020 Request**	**FY 2020 Request vs FY 2019 Enacted**
Accelerator Improvement Projects (AIP)						
Greater than or Equal to $5M and less than $20M						
VENUS, Spallation Neutron Source, ORNL	13,400	N/A	—	13,400	—	-13,400
DISCOVER, Spallation Neutron Source, ORNL	18,500	N/A	—	—	18,500	+18,500
Total AIPs (great than or equal to $5M and less than $20M)	N/A	N/A	—	13,400	18,500	+5,100
Total AIPs less than $5M[a]	N/A	N/A	9,950	20,400	11,000	-9,400
Total, Accelerator Improvement Projects	N/A	N/A	9,950	33,800	29,500	-4,300
Total, Minor Construction Activities	**N/A**	**N/A**	**10,950**	**36,800**	**30,500**	**-6,300**

[a] AIP activities less than $5M include minor construction at an existing accelerator facility.

Basic Energy Science
Major Item of Equipment Description(s)

Scientific User Facilities MIEs:
The *NSLS-II Experimental Tools-II (NEXT-II) Project:* The NSLS-II Experimental Tools-II project proposes to add three world-class beamlines to the NSLS-II Facility as part of a phased buildout of beamlines to provide advances in scientific capabilities for the soft x-ray user community. These beamlines will focus on the techniques of coherent diffraction imaging, soft x-ray spectromicroscopy, and nanoscale probes of electronic excitations. The preliminary notional cost range for this project is $40M to $60M. The preliminary total project cost (TPC) point estimate is $60M based on a project finish in FY 2026.

The *NSRC Recapitalization Project*: The Nanoscale Science Research Centers (NSRCs) started early operations in 2006-2007 and now, a decade later, they need to recapitalize their instrumentation to continue to perform cutting edge science to support and accelerate advances in the fields of nanoscience, materials, chemistry, and biology. The recapitalization will also provide essential support for quantum information science and systems. The preliminary notional cost range for this project is $50M to $90M. The preliminary TPC point estimate is $60M based on a project finish in FY 2026.

Basic Energy Sciences
Construction Projects Summary

(dollars in thousands)

	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
19-SC-14, Second Target Station (STS), ORNL						
TEC	1,204,000	—	—	1,000	1,000	—
OPC	45,300	—	—	5,000	—	-5,000
TPC	**1,249,300**	—	—	**6,000**	**1,000**	-5,000
18-SC-10, Advanced Photon Source Upgrade (APS-U), ANL						
TEC	815,000	—	93,000	130,000	150,000	+20,000
OPC	—	—	—	—	—	—
TPC	**815,000**	—[a]	**93,000**	**130,000**	**150,000**	**+20,000**
18-SC-11, Proton Power Upgrade (PPU), ORNL						
TEC	250,000	—	36,000	60,000	5,000	-55,000
OPC	—	—	—	—	—	—
TPC	**250,000**	—	**36,000**	**60,000**	**5,000**	**-55,000**
18-SC-12, Advanced Light Source Upgrade (ALS-U), LBNL						
TEC	338,000	—	16,000	60,000	13,000	-47,000
OPC	30,000	10,000	14,000	2,000	2,000	—
TPC	**368,000**	**10,000**	**30,000**	**62,000**	**15,000**	**-47,000**
18-SC-13, Linac Coherent Light Source-II-HE (LCLS-II-HE), SLAC						
TEC	348,000	—	8,000	28,000	14,000	-14,000
OPC	20,000	—	2,000	6,000	4,000	-2,000
TPC	**368,000**	—	**10,000**	**34,000**	**18,000**	**-16,000**

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

(dollars in thousands)

	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
13-SC-10, Linac Coherent Light Source-II (LCLS-II), SLAC						
TEC	993,100	671,700	192,100	129,300	—	-129,300
OPC	51,900	37,900	7,900	6,100	—	-6,100
TPC	**1,045,000**	**709,600**[a]	**200,000**	**135,400**	—	**-135,400**
Total, Construction						
TEC	N/A	N/A	345,100	408,300	183,000	-225,300
OPC	N/A	N/A	23,900	19,100	6,000	-13,100
TPC	**N/A**	**N/A**	**369,000**	**427,400**	**189,000**	**-238,400**

Funding Summary

(dollars in thousands)

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Research	821,403	815,600	799,877	-15,723
Facility Operations	898,597	922,000	866,408	-55,592
Projects	369,000	427,400	191,000	-236,400
Other[b]	1,000	1,000	1,000	—
Total, Basic Energy Sciences	**2,090,000**	**2,166,000**	**1,858,285**	**-307,715**

[a] LCLS-II received $85,600,000 in FY 2010-FY 2013 as an MIE.
[b] Includes non-Facility related GPP.

Basic Energy Sciences
Scientific User Facility Operations

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.

(dollars in thousands)

	FY 2018 Enacted	FY 2018 Current	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
TYPE A FACILITIES					
Advanced Light Source	**$64,606**	**$64,606**	**$66,283**	**$62,511**	**-$3,772**
Number of Users	2,066	2,066	2,000	1,800	-200
Achieved operating hours	N/A	5,228	N/A	N/A	N/A
Planned operating hours	5,100	5,100	4,700	4,600	-100
Optimal hours	5,300	5,300	4,700[a]	5,300	+600
Percent optimal hours	96.2%	98.6%	100.0%	86.8%	N/A
Unscheduled downtime hours	<10%	<10%	<10%	<10%	N/A

[a] Optimal hours decreased for scheduled maintenance.

	(dollars in thousands)				
	FY 2018 Enacted	**FY 2018 Current**	**FY 2019 Enacted**	**FY 2020 Request**	**FY 2020 Request vs FY 2019 Enacted**
Advanced Photon Source	**$133,285**	**$133,285**	**$136,743**	**$128,962**	**-$7,781**
Number of Users	5,704	5,704	5,700	4,900	-800
Achieved operating hours	N/A	4,883	N/A	N/A	N/A
Planned operating hours	5,000	5,000	5,000	4,350	-650
Optimal hours	5,000	5,000	5,000	5,000	—
Percent optimal hours	100.0%	97.7%	100.0%	87.0%	N/A
Unscheduled downtime hours	<10%	<10%	<10%	<10%	N/A
National Synchrotron Light Source-II, BNL	**$111,241**	**$111,241**	**$114,127**	**$107,633**	**-$6,494**
Number of Users	1,364	1,364	1,600	1,350	-250
Achieved operating hours	N/A	4,589	N/A	N/A	N/A
Planned operating hours	4,750	4,750	5,000	4,350	-650
Optimal hours	5,000	5,000	5,000	5,000	—
Percent optimal hours	95.0%	91.8%	100.0%	87.0%	N/A
Unscheduled downtime hours	<10%	<10%	<10%	<10%	N/A
Stanford Synchrotron Radiation Lightsource	**$41,763**	**$41,763**	**$42,847**	**$40,408**	**-$2,439**
Number of Users	1,752	1,752	1,650	1,500	-150
Achieved operating hours	N/A	5,076	N/A	N/A	N/A
Planned operating hours	5,200	5,200	5,070	4,700	-370
Optimal hours	5,400	5,400	5,070[a]	5,400	330
Percent optimal hours	96.3%	94.0%	100.0%	87.0%	N/A
Unscheduled downtime hours	<10%	<10%	<10%	<10%	N/A
Linac Coherent Light Source	**$138,008**	**$138,008**	**$145,000**	**$145,000**	—
Number of Users	937	937	300	500	+200
Achieved operating hours	N/A	4,535	N/A	N/A	N/A
Planned operating hours	4,750	4,750	1,600	2,900	+1,300
Optimal hours	5,000	5,000	1,600[b]	3,000	+1,400
Percent optimal hours	95.0%	90.7%	100.0%	96.7%	N/A
Unscheduled downtime hours	<10%	<10%	<10%	<10%	N/A

[a] Optimal hours decreased for scheduled maintenance.
[b] LCLS Optimal hours reduced in preparation for installation activities related to LCLS-II.

	(dollars in thousands)				
	FY 2018 Enacted	FY 2018 Current	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Spallation Neutron Source	**$204,098**	**$204,098**	**$205,714**	**$185,774**	**-$19,940**
Number of Users	644	644	800	730	-70
Achieved operating hours	N/A	3,010	N/A	N/A	N/A
Planned operating hours	2,850	2,850	4,900	4,350	-550
Optimal hours	3,000[a]	3,000[a]	4,900	5,000	100
Percent optimal hours	95.0%	100.3%	100.0%	87.0%	N/A
Unscheduled downtime hours	<10%	<10%	<10%	<10%	N/A
High Flux Isotope Reactor	**$74,670**	**$74,670**	**$76,286**	**$68,891**	**-$7,395**
Number of Users	561	561	560	500	-60
Achieved operating hours	N/A	4,059	N/A	N/A	N/A
Planned operating hours	3,900	3,900	4,000	3,500	-500
Optimal hours	4,000	4,000	4,000	4,000	—
Percent optimal hours	97.5%	101.5%	100.0%	87.5%	N/A
Unscheduled downtime hours	<10%	<10%	<10%	<10%	N/A
Lujan Neutron Scattering Center	**$1,000**	$1,000	—	—	—
Achieved operating hours	N/A	N/A	N/A	N/A	N/A
Planned operating hours	—	—	—	—	—
Optimal hours	—	—	—	—	—
Percent optimal hours	N/A	N/A	N/A	N/A	N/A
Unscheduled downtime hours	N/A	N/A	N/A	N/A	N/A
TYPE B FACILITIES					
Center for Nanoscale Materials	**$26,783**	**$26,783**	**$27,704**	**$26,109**	**-$1,595**
Number of users	608	608	600	530	-70
Center for Functional Nanomaterials	**$22,759**	**$22,759**	**$24,148**	**$22,758**	**-$1,390**
Number of users	581	581	580	510	-70
Molecular Foundry	**$30,184**	**$30,184**	**$31,237**	**$29,438**	**-$1,799**
Number of users	939	939	700	600	-100

(dollars in thousands)

	FY 2018 Enacted	FY 2018 Current	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Center for Nanophase Materials Sciences	**$26,180**	**$26,180**	**$27,078**	**$25,520**	**-$1,558**
Number of users	640	640	600	530	-70
Center for Integrated Nanotechnologies	**$24,020**	**$24,020**	**$24,833**	**$23,404**	**-$1,429**
Number of users	659	659	600	530	-70
Total, All Facilities	**$898,597**	**$898,597**	**$922,000**	**$866,408**	**-$55,592**
Number of Users	16,455	16,455	15,690	13,980	-1,710
Achieved operating hours	N/A	31,380	N/A	N/A	N/A
Planned operating hours	31,550	31,550	30,270	28,750	-1,520
Optimal hours	32,700	32,700	30,270	32,700	+2,430
Percent of optimal hours	96.3%	96.5%	98.6%	88.9%	N/A
Unscheduled downtime hours	<10%	<10%	<10%	<10%	N/A

Scientific Employment

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Number of permanent Ph.D.'s (FTEs)	4,870	4,800	4,520	-280
Number of postdoctoral associates (FTEs)	1,340	1,310	1,250	-60
Number of graduate students (FTEs)	2,090	2,050	1,960	-90
Other[a]	3,060	3,030	2,820	-210

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

19-SC-14, Second Target Station
Oak Ridge National Laboratory, Oak Ridge, Tennessee
Project is for Design and Construction

1. Summary, Significant Changes, and Schedule and Cost History

Summary

The FY 2020 Request for Second Target Station (STS) project is $1,000,000. The most recent DOE O 413.3B approved Critical Decision (CD) is CD-0 (Approve Mission Need), approved on January 7, 2009. The current Total Project Cost (TPC) range is $800,000,000 - $1,500,000,000.

Significant Changes

This initial construction project data sheet (CPDS) for FY 2020 funding does not include a new start for the budget year.

In FY 2019, the project will advance the planning, research and development, prototyping, and conceptual design. In FY 2020, the project continues planning, targeted R&D and engineering design, and other activities required to advance the STS project using Other Project Costs (OPC) funds appropriated in prior years. FY 2020 construction funds will be executed after the appropriate critical decision (CD) approvals are received.

A Federal Project Director has not yet been assigned to this project.

Critical Milestone History

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2020[a]	1/7/2009	2Q FY 2022	2Q FY 2022	2Q FY 2023	2Q FY 2025	2Q FY 2024	N/A	4Q FY 2031

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

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D	OPC, D&D	OPC, Total	TPC
FY 2020[a]	65,500	1,138,500	1,204,000	45,300	—	45,300	1,249,300

2. Project Scope and Justification

Scope

The global landscape in neutron scattering science is changing rapidly. To sustain our position at the frontier in materials and chemical characterization, dramatic improvements in experimental capabilities are needed. In particular, upgraded neutron sources are necessary to achieve the Basic Energy Sciences (BES) mission.

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

The 2015 Basic Energy Sciences Advisory Committee report "Challenges at the Frontiers of Matter and Energy: Transformative Opportunities for Discovery Science" identified five new transformative opportunities that have the potential to transform many of today's energy-related technologies involving matter and energy. Advances in neutron sources and instrumentation play a direct part in advancing science to achieve those opportunities.

The two neutron scattering facilities in the BES portfolio, the High Flux Isotope Reactor (HFIR) and the SNS are both sited at Oak Ridge National Laboratory (ORNL) and address one of the DOE's key research areas—the use of neutrons and sophisticated instrumentation to probe materials. Many technical margins were built into SNS systems to facilitate a power upgrade to at least 2 MW, with the ability to extract some of that power to a second target station.

To address the gap in advanced neutron sources and instrumentation, the SNS project will design, build, install, and test the equipment necessary to provide the four primary elements of the new SNS facility: the neutron target and moderators; the accelerator systems; the instruments; and the conventional facilities. Costs for acceptance testing, integrated testing, and initial commissioning to demonstrate achievement of the KPPs are included in the STS scope.

The STS features an optimally sized 30 cm^2 proton beam that is concentrated into one-fifth the area of the FTS beam to produce a very high density beam of protons that strikes a 1.1 meter diameter rotating solid tungsten target. The produced neutron beam illuminates three moderators located above and below the target that will feed up to 22 experimental beamlines with neutron energies conditioned for specific instruments. The small-volume cold neutron moderator system is geometrically optimized to deliver higher peak brightness neutrons.

The SNS Proton Power Upgrade (PPU) project will double the power of the SNS accelerator complex to 2.8 MW so that STS can use one out of every six proton pulses to produce cold neutron beams with the highest peak brilliance of any current or projected neutron sources. The high-brightness pulsed source optimized for cold neutron production will operate at 15 Hz (as compared to FTS at 60 Hz) to provide the large time-of-flight intervals corresponding to the broad time and length scales required to characterize complex materials. The project will provide a series of kicker magnets to divert every sixth proton pulse away from the FTS to a new line feeding the STS. Additional magnets will further deflect the beam into the transport line to the new target. A final set of quadrupole magnets will tailor the proton beam shape and distribution to match the compact source design.

An initial set of 22 instrument concepts, developed with input from the user community, are largely built on known and demonstrated technologies but will need some research and development to deliver unprecedented levels of performance. Advanced neutron optics designs are needed for high alignment and stability requirements. The lower repetition rate of STS pushes the chopper design to larger diameter rotating elements with tighter limits on allowed mechanical vibration. The higher peak neutron production of STS will put a greater demand on neutron detector technology.

The STS complex will be located in unoccupied space east of the existing FTS. The project requires approximately 380,000 ft2 of new buildings, making conventional facility construction a major contributor to project costs. The layout can consolidate instruments with beamlines less than 40 m long in a hall adjacent to the STS target building to free up space for the longest beamlines (50% longer than the longest FTS beamline) on the opposite side of the STS target.

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." BES accomplishes its mission by operation of large-scale user facilities consisting of a complementary set of intense x-rays sources, neutron scattering centers, electron beam characterization capabilities, and research centers for nanoscale science.

In the area of neutron science, the scientific justification and need for a very high-intensity pulsed neutron source in the U.S. has been established by numerous studies by the scientific community since the 1970s. This need is currently being fulfilled by the SNS, which began its user program at ORNL in 2007. In accordance with the 1996 BESAC (Russell Panel) Report recommendation, the SNS was designed to be upgradeable so as to maintain its position of scientific leadership in the future, and many technical margins were built into the SNS systems to facilitate a power upgrade into the 2-4 MW range.

An upgraded SNS would enable many advances in the opportunities described in the 2015 BESAC report "Challenges at the Frontiers of Matter and Energy: Transformative Opportunities for Discovery Science." Four workshops were held to assess the neutron scattering needs in quantum condensed matter, soft matter, biology, and the frontiers in materials discovery. These four areas encompass and directly map to the transformative opportunities identified in the BES Grand Challenges update. Quantum materials map most directly to harnessing coherence in light and matter, while soft matter and biology are aligned primarily with mastering hierarchical architectures and beyond-equilibrium matter, and frontiers in materials discovery explored many of the topics in beyond ideal materials and systems: understanding the critical roles of heterogeneity, interfaces, and disorder. As an example, while neutrons already play an important role in the areas of biology and soft matter, step change improvements in capability will be required to make full use of the unique properties of neutrons to meet challenges in mastering hierarchical architectures and beyond-equilibrium matter and understanding the critical roles of heterogeneity and interfaces. The uniform conclusion from all workshops was that in the areas of science covered, neutrons play a unique and pivotal role in understanding structure and dynamics in materials required to develop future technologies.

The project is being conducted in accordance with the project management requirements in DOE O 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 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. If project performance is sustained and funds are available, the project will attain the objective KPPs. The KPPs presented here are preliminary, pre-baseline values. The final key parameters will be established as part of CD-2, Approve Performance Baseline.

Performance Measure	Threshold	Objective
Beam power on target	0.25 MW at 1.0 GeV	0.47 MW at 1.3 GeV
Beam energy	1.3 GeV	≥ 1.3 GeV
Target operational lifetime without failure	2,000 hours at 0.25 MW	2,500 hours at 0.5 MW
Proton Beam size	≤ 60 cm^2	30 cm^2
Neutron peak brightness	1.7×10^{14}	3.5×10^{14}
Number of operating instruments at CD-4	6	8

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design			
FY 2019	1,000	1,000	—
FY 2020	1,000	1,000	—
Outyears	63,500	63,500	65,500
Total, Design	65,500	65,500	65,500
Construction			
Outyears	1,138,500	1,138,500	1,138,500

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total, Construction	1,138,500	1,138,500	1,138,500
Total Estimated Costs (TEC)			
FY 2019	1,000	1,000	—
FY 2020	1,000	1,000	—
Outyears	1,202,000	1,202,000	1,204,000
Total, TEC	**1,204,000**	**1,204,000**	**1,204,000**
Other Project Costs (OPC)			
FY 2016	6,500	6,500	3,069
FY 2017	—	—	2,870
FY 2018	—	—	227
FY 2019	5,000	5,000	4,700
FY 2020	—	—	425
Outyears	33,800	33,800	34,009
Total, OPC	**45,300**	**45,300**	**45,300**
Total Project Costs (TPC)			
FY 2016	6,500	6,500	3,069
FY 2017	—	—	2,870
FY 2018	—	—	227
FY 2019	6,000	6,000	4,700
FY 2020	1,000	1,000	425
Outyears	1,235,800	1,235,800	1,238,009
Total, TPC[a]	**1,249,300**	**1,249,300**	**1,249,300**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	48,500	N/A	N/A
Contingency	17,000	N/A	N/A
Total, Design	65,500	N/A	N/A
Construction			
Construction	845,000	N/A	N/A
Contingency	293,500	N/A	N/A
Total, Construction	1,138,500	N/A	N/A
Total, TEC	**1,204,000**	N/A	N/A
Contingency, TEC	*310,500*	*N/A*	*N/A*
Other Project Cost (OPC)			
OPC except D&D			
R&D	1,500	N/A	N/A

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

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Conceptual Design	18,375	N/A	N/A
Start-Up	14,100	N/A	N/A
Contingency	11,325	N/A	N/A
Total, OPC	**45,300**	N/A	N/A
Contingency, OPC	*11,325*	*N/A*	*N/A*
Total Project Cost[a]	**1,249,300**	**N/A**	**N/A**
Total, Contingency (TEC+OPC)	***321,825***	***N/A***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2018	FY 2019[a]	FY 2020	Outyears	Total
FY 2020	TEC	—	—	1,000	1,000	1,202,000	1,204,000
	OPC	6,500	—	5,000	—	33,800	45,300
	TPC	6,500	—	6,000	1,000	1,235,800	1,249,300

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy (fiscal quarter or date)	4Q FY 2031
Expected Useful Life (number of years)	25
Expected Future Start of D&D of this capital asset (fiscal quarter)	4Q FY 2056

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Previous Total Estimate	Current Total Estimate	Previous Total Estimate	Current Total Estimate
Operations and Maintenance	N/A	45,000	N/A	1,125,000

The numbers presented are the incremental operations and maintenance costs above the existing SNS facility without escalation. The estimate will be updated and additional details will be provided after CD-2, Approve Performance Baseline.

[a] While no funding was requested, Congress appropriated $6,000,000 for STS in FY 2019.

7. 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 ORNL	~380,000
Area of D&D in this project at ORNL	—
Area at ORNL to be transferred, sold, and/or D&D outside the project, including area previously "banked"	~380,000
Area of D&D in this project at other sites	—
Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked"	—
Total area eliminated	—

8. Acquisition Approach

DOE has determined that the STS project will be acquired by ORNL under the existing DOE Management and Operations (M&O) contract.

A Technical Design Report for the STS project has been prepared. Key design activities, requirements, and high-risk subsystem components have been 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 an ORNL-wide resource.

ORNL will partner with other laboratories for design and procurement of key technical subsystem components. Some technical system designs will require research and development activities. Preliminary cost estimates for these systems are based on operating experience of SNS and vendor quotes. Design of the technical systems will be completed by ORNL, partner laboratory staff, and/or vendors. Technical equipment will be fabricated by vendors and/or partner labs 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 STS.

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

1. Summary, Significant Changes, and Schedule and Cost History

Summary

The FY 2020 Request for the Advanced Photon Source-Upgrade (APS-U) project is $150,000,000. The most recent DOE Order 413.3B approved Critical Decision, CD-2 (Approve Performance Baseline), was approved on December 9, 2018, with a Total Project Cost (TPC) of $815,000,000 and CD-4, Approve Project Completion, in FY 2026.

Significant Changes

This Construction Project Data Sheet (CPDS) is an update of the FY 2019 CPDS and does not include a new start for the budget year. The TPC increased from $770,000,000 to $815,000,000 to meet the mission need of delivering a world-class hard x-ray light source scientific user facility. The APS-U project performed multiple scientific and technical reviews to incorporate the recommendations from the scientific user community. This resulted in additional world-leading scientific instruments being recommended and incorporated into the project scope that will provide new and advanced capabilities, particularly in the areas of coherent scattering, coherent imaging, and high energy microscopy. The project cost and Key Performance Parameters (KPPs) have been updated to include these enhancements that take full advantage of the upgraded APS source and storage ring.

In FY 2018, APS-U procured accelerator, experimental systems, and front end components needed to maintain the project schedule. APS-U awarded contracts for more than half of the storage ring magnets, critical superconducting RF system components, and state of the art beamline optics in addition to key materials for the front ends and undulators as long lead and advanced procurements (LLP/APs). FY 2019 funding completes the majority of equipment prototyping and development work. Engineering design, testing, fabrication, installation, additional LLP/APs, and site preparation for the long beamlines continue. Planned activities for FY 2020 include continuing targeted development, prototyping and finishing associated engineering designs, testing, and fabrication. Receipt, acceptance, and preparation for installation of incoming vendor fabricated components procured as LLP/APs will occur along with initial system integration and assembly. After CD-3, procurements beyond the currently approved LLP/APs will begin. Further site preparation and civil construction associated with the long beamlines will occur.

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

Critical Milestone History

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2018	4/22/2010	9/18/2015	2/4/2016	1Q FY 2019	2Q FY 2020	4Q FY 2019	N/A	1Q FY 2026
FY 2019	4/22/2010	9/18/2015	2/4/2016	2Q FY 2019	4Q FY 2021	1Q FY 2020	N/A	2Q FY 2026
FY 2020	4/22/2010	9/18/2015	2/4/2016	12/09/2018	1Q FY 2022	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 or will be completed (if applicable)
CD-1 – Approve Design Scope and Project Cost and Schedule Ranges
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 Project Completion

Fiscal Year	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
FY 2020	12/09/2018	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.

Project Cost History

(dollars in thousands)

Fiscal Year	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	167,000	590,100	757,100	12,900	N/A	12,900	770,000
FY 2020	162,825	633,675	796,500	18,500	N/A	18,500	815,000

2. 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 at Argonne National Laboratory (ANL), 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 light 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 an 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 also 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.

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 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 an 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 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. If project performance is sustained and funds are available, the project will strive to attain the objective KPPs.

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 injection mode with systems installed for 200 mA operation	200 mA in top-up injection mode
Horizontal Emittance	< 130 pm-rad at 25 mA	≤ 42 pm-rad at 200 mA
Brightness @ 20 keV[1]	> 1×10^{20}	1×10^{22}
Brightness @ 60 keV[1]	> 1×10^{19}	1×10^{21}
New APS-U Beamlines Transitioned to Operations	7	≥ 9

[1]Units = photons/sec/mm^2/mrad^2/0.1% BW

3. **Financial Schedule**

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design			
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	28,775	28,775	23,098
FY 2018	—	—	12,716
FY 2019	—	—	2,343
Total, MIE funding	119,990	119,990	119,990
Line item construction funding			
FY 2018	32,000	32,000	3,021
FY 2019	7,735	7,735	17,150
FY 2020	3,100	3,100	19,850
FY 2021	—	—	2,814
Total, Line item construction funding	42,835	42,835	42,835
Total, Design	162,825	162,825	162,825
Construction			
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	—	—	677
FY 2016	—	—	—
FY 2017	13,725	13,725	389
FY 2018	—	—	7,497
FY 2019	—	—	5,064
FY 2020	—	—	775
Total, MIE funding	22,510	22,510	22,510
Line item construction funding			
FY 2018	61,000	61,000	6,902
FY 2019	122,265	122,265	127,833
FY 2020	146,900	146,900	171,250
FY 2021	160,000	160,000	161,500
FY 2022	121,000	121,000	126,250
FY 2023	—	—	15,375
FY 2024	—	—	2,055
Total, Line item construction funding	611,165	611,165	611,165
Total, Construction	633,675	633,675	633,675

(dollars in thousands)

	Budget Authority (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	—	—	20,213
FY 2019	—	—	7,407
FY 2020	—	—	775
Total, MIE funding	142,500	142,500	142,500
Line item construction funding			
FY 2018	93,000	93,000	9,923
FY 2019	130,000	130,000	144,983
FY 2020	150,000	150,000	191,100
FY 2021	160,000	160,000	164,314
FY 2022	121,000	121,000	126,250
FY 2023	—	—	15,375
FY 2024	—	—	2,055
Total, Line item construction funding	654,000	654,000	654,000
Total, TEC	**796,500**	**796,500**	**796,500**
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	—	—	4,217
Total MIE funding	8,500	8,500	8,500
Line item construction funding			
FY 2021	5,000	5,000	4,500
FY 2022	5,000	5,000	4,500
FY 2023	—	—	1,000
Total, Line item construction funding	10,000	10,000	10,000
Total, OPC	**18,500**	**18,500**	**18,500**
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

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
FY 2016	20,000	20,000	22,529
FY 2017	42,500	42,500	23,487
FY 2018	—	—	20,213
FY 2019	—	—	7,407
FY 2020	—	—	775
Total, MIE funding	151,000	151,000	151,000
Line item construction funding			
FY 2018	93,000	93,000	9,923
FY 2019	130,000	130,000	144,983
FY 2020	150,000	150,000	191,100
FY 2021	165,000	165,000	168,814
FY 2022	126,000	126,000	130,750
FY 2023	—	—	16,375
FY 2024	—	—	2,055
Total, Line item construction funding	664,000	664,000	664,000
Total, TPC	**815,000**	**815,000**	**815,000**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	146,825	157,150	N/A
Contingency	16,000	9,850	N/A
Total, Design	162,825	167,000	N/A
Construction			
Equipment	483,575	426,420	N/A
Other Construction	15,000	14,680	N/A
Contingency	135,100	149,000	N/A
Total, Construction	633,675	590,100	N/A
Total, TEC	**796,500**	**757,100**	**N/A**
Contingency, TEC	*151,100*	*158,850*	*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	7,800	3,250	N/A
Contingency	2,200	1,150	N/A
Total, OPC	**18,500**	**12,900**	**N/A**
Contingency, OPC	*2,200*	*1,150*	*N/A*
Total Project Cost	**815,000**	**770,000**	**N/A**
Total Contingency (TEC+OPC)	***153,300***	***160,000***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2018	TEC	142,500	20,000	81,772	152,419	160,000	82,500	79,809	—	719,000
	OPC	8,500	—	—	—	5,000	27,500	10,000	—	51,000
	TPC	151,000	20,000	81,772	152,419	165,000	110,000	89,809	—	770,000
FY 2019	TEC	142,500	20,000	60,000	150,000	159,780	133,100	91,720	—	757,100
	OPC	8,500	—	—	—	—	2,200	2,200	—	12,900
	TPC	151,000	20,000	60,000	150,000	159,780	135,300	93,920	—	770,000
FY 2020	TEC	142,500	93,000	130,000	150,000	160,000	121,000	—	—	796,500
	OPC	8,500	—	—	—	5,000	5,000	—	—	18,500
	TPC	151,000	93,000	130,000	150,000	165,000	126,000	—	—	815,000

6. 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
(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Previous Total Estimate	Current Total Estimate	Previous Total Estimate	Current Total Estimate
Operations and Maintenance	N/A	18,000	N/A	450,000

The numbers presented are the incremental operations and maintenance costs above the existing APS facility without escalation. The estimate will be updated as the project is executed.

7. 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	—
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	—
Area at other sites to be transferred, sold, and/or D&D outside the project including area previously "banked"	—
Total area eliminated	—

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

8. Acquisition Approach

The APS-U project will be acquired by the Argonne National Laboratory (ANL) under the existing DOE Management and Operations (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 an 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.

18-SC-11, Proton Power Upgrade
Oak Ridge National Laboratory, Oak Ridge, Tennessee
Project is for Design and Construction

1. Summary, Significant Changes, and Schedule and Cost History

Summary

The FY 2020 Request for the Proton Power Upgrade (PPU) project is $5,000,000. The most recent DOE O 413.3B approved Critical Decision (CD) is CD-3A (Approve Long Lead Procurements), approved on October 5, 2018. The preliminary Total Project Cost (TPC) range, based on early concepts under consideration, is $184,000,000 - $320,000,000.

Significant Changes

Congress first appropriated funds for PPU in FY 2018 and was a new start in that year. This Construction Project Data Sheet (CPDS) for FY 2020 funding does not include a new start for the budget year.

In FY 2018, PPU advanced the technical system designs, including completing the status report on the 2 MW target conceptual design scoping analysis. The project received CD-1 (Approve Alternative Selection and Cost Range) approval on April 4, 2018 for a TPC range of $184,000,000 - $320,000,000. CD-3A (Approve Long Lead Procurements) approval was received on October 5, 2018 for up to $10,505,000 for niobium material, cryomodule cavities, and related cryomodule procurements. No funding was requested for PPU in FY 2019; however, Congress appropriated $60,000,000 in FY 2019, which enables R&D, engineering, prototyping, preliminary and final design, long-lead procurement, and target R&D aimed at further advancing the target performance in coordination with SNS operations target management. In FY 2020, funds will be utilized for R&D, engineering, prototyping, preliminary and final design. Target R&D will continue. Additional long lead procurement authority (CD-3B), if approved, will advance the klystron gallery buildout, RF procurements, and cryomodule hardware procurements and assembly.

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

Critical Milestone History

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2020[a]	1/7/2009	8/1/2017	4/4/2018	2Q FY 2021	4Q FY 2022	3Q FY 2022	N/A	3Q FY 2027

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

Fiscal Year	Performance Baseline Validation	CD-3A	CD-3B
FY 2020[a]	2Q FY 2021	10/5/2018	2Q FY 2020

CD-3A – Approve Long-Lead Procurements, niobium material, cryomodule cavities, and related cryomodule procurements.
CD-3B – Approve Long-Lead Procurements, klystron gallery buildout, RF procurements, and cryomodule hardware.

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

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D	OPC, D&D	OPC, Total	TPC
FY 2020[a]	27,300	210,000	237,300	12,700	N/A	12,700	250,000

2. Project Scope and Justification

Scope

The global landscape in neutron scattering science is changing rapidly. To sustain the U.S.'s position at the frontier in materials and chemical characterization, dramatic improvements in experimental capabilities are needed. In particular, upgraded neutron sources are necessary to achieve the Basic Energy Sciences (BES) mission.

The 2015 Basic Energy Sciences Advisory Committee report "Challenges at the Frontiers of Matter and Energy: Transformative Opportunities for Discovery Science" identified five new transformative opportunities that have the potential to transform many of today's energy-related technologies involving matter and energy.b Advances in neutron sources and instrumentation directly play a part in achieving four of those five goals.

The two neutron scattering facilities in the BES portfolio, the High Flux Isotope Reactor (HFIR) and the SNS, are both sited at Oak Ridge National Laboratory (ORNL) and address one of the DOE's key research areas—the use of neutrons and sophisticated instrumentation to probe materials. Many technical margins were built into SNS systems to facilitate a power upgrade to at least 2 MW, with the ability to extract some of that power to a second target station.

To address the gap in advanced neutron sources and instrumentation, the PPU project will design, build, install, and test the equipment necessary to double the accelerator power from 1.4 MW to 2.8 MW, upgrade the existing SNS target system to accommodate beam power up to 2 MW, and deliver a 2 MW qualified target. PPU also includes the provision for a stub-out in the SNS transport line to the existing target to facilitate rapid connection to a new proton beamline. The project also includes modifications to some buildings and services. Costs for acceptance testing, integrated testing, and initial commissioning to demonstrate achievement of the KPPs are included in the PPU scope.

PPU will accomplish the energy upgrade by fabricating and installing seven new superconducting RF cryomodules, with supporting RF equipment, in the existing SNS linac tunnel and klystron gallery. The high voltage converter modulators and klystrons for some of the existing installed RF equipment will be upgraded to handle the higher beam current. The accumulator ring will be upgraded with minor modifications to the injection and extraction areas. A new high volume gas injection system for pressure pulse mitigation in the mercury target and a redesigned mercury target vessel will allow the first target station to handle the increased beam power of 2 MW.

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." BES accomplishes its mission by operating large-scale user facilities consisting of a complementary set of intense x-rays sources, neutron scattering centers, electron beam characterization capabilities, and research centers for nanoscale science.

In the area of neutron science, numerous studies by the scientific community since the 1970s have established the scientific justification and need for a very high-intensity pulsed neutron source in the U.S. The SNS, which began its user program at ORNL in 2007, currently fulfills the need. In accordance with the 1996 BESAC (Russell Panel) Report recommendation, the

[a] The project is pre-CD-2; the estimated cost and schedule shown are preliminary. Construction will not be executed without appropriate CD approvals.
[b] https://science.energy.gov/~/media/bes/besac/pdf/Reports/Challenges_at_the_Frontiers_of_Matter_and_Energy_rpt.pdf

SNS was designed to be upgradeable so as to maintain its position of scientific leadership in the future, and many technical margins were built into the SNS systems to facilitate a power upgrade into the 2-4 MW range.

An upgraded SNS will enable many advances in the opportunities described in the 2015 BESAC report “Challenges at the Frontiers of Matter and Energy: Transformative Opportunities for Discovery Science.” Four workshops were held by ORNL to assess the neutron scattering needs in quantum condensed matter, soft matter, biology, and the frontiers in materials discovery. These four areas encompass and directly map to the transformative opportunities identified in the BES Grand Challenges update. Quantum materials map most directly to harnessing coherence in light and matter, while soft matter and biology align primarily with mastering hierarchical architectures and beyond-equilibrium matter, and frontiers in materials discovery explored many of the topics in beyond ideal materials and systems: understanding the critical roles of heterogeneity, interfaces, and disorder. As an example, while neutrons already play an important role in the areas of biology and soft matter, step change improvements in capability will be required to make full use of the unique properties of neutrons to meet challenges in mastering hierarchical architectures and beyond-equilibrium matter and understanding the critical roles of heterogeneity and interfaces. The uniform conclusion from all workshops was that in the areas of science covered, neutrons play a unique and pivotal role in understanding structure and dynamics in materials required to develop future technologies.

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. If project performance is sustained and funds are available, the project will attain the objective KPPs. The KPPs presented here are preliminary, pre-baseline values. The final key parameters will be established as part of CD-2, Approve Performance Baseline.

Performance Measure	Threshold	Objective
Beam power on target	1.7 MW at 1.25 GeV	2.0 MW at 1.3 GeV
Beam energy	1.25 GeV	1.3 GeV
Target operational time without failure	1,250 hours at 1.7 MW	1,250 hours at 2.0 MW
Stored beam intensity in ring	≥ 1.6×10^{14} protons at 1.25 GeV	≥ 2.24×10^{14} protons at 1.3 GeV
Number of PPU installed cryomodules	6	7

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design			
FY 2018	5,000	5,000	2,655
FY 2019	18,000	18,000	19,400
FY 2020	4,300	4,300	4,450
Outyears	—	—	795
Total, Design	27,300	27,300	27,300
Construction			
FY 2018	31,000	31,000	1,794

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
FY 2019	42,000	42,000	30,600
FY 2020	700	700	34,250
Outyears	136,300	136,300	143,356
Total, Construction	210,000	210,000	210,000
Total Estimated Costs (TEC)			
FY 2018	36,000	36,000	4,449
FY 2019	60,000	60,000	50,000
FY 2020	5,000	5,000	38,700
Outyears	136,300	136,300	144,151
Total, TEC	**237,300**	**237,300**	**237,300**
Other Project Costs (OPC)			
FY 2016	3,500	3,500	1,267
FY 2017	6,800	6,800	3,773
FY 2018	—	—	3,004
FY 2019	—	—	2,256
FY 2020	—	—	—
Outyears	2,400	2,400	2,400
Total, OPC	**12,700**	**12,700**	**12,700**
Total Project Costs (TPC)			
FY 2016	3,500	3,500	1,267
FY 2017	6,800	6,800	3,773
FY 2018	36,000	36,000	7,453
FY 2019	60,000	60,000	52,256
FY 2020	5,000	5,000	38,700
Outyears	138,700	138,700	146,551
Total, TPC[a]	**250,000**	**250,000**	**250,000**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	20,800	N/A	N/A
Contingency	6,500	N/A	N/A
Total, Design	27,300	N/A	N/A
Construction			
Construction	156,000	N/A	N/A
Contingency	54,000	N/A	N/A
Total, Construction	210,000	N/A	N/A
Total, TEC	**237,300**	**N/A**	**N/A**

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

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Contingency, TEC	*60,500*	*N/A*	*N/A*
Other Project Cost (OPC)			
OPC except D&D			
R&D	2,500	N/A	N/A
Conceptual Design	5,225	N/A	N/A
Other OPC Costs	1,800	N/A	N/A
Contingency	3,175	N/A	N/A
Total, OPC	**12,700**	**N/A**	**N/A**
Contingency, OPC	*3,175*	*N/A*	*N/A*
Total Project Cost[a]	**250,000**	**N/A**	**N/A**
Total, Contingency (TEC+OPC)	**63,675**	***N/A***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2018[a]	FY 2019[b]	FY 2020	Outyears	Total
FY 2020	TEC	—	36,000	60,000	5,000	136,300	237,300
	OPC	10,300	—	—	—	2,400	12,700
	TPC	10,300	36,000	60,000	5,000	138,700	250,000

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy (fiscal quarter or date)	3Q FY 2027
Expected Useful Life (number of years)	40
Expected Future Start of D&D of this capital asset (fiscal quarter)	3Q FY 2067

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Previous Total Estimate	Current Total Estimate	Previous Total Estimate	Current Total Estimate
Operations and Maintenance	N/A	9,325	N/A	373,000

The numbers presented are the incremental operations and maintenance costs above the existing SNS facility without escalation. The estimate will be updated and additional details will be provided after CD-2, Approve Performance Baseline.

[a] While no funding was requested, Congress appropriated $36,000,000 for PPU in FY 2018.
[b] While no funding was requested, Congress appropriated $60,000,000 for PPU in FY 2019.

7. 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 ORNL	3,000–4,000
Area of D&D in this project at ORNL	—
Area at ORNL to be transferred, sold, and/or D&D outside the project, including area previously "banked"	3,000–4,000
Area of D&D in this project at other sites	—
Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked"	—
Total area eliminated	—

8. Acquisition Approach

DOE has determined that the PPU project will be acquired by ORNL under the existing DOE Management and Operations (M&O) contract.

A Conceptual Design Report for the PPU project has been completed. Key design activities, requirements, and high-risk subsystem components have been 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 an ORNL-wide resource.

ORNL will partner with other laboratories for design and procurement of key technical subsystem components. Some technical system designs will require research and development activities. Preliminary cost estimates for these systems are based on operating experience of SNS and vendor quotes. Design of the technical systems will be completed by ORNL, partner laboratory staff, and/or vendors. Technical equipment will be fabricated by vendors and/or partner labs 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 PPU.

18-SC-12 Advanced Light Source Upgrade
Lawrence Berkeley National Laboratory
Project is for Design and Construction

1. Summary, Significant Changes, and Schedule and Cost History

Summary
The FY 2020 Request for the Advanced Light Source Upgrade (ALS-U) project is $15,000,000, including $13,000,000 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 Decision (CD) is CD-1 (Approve Alternate Selection and Cost Range), approved September 21, 2018. The preliminary Total Project Cost (TPC) range, based on the reviewed conceptual design, is $330,000,000 - $495,000,000.

Significant Changes
This Construction Project Data Sheet (CPDS) is an update of the FY 2019 CPDS and does not include a new start for FY 2020. The current TPC estimate increased from $320,000,000 to $368,000,000 and the Project Completion Date (CD-4) was extended by nearly two years to 2Q FY 2028. An independent cost review in July 2018 recommended a new TPC range of $330,000,000 - $495,000,000 based on the quality of the cost estimate, and a point estimate of $368,000,000 for the total cost. The increase in the estimated TPC is due to the conceptual design process, which results in design changes, refinement of the engineering cost estimates, and cost escalation. Changes to the planned project funding profile results in the extension of the project completion date.

In FY 2018, ALS-U developed and completed their Conceptual Design and underwent both an Independent Cost Review by DOE's Office of Project Management and an Independent Project Review by SC's Office of Project Assessment in July 2018. The project received CD-1, Approve Alternative Selection and Cost Range, in September 2018. FY 2019 funding continues to support planning, engineering, design, research and development (R&D), prototyping activities and initiate long lead procurements to the extent supported by design maturity. FY 2020 funding will continue the support of planning, engineering, design, and R&D prototyping activities and additional long lead procurements.

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

Critical Milestone History

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2019	9/27/2016	4Q FY 2019	4Q FY 2019	4Q FY 2020	4Q FY 2022	4Q FY 2021	N/A	4Q FY 2026
FY 2020[a]	9/27/2016	4/30/2018	9/21/2018	2Q FY 2021	4Q FY 2021	1Q FY 2022	N/A	2Q FY 2028

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 or will be 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

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

Fiscal Year	Performance Baseline Validation	CD-3A
FY 2019	4Q FY 2020	4Q FY 2020
FY 2020[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.

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D	OPC, D&D	OPC, Total	TPC
FY 2019	39,000	243,000	282,000	38,000	N/A	38,000	320,000
FY 2020[b]	89,750	248,250	338,000	30,000	N/A	30,000	368,000

2. 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 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

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

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. 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.

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.

Performance Measure	Threshold	Objective
Storage Ring Energy	≥ 1.9 GeV	2.0 GeV
Beam Current	> 25 mA	500 mA
Horizontal Emittance	< 150 pm-rad	< 85 pm-rad
Brightness @ 1 keV[1]	> 2 x 10^{19}	≥ 2 x 10^{21}
New MBA Beamlines	2	≥ 2

[1]Units = photons/sec/0.1% BW/mm^2/$mrad^2$

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design			
FY 2018	16,000	16,000	—
FY 2019	35,000	35,000	30,000
FY 2020	10,000	10,000	20,000
Outyears	28,750	28,750	39,750
Total, Design	89,750	89,750	89,750
Construction			
FY 2019	25,000	25,000	15,000
FY 2020	3,000	3,000	10,000
Outyears	220,250	220,250	223,250
Total, Construction	248,250	248,250	248,250
Total Estimated Costs (TEC)			
FY 2018	16,000	16,000	—
FY 2019	60,000	60,000	45,000
FY 2020	13,000	13,000	30,000
Outyears	249,000	249,000	263,000
Total, TEC	**338,000**	**338,000**	**338,000**
Other Project Costs (OPC)			
OPC except D&D			
FY 2016	5,000	5,000	1,430
FY 2017	5,000	5,000	5,306
FY 2018	14,000	14,000	11,699
FY 2019	2,000	2,000	4,000
FY 2020	2,000	2,000	3,500
Outyears	2,000	2,000	4,065
Total, OPC	30,000	30,000	30,000
Total Project Cost (TPC)			
FY 2016	5,000	5,000	1,430
FY 2017	5,000	5,000	5,306
FY 2018	30,000	30,000	11,699

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
FY 2019	62,000	62,000	49,000
FY 2020	15,000	15,000	33,500
Outyears	251,000	251,000	267,065
Total, TPC[a]	**368,000**	**368,000**	**368,000**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	69,800	30,000	N/A
Contingency	19,950	9,000	N/A
Total, Design	89,750	39,000	N/A
Construction			
Site Preparation	—	5,000	N/A
Equipment	188,500	170,000	N/A
Other Construction	—	—	N/A
Contingency	59,750	68,000	N/A
Total, Construction	248,250	243,000	N/A
Total, TEC	**338,000**	**282,000**	**N/A**
Contingency, TEC	*79,700*	*77,000*	*N/A*
Other Project Cost (OPC)			
OPC except D&D			N/A
Conceptual Planning	2,000	2,000	N/A
Conceptual Design	12,100	12,000	N/A
Research and Development	8,000	10,000	N/A
Start-Up	1,200	6,000	N/A
Contingency	6,700	8,000	N/A
Total, OPC	**30,000**	**38,000**	**N/A**
Contingency, OPC	*6,700*	*8,000*	*N/A*
Total Project Cost[a]	**368,000**	**320,000**	**N/A**
Total, Contingency (TEC+OPC)	***86,400***	***85,000***	***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.

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2018[a]	FY 2019	FY 2020	Outyears	Total
FY 2019	TEC	—	—	10,000	26,540	245,460	282,000
	OPC	10,000	—	2,000	5,000	21,000	38,000
	TPC	10,000	—	12,000	31,540	266,460	320,000
FY 2020	TEC	—	16,000	60,000	13,000	249,000	338,000
	OPC	10,000	14,000	2,000	2,000	2,000	30,000
	TPC	10,000	30,000	62,000	15,000	251,000	368,000

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy (fiscal quarter or date)	2Q FY 2028
Expected Useful Life (number of years)	25
Expected Future Start of D&D of this capital asset (fiscal quarter)	2Q FY 2053

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Previous Total Estimate	Current Total Estimate	Previous Total Estimate	Current Total Estimate
Operations and Maintenance	N/A	—	N/A	—

No additional operations and maintenance costs are expected above the existing ALS facility. The estimate will be updated and additional details will be provided after CD-2, Approve Project Performance Baseline.

7. 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.

8. Preliminary Acquisition Approach

DOE has determined that the ALS-U project will be acquired by the Lawrence Berkeley National Laboratory (LBNL) under the existing DOE Management and Operations contract.

A Conceptual Design Report for the ALS-U project has been prepared. Key design activities, requirements, and high-risk subsystem components have been 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 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] While no funding was requested, Congress appropriated $30,000,000 for ALS-U in FY 2018.

18-SC-13, Linac Coherent Light Source-II High Energy
SLAC National Accelerator Laboratory
Project is for Design and Construction

1. Summary, Significant Changes, and Schedule and Cost History

Summary

The FY 2020 Request for the Linac Coherent Light Source-II High Energy (LCLS-II-HE) project is $18,000,000, including $14,000,000 in Total Estimated Cost (TEC) funds and $4,000,000 in Other Project Costs (OPC) funds. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-1 (Approve Alternate Selection and Cost Range), approved on September 21, 2018. The preliminary Total Project Cost (TPC) range based on the reviewed conceptual design is $290,000,000 - $480,000,000.

Significant Changes

This Construction Project Data Sheet (CPDS) is an update of the FY 2019 CPDS and does not include a new start for FY 2020. The current Total Project Cost (TPC) estimate increased from $320,000,000 to $368,000,000 and the Project Completion Date (CD-4) was extended by nearly two years to 1Q FY 2028. The independent cost review in June 2018 recommended a new TPC range of $290,000,000 - $480,000,000 based on the quality of the cost estimate, and a point estimate of $368,000,000 for the total cost. The increase in the estimated TPC was due to the conceptual design process which resulted in design changes and refinement of the engineering cost estimates. Changes to the project funding profile resulted in the extension of the project completion date.

In FY 2018, LCLS-II-HE developed and completed their Conceptual Design and underwent both an Independent Cost Review by DOE's Office of Project Management and an Independent Project Review by SC's Office of Project Assessment in June 2018. The project received CD-1, Approve Alternative Selection and Cost Range, in September 2018. The project also initiated a research and development (R&D) program aimed at further advancing the performance of the superconducting radio frequency (RF) cavities. FY 2019 funding supports the continued planning, engineering, design, R&D, prototyping activities, and initiates long lead and/or advanced procurements to the extent supported by design maturity. FY 2020 funding will continue the support of planning, engineering, design, R&D prototyping, and additional long lead procurements, as appropriate.

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

Critical Milestone History

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2019	12/15/2016	3Q FY 2019	3Q FY 2019	1Q FY 2021	1Q FY 2023	2Q FY 2022	N/A	2Q FY 2026
FY 2020[a]	12/15/2016	3/23/2018	9/21/2018	2Q FY 2023	1Q FY 2023	2Q FY 2023	N/A	1Q FY 2028

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 or will be 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.

Fiscal Year	Performance Baseline Validation	CD-3A
FY 2019	1Q FY 2021	4Q FY 2019
FY 2020[a]	2Q FY 2023	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.

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D	OPC, D&D	OPC, Total	TPC
FY 2019	34,000	266,000	300,000	20,000	N/A	20,000	320,000
FY 2020[a]	34,000	314,000	348,000	20,000	N/A	20,000	368,000

2. 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 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-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.

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

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 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.

Performance Measure	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)	5×10^{8} (50x spontaneous @8 keV)	$> 10^{11}$ @ 8 keV (200 μJ) or $> 10^{10}$ @ 12.8 keV (20 μJ)

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design			
FY 2018	2,000	2,000	—
FY 2019	10,000	10,000	8,000

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
FY 2020	6,000	6,000	8,000
Outyears	16,000	16,000	18,000
Total, Design	34,000	34,000	34,000
Construction			
FY 2018	6,000	6,000	—
FY 2019	18,000	18,000	18,000
FY 2020	8,000	8,000	14,000
Outyears	282,000	282,000	282,000
Total, Construction	314,000	314,000	314,000
Total Estimated Costs (TEC)			
FY 2018	8,000	8,000	—
FY 2019	28,000	28,000	26,000
FY 2020	14,000	14,000	22,000
Outyears	298,000	298,000	300,000
Total, TEC	**348,000**	**348,000**	**348,000**
Other Project Costs (OPC)			
OPC except D&D			
FY 2018	2,000	2,000	1,191
FY 2019	6,000	6,000	6,000
FY 2020	4,000	4,000	4,000
Outyears	8,000	8,000	8,809
Total, OPC	20,000	20,000	20,000
Total Project Cost (TPC)			
FY 2018	10,000	10,000	1,191
FY 2019	34,000	34,000	32,000
FY 2020	18,000	18,000	26,000
Outyears	306,000	306,000	308,809
Total, TPC[a]	**368,000**	**368,000**	**368,000**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	30,500	30,500	N/A
Contingency	3,500	3,500	N/A
Total, Design	34,000	34,000	N/A
Construction			
Site Preparation	3,000	3,000	N/A
Equipment	236,000	182,000	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 Construction	9,000	9,000	N/A
Contingency	66,000	72,000	N/A
Total, Construction	314,000	266,000	N/A
Total, TEC	**348,000**	**300,000**	**N/A**
Contingency, TEC	*69,500*	*75,500*	*N/A*
Other Project Cost (OPC)			
OPC except D&D			
Conceptual Planning	1,500	1,500	N/A
Conceptual Design	2,000	4,000	N/A
Research and Development	4,000	4,000	N/A
Start-Up	6,500	8,000	N/A
Contingency	6,000	2,500	N/A
Total, OPC	**20,000**	**20,000**	**N/A**
Contingency, OPC	*6,000*	*2,500*	*N/A*
Total Project Cost[a]	**368,000**	**320,000**	**N/A**
Total Contingency (TEC+OPC)	***75,500***	***78,000***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2018[b]	FY 2019	FY 2020	Outyears	Total
FY 2019	TEC	—	—	5,000	20,060	274,940	300,000
	OPC	—	—	2,000	4,000	14,000	20,000
	TPC	—	—	7,000	24,060	288,940	320,000
FY 2020	TEC	—	8,000	28,000	14,000	298,000	348,000
	OPC	—	2,000	6,000	4,000	8,000	20,000
	TPC	—	10,000	34,000	18,000	306,000	368,000

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy (fiscal quarter or date)	1Q FY 2028
Expected Useful Life (number of years)	25
Expected Future Start of D&D of this capital asset (fiscal quarter)	1Q FY 2053

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Previous Total Estimate	Current Total Estimate	Previous Total Estimate	Current Total Estimate
Operations and Maintenance	N/A	21,500	N/A	537,500

[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.
[b] While no funding was requested, Congress appropriated $10,000,000 for LCLS-II-HE in FY 2018.

The numbers presented are the incremental operations and maintenance costs above the LCLS-II facility without escalation. The estimate will be updated and additional details will be provided after CD-2, Approve Project Performance Baseline.

7. 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.

8. Acquisition Approach

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

A Conceptual Design Report for the LCLS-II-HE project has been prepared. Key design activities, requirements, and high-risk subsystem components have been 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 will 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 three 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 2020 Request

The FY 2020 Request for $494,434,000 directly aligns with the FY 2020 Administration research and development (R&D) Budget Priorities memo[a] issued by OMB and OSTP that identifies eight priority R&D subjects and five practices for leveraging R&D resources more effectively. BER research on secure biodesign aligns with the R&D priority Security of the American People, to underpin improving the security and resilience of the Nation from emerging threats from biological agents; investments in novel quantum sensors for biological and ecological systems aligns with the R&D priority American

[a] https://www.whitehouse.gov/wp-content/uploads/2018/07/M-18-22.pdf

Leadership in Quantum Information Science (QIS); and investments in early-stage research and innovative technologies at the four Bioenergy Research Centers align with the R&D priority American Energy Dominance, and can lead to domestic sources of clean, affordable, and reliable energy. These priority R&D subjects and the FY 2020 Request will reflect priority practices in Educating and Training a Workforce for the 21st Century Economy, Managing and Modernizing R&D Infrastructure, and Maximizing Interagency Coordination and Cross-Disciplinary Collaboration. BER research continues to build on 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 DOE's core missions 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 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].

Key elements in the FY 2020 Request include:

Research

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 third year of the four DOE 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. Secure biosystems design activities will be extended to test the fundamental engineering principles that control plant and microbial 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 and testbeds. Computational Biosciences efforts will combine structural, molecular, and genomic scale information within the DOE Systems Biology Knowledgebase and to develop integrated networks and computational models of system dynamics and behavior.

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 QIS and advanced sensors will contribute to a systems-level predictive understanding of biological processes.

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 watershed scale hydro-biogeochemical modeling. 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, including exascale, and enhanced usability, testing, adaptability, multi-scale treatments, and provenance. In addition to leveraging of existing data from other agencies, modeling efforts will be validated against new atmospheric and terrestrial observations.

The Data Management effort will continue to enhance data archiving and management capabilities but will also focus on using and demonstrating artificial intelligence (AI) and machine learning (ML) tools to observations and data from environmental field experiments.

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

Scientific User Facilities

The DOE 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. JGI operations are reduced to accommodate the FY 2020 move into the Integrative Genomics Building on the Lawrence Berkeley National Laboratory campus.

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, but operations at the East North Atlantic (Azores) will be limited to basic data collection. In addition, the Arctic mobile facility deployed at Oliktok Point will limit research activities to the summer season. One mobile facility will be deployed to Norway to study “Cold-Air Outbreaks in the Marine Boundary Layer” to improve parameterizations in multiscale models. The ARM user facility will continue to develop the aerial capability that will be acquired in FY 2019.

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.

Biological and Environmental Research supports the following FY 2020 Administration Priorities:

FY 2020 Administration Priorities

(dollars in thousands)

	Biosecurity	**Exascale Computing Initiative (ECI)**	**Artificial Intelligence (AI)**	**Quantum Information Science (QIS)**
Biological and Environmental Research	20,000	10,000	3,000	12,000

Biological and Environmental Research
Funding

(dollars in thousands)

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Biological Systems Science				
Genomic Science				
Foundational Genomics Research	104,199	90,194	100,000	+9,806
Biosecurity (non-add)	*(—)*	*(4,000)*	*(20,000)*	*(+16,000)*
Environmental Genomics[a]	28,000	29,000	15,000	-14,000
Computational Biosciences	17,000	30,501	15,000	-15,501
Bioenergy Research Centers	90,000	100,000	100,000	—
Total, Genomic Science	**239,199**	**249,695**	**230,000**	**-19,695**
Biomolecular Characterization and Imaging Science[b]	**30,000**	**34,908**	**24,908**	**-10,000**
Biological Systems Facilities and Infrastructure				
Joint Genome Institute	69,401	70,000	60,000	-10,000
Total, Biological Systems Facilities and Infrastructure	**69,401**	**70,000**	**60,000**	**-10,000**
SBIR/STTR	12,789	13,194	11,892	-1,302
Total, Biological Systems Science	**351,389**	**367,797**	**326,800**	**-40,997**
Earth and Environmental Systems Sciences				
Atmospheric System Research	**28,000**	**28,000**	**12,000**	**-16,000**
Environmental System Science				
Terrestrial Ecosystem Science	41,000	40,000	14,000	-26,000
Subsurface Biogeochemical Research	26,000	22,143	5,000	-17,143
Total, Environmental System Science	**67,000**	**62,143**	**19,000**	**-43,143**
Earth and Environmental Systems Modeling[c]	**92,000**	**97,000**	**37,643**	**-59,357**

[a] Environmental Genomics contains previous subprograms of Genomics Analysis and Validation, and Metabolic Synthesis and Conversion.
[b] Biomolecular Characterization and Imaging Science contains previous Mesoscale to Molecules, and Structural Biology Infrastructure.
[c] Earth and Environmental Systems Modeling reflects all previous Modeling activities (Regional and Global Model Analysis, Earth System Modeling, and Integrated Assessment).

(dollars in thousands)

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Earth and Environmental Systems Sciences Facilities and Infrastructure				
Atmospheric Radiation Measurement Research Facility	70,000	85,500	43,000	-42,500
Environmental Molecular Sciences Laboratory	45,000	45,000	40,000	-5,000
Data Management	8,000	8,000	10,000	+2,000
Total, Earth and Environmental Systems Sciences Facilities and Infrastructure	**123,000**	**138,500**	**93,000**	**-45,500**
SBIR/STTR	11,611	11,560	5,991	-5,569
Total, Earth and Environmental Systems Sciences	**321,611**	**337,203**	**167,634**	**-169,569**
Total, Biological and Environmental Research	**673,000**	**705,000**	**494,434**	**-210,566**

SBIR/STTR Funding:

- FY 2018 Enacted: SBIR $21,393,000 and STTR $3,007,000
- FY 2019 Enacted: SBIR $21,702,000 and STTR $3,052,000
- FY 2020 Request: SBIR $15,679,000 and STTR $2,204,000

Biological and Environmental Research
Explanation of Major Changes

	(dollars in thousands) FY 2020 Request vs FY 2019 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 expanded secure biosystems design research to understand the fundamental genome structure and functional relationships that result in specific, stable and predictable, new, and beneficial traits in model plant and microbial systems. Environmental Genomics will limit research to understanding environmentally relevant microbiomes and the interdependencies between plants and microbes in a sustainable and resilient ecosystem. Computational Bioscience will focus on an integrated computational platform for microbiome and bioenergy-related research with the completion of initial funding for a national microbiome database. The Request fully supports the four DOE Bioenergy Research Centers in their third 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 will include expanded integrative imaging and analysis platforms and biosensors, including using QIS materials, to understand the expression, structure, and function of genome information encoded within cells and for real-time measurements in ecosystems and field sites of mission relevance. User access to static protein crystallographic structural analysis is reduced. The Request reduces support for operations at JGI to accommodate the move to the Integrated Genomics Building on the LBNL campus.	**-40,997**
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 modeling the fate and transport of nutrients. Using observations from the ARM facility, Atmospheric System Research will focus activities to advance knowledge and improve model representations of atmospheric gases, aerosols, and clouds on the Earth's energy balance. One ARM mobile facility will be deployed to Norway; operations of the Arctic mobile facility at Oliktok and the East North Atlantic fixed site will be limited. EMSL will focus on biological and environmental molecular science with reduced user support. Data management activities will include applying advanced AI methods to observations and environmental field data.	**-169,569**
Total, Biological and Environmental Research	**-210,566**

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.

Specifically, BER coordinates its fundamental research on bioenergy crops with other federal agencies through the Biomass Research and Development Initiative (BRDi) Board. DOE-EERE and USDA jointly issue a solicitation for applied funding topics informed by a BRDi federal technical advisory committee. BER supports some interagency projects to manage databases (such as the Protein Database) through interagency awards and funding for complementary community resources (such as beamlines and electron cryomicroscopy), mostly with NIH and NSF. BER participates in some co-funded interagency calls with USDA.

All Earth systems research activities are specifically coordinated through the interagency U.S. Global Change Research Program. For example, the Energy Exascale Earth System Model (E3SM) modeling system has evolved to become the world's highest resolution capability, and the v1 release in April 2018 provided numerous universities the ability to conduct research with this model. Other agencies, e.g., NOAA, NASA, the Navy, and NSF, are following developments in E3SM via the Earth System Prediction Capability forum (led by DOD and NOAA weather services, but with DOE as a member), so that their modeling platforms can adopt the best practices in physics and computing developed by DOE. The National Geospatial-Intelligence Agency has indicated significant interest in E3SM, as a platform to incorporate their data to address national security problems. The E3SM research also provides BER with strong linkages to DOE applied programs and DOE Office of Policy.

Program Accomplishments

Genomic Science conducts research on complex biological systems by analyzing genetic material and associated relationships with the surrounding environment. Recent advances using genome-enabled techniques are unlocking key insights into how plants and associated microbial communities function in the environment and within microbiomes. Researchers at the USDA Agricultural Research Station in Lincoln, NE have deciphered the active metabolic and gene expression signals found in dormant switchgrass that could lead to improving the cold tolerance of this potential bioenergy crop. The fundamental research points towards ways to engineer new strains of switchgrass with an extended northern growing range. Researchers at the University of Minnesota are developing innovative methods for genome engineering in plants. Using a combination of techniques including CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats)-based systems, the group has developed a comprehensive toolset for gene editing in plants that can accommodate single or multiple gene deletions and gene editing. The work highlights improvements in gene editing-based techniques for plants for a variety of agricultural and biotechnological purposes. University of California-Berkeley and Lawrence Berkeley National Laboratory researchers, using a range of metagenomics and metabolomics analyses to explore plant-microbe interactions in the field, have uncovered predictable patterns in shifts in microbial community composition and function with plant growth. The work documents how plant exudates change during growth and how these compounds impact the growth and composition of the soil microbiology. Thus, the data captures the activity of an environmental microbiome across multiple growth seasons and provides a mechanistic, genomic basis to predict change in microbiome structure and function. All these latest results are examples of how genome-enabled science is continuing to yield valuable insights into the functioning of plant and microbial systems and how this information could be used to engineer solutions to a range of bioenergy and environmental challenges.

Bioenergy Research Centers' research continues to highlight significant basic science advances underpinning biofuels and bioproduct production from sustainable plant biomass. At the Center for Bioenergy Innovation, new understanding of the composition of plant cell walls in switchgrass and poplar has revealed a series of genes controlling pectin biosynthesis that, when downregulated, produce a plant much more amendable to conversion to biofuel. Using RNA silencing, the resulting plants exhibit up to seven fold increased ethanol production relative to controls. The engineered traits were also maintained in the plants during a 3-year field trials demonstrating the robustness of strains under environmental conditions. At the Center for Advanced Bioenergy and Bioproducts Innovation, new genome editing techniques are being developed for industrial yeast strains for a range of biotechnology purposes. These new techniques take advantage of CRISPR/Cas9 methods to perform multiplex genome engineering on complex polyploid yeast strains. This work extends gene editing techniques to commonly used, but genetically complex, industrial yeast strains thereby broadening the range of genome engineering tools with these strains. Joint BioEnergy Institute researchers are exploring innovative approaches to metabolic engineering by coupling genes from disparate organisms together in pathways to boost fatty alcohol production in model yeast strains. Fatty acid reductase from the common mouse is used to boost fatty alcohol production in an engineered yeast to the highest titers yet observed for this strain. The work highlights an efficient and renewable source of fatty alcohols from lignocellulosic sugars for fuels and products. Great Lakes Bioenergy Research Center researchers evaluating land use changes into and out of agricultural and bioenergy production show important changes in ecosystem carbon balance. Results from an 8-year field experiment suggest cropland fields converted to grasslands will accumulate carbon whereas converting grasslands to croplands results in net carbon loss to the atmosphere. The work has important implications for bioenergy (and agricultural) crop production and assessments of carbon capture and storage within landscapes.

Earth and Environmental Systems Sciences conducts research on Earth systems at the local to global scales to further understanding of all system components, including atmospheric circulation, terrestrial biogeochemistry, and the coupling of all components using numeric modeling. Incorporation of advanced modeling concepts, high performance computing, and new observations allows emerging Earth System models to more confidently capture changes to the hydrologic cycle, the cryosphere, and extreme weather events. A new DOE high-resolution Earth System model, the E3SM v1 was released in April 2018 as the world's highest resolution capability to study multi-annual to decadal-scale interdependencies involving the atmosphere, oceans, cryosphere, and terrestrial processes. The E3SM model is currently running at all of DOE's best-in-class high performance computing platforms and the project is now open-source, to foster increased collaboration on next-generation model developments. The next version (v2) will focus higher-resolution over North America in order to enhance research on extremes in precipitation, storms, floods and droughts, vegetation changes and coastal impacts. Simulations also capture detailed interactions between ice sheets and ocean waters to improve our understanding of ice sheet stability vulnerabilities.

User Facilities house state-of-the-art tools and expertise to enable the scientific community to address and solve research questions for biological and environmental systems. High resolution patterns of environmental processes influence microbial degradation of soil carbon in Arctic permafrost.

- A research effort using capabilities at the *Joint Genome Institute (JGI)* was carried out to ascertain how spatial patterns of hydrology and biogeochemistry influence the ability of microbial communities to mediate air-surface gas exchange in the polygonal Arctic permafrost soil landscapes. Using comparative metagenomics, genome binning of novel microbes, and gas flux measurements, it was found that microbial activity and gas production strongly correlate with fine-scale topography. Microbial functions such as fermentation and methanogenesis were dominant in wetter portions of polygons, and drier portions of polygons supported carbon mineralization and methane oxidation.
- At the *Environmental Molecular Sciences Laboratory (EMSL),* a team of scientists from several universities produced a three-dimensional map of the metabolic products of bacteria found in the root nodules. Using EMSL's high-field Fourier transform ion cyclotron resonance mass spectrometers, the team was able to visualize metabolites co-located into different compartments within the nodules. This spatial perspective will help to unravel the complexity of these highly interdependent organisms and optimize crop production and enable more sustainable agricultural practices for food crops used all over the world.
- Data from the *Atmospheric Radiation Measurement (ARM)* scientific user facility were analyzed and assimilated into predictive models to demonstrate improved predictability, with a particular focus on processes and mechanisms

responsible for observed storm intensification of atmospheric convection. Findings indicated that ultrafine aerosol particles can invigorate thunderstorms in a much more powerful manner than their larger counterparts through an enhanced condensation mechanism. This is contrary to previous assumptions about the impacts of ultrafine aerosol particles, thus opening up the opportunity to make major scientific advances towards improved predictions of severe storms.

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 in 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. BER's contribution towards understanding and anticipating the *convergence* of advanced genomics science with other fields is critical for foresight into secure technology development, leveraging scientific communities across biological, physical, and computational science fields with the unique ability to evaluate systems across disciplinary boundaries. All secure biosystems design efforts on plant and microbial systems will be consistent with the National Biodefense Strategy framework.

Environmental Genomics 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 advance the development of 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 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 develop QIS materials for imaging and characterization and to advance design of sensors and detectors based on correlated materials for real-time biological and environmental sensing technology. 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. Related efforts to use genomic information to infer natural product production from microorganisms and plants are also underway. 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 bioproducts research, 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 2019 Enacted		FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
Biological Systems Science	**$367,797,000**	**$326,800,000**	**-$40,997,000**
Genomic Science	$249,695,000	$230,000,000	-$19,695,000
The FY 2019 Enacted budget for Foundational Genomics research supports 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 focuses on environmental microbiome research and develops 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.		The Request for Foundational Genomics will support biosystems design techniques to modify microbes and plants for beneficial bioenergy, bioproduct and biotechnology purposes. Funding will also support complementary efforts on genome-modification techniques to identify and predict biosecurity implications for energy and the environment. Environmental Genomics will focus on sustainable plant and microbial community interactions in model and natural microbiomes, and complementary research on plant and microbial physiology for bioenergy and ecosystem purposes.	Foundational Genomics increases to support Biosystems Design research, including broader investigations of genome modification techniques to inform biosecurity research purposes. Environmental Genomics will decrease, limiting research to understanding environmentally relevant microbiomes and the interdependencies between plants and microbes in a sustainable and resilient ecosystem.
The FY 2019 Enacted budget for Computational Bioscience focuses 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 activity establishes and fully funds a platform for a national microbiome data collaborative.		The Request for Computational Bioscience will merge bioinformatics capabilities within the JGI and the DOE Systems Biology Knowledgebase to produce an open source, integrated computational platform for microbiome and bioenergy-related research.	Computational Biosciences will focus on advanced computational techniques to facilitate the analysis of environmental microbiomes. The activity to establish a platform for a national microbiome data collaborative was completed in FY 2019.
The FY 2019 Enacted budget supports the four BRCs as they begin their second year of support. Research focuses 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		The Request for the four BRCs will begin their third year of operations to develop bioenergy crops with enhanced tolerance to environmental stress, biomass deconstruction techniques to breakdown biomass, biotechnology approaches to produce fuels, chemicals and products from lignocellulosic materials, and	The BRCs will focus on development of dedicated bioenergy crops and conversion technologies that produce fuels, chemicals, and products sustainably from renewable plant biomass.

FY 2019 Enacted	FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
from cellulose and lignin, and new ways to sustainably cultivate bioenergy crops on marginal lands.	research to understand sustainable regional-scale bioenergy crop production.	
Biomolecular Characterization and Imaging Science[a] $34,908,000	$24,908,000	-$10,000,000
The FY 2019 Enacted budget for Biomolecular Characterization and Imaging Science supports 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. Funding supports investments in electron cryomicroscopy that leverage other capabilities at the Office of Science user facilities. Development of multi-functional techniques continues and includes 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.	The Request for Biomolecular Characterization and Imaging Science will support new multi-modal imaging, visualization and structural characterization of biomolecular processes occurring in plants and microbes in support of systems biology research. Investments in electron cryomicroscopy instrumentation at SC light sources are completed, and support is reduced for user access for static protein crystallography structural analysis. Research funding will support exploring new imaging, characterization and/or sensor techniques that take advantage of quantum-enabled science concepts, with an emphasis on improvements in quantifying nutrient and metabolite flows in situ in field environments.	The research will focus on opportunities for broader development of visualization and characterization technologies. FY 2020 budget priorities will emphasize efforts in quantum-enabled research for imaging/characterization and advances in designing sensors and detectors based on correlated materials for real-time sensing technology.
Biological Systems Science Facilities and Infrastructure $70,000,000	$60,000,000	-$10,000,000
The FY 2019 Enacted budget for JGI continues to serve as a primary source of genomic sequences of plants, microorganisms and microbial communities for BER programs and the broader research community. It continues 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 continues to collaborate with the DOE Systems Biology	The Request for the JGI serves as a central source for genome sequence production capabilities for plants, microbes and microbial communities. These services are crucial to BER programs, such as the BRCs, and are also available to the larger research community. JGI will focus on metagenomics efforts to support microbiome research, and production of complex plant, fungal and microbial genomes supporting systems biology research within the BRCs and the BER portfolio. The resulting data and analyses will be	The Request includes a reduction associated with moving the facility to the LBNL campus, during which time JGI will reduce sequencing and analysis capabilities intermittently. These reductions will lower the number of users for a period of 30-90 days.

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

FY 2019 Enacted	FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
Knowledgebase and prepare for a move to the LBNL campus. Structural Biology Infrastructure is moved and combined within the Biomolecular Characterization and Imaging Science activity, as noted above.	closely coupled with KBase for open access on an integrated bioinformatics platform. JGI (and KBase) will move to Integrated Genomics Building on the LBNL campus.	
SBIR/STTR $13,194,000	$11,892,000	-$1,302,000
In FY 2019, SBIR/STTR funding is set at 3.65% of non-capital funding.	In FY 2020, SBIR/STTR funding is set at 3.65% of non-capital funding.	The SBIR/STTR funding will be consistent with the BER total budget.

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. SC 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.

<u>Atmospheric System Research</u>

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.

<u>Environmental System Science</u>

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 watersheds, including environmental contamination from past nuclear weapons production.

The activity also supports Ameriflux, a network of 373 field sites funded by a variety of federal agencies and other research institutions to measure the exchange of heat, moisture and other gases between the atmosphere and the surface to maintain data quality and organizational support to the network and funding for 13 of the network sites.

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 (ESMs), in coordination with other Federal efforts. The research specifically focuses on quantifying and reducing the uncertainties in ESMs 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 2020, ARM will continue operations at the three fixed sites, maintaining mobile facility seasonal observations at Oliktok. One mobile facility will be deployed to Norway to study Cold-Air Outbreaks in the Marine Boundary Layer to improve parameterizations in multiscale models. 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.

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 will continue to develop the aerial capability that will be acquired in FY 2019. The replacement aircraft will undergo field testing in FY 2020 in order to evaluate its capabilities under a variety of conditions.

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 (HRMAC), 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, Ameriflux and NGEE field experiments.

Activities and Explanation of Changes

FY 2019 Enacted	FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
Earth and Environmental Systems Sciences $337,203,000	**$167,634,000**	**-$169,569,000**
Atmospheric System Research (ASR) $28,000,000	$12,000,000	-$16,000,000
The FY 2019 Enacted budget for ASR continues research on cloud, aerosol, and thermodynamic processes, with a focus on data from the three 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.	The Request for ASR will continue research on clouds, aerosols, and thermodynamic processes, with a focus on data from the Oklahoma and Alaska fixed sites, and using data from prior and ongoing field campaigns in Argentina, Norway, and the Southern Ocean. ASR will continue to make use of data generated by Large Eddy Simulations at the ARM Oklahoma site.	ASR will focus its investments on the Arctic and deep convection in mid-latitudes. Analysis of emerging data from the Norway field campaign will be conducted over multiple years rather than immediately following the field campaign, delaying the scientific impact of the new observations.
Environmental System Science (ESS) $62,143,000	$19,000,000	-$43,143,000
The FY 2019 Enacted budget for ESS supports research on permafrost and tropical ecology, and maintains its investments in observational and modeling studies involving boreal ecology and hydro-biogeochemistry of river catchments. Support to the management of the Ameriflux network continues. ESS initiates a pilot project on ecology of Terrestrial-Aquatic Interfaces (TAIs) and maintains investments in subsurface biogeochemistry.	The Request for ESS will focus research on permafrost and will maintain limited investments in studies of boreal ecology and modeling hydrobiogeochemistry of watersheds and terrestrial-aquatic interfaces. Research on tropical ecology and subsurface biogeochemistry research on radionuclides and mercury will be terminated.	ESS will prioritize challenges involving research on the ecology, biogeochemistry, and the water cycle, emphasizing Arctic regimes. Analysis of the data from the pilot TAIs continues, however no further TAI field studies will be initiated. Modeling and experimental research involving subsurface fate and transport of radionuclides will be terminated.

FY 2019 Enacted	FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
Earth and Environmental Systems Modeling $97,000,000	$37,643,000	-$59,357,000
The FY 2019 Enacted budget for Earth and Environmental Systems Modeling focuses its investment in further development of non-hydrostatic dynamical cores for the atmospheric component of the E3SM model that targets higher resolution over scales from seasonal to multi-decadal. Research activities continue to assimilate the best available software for E3SM to exploit DOE's high-performance computing architectures in order to analyze, model, and characterize extreme events within the earth system.	The Request for Earth and Environmental Systems Modeling will focus investments on further refinement of the science underpinning non-hydrostatic modeling, and incorporating the necessary software for deployment of the model onto exascale computing architectures. The Request will continue to support research at a reduced level, on the modeling of extreme phenomena (e.g., hurricanes), improved representation of biogeochemistry, and a better understanding of the water cycle.	The E3SM model will emphasize improvements based on the incorporation of advanced software and further development of the science governing extreme phenomena. Investments in tropical-extratropical-midlatitude interactions will be eliminated. E3SM model development timetable will be less ambitious. Further development of the cryospheric and Arctic component of the model will be delayed several years, reducing E3SMs full use of future exascale computing capabilities.
The FY 2019 Enacted budget continues to support research in model intercomparison and diagnostics. Research focuses on the water cycle in order to understand how uncertainties involving the spatial and temporal patterns of drought can be characterized.	The Request will continue support core research in model intercomparisons and diagnostics. In addition, research will focus on understanding the fine scale physics and dynamics that govern interactions between the Arctic and midlatitudes.	Research will prioritize further studies of the water cycle, with efforts to incorporate representations of groundwater into regional and global models.
Earth and Environmental Systems Sciences Facilities and Infrastructure $138,500,000	$93,000,000	-$45,500,000
The FY 2019 Enacted budget for ARM continues to provide new observations, through long-term measurements at fixed sites in Alaska, Oklahoma, and the Eastern North Atlantic. The mobile unit at Oliktok operates seasonally. All ARM activities are prioritized for critical observations necessary to advance the E3SM model. ARM deploys a mobile facility to the Southern Andes and one as an icebreaker-based Arctic observatory. ARM acquires a manned aircraft, to replace the existing Battelle-owned G1 aircraft that is retired in FY 2019. The completed analysis of alternatives indicates that purchase of a used aircraft	The Request for ARM will continue to provide new observations, through long term measurements at fixed sites in Alaska and Oklahoma; activities at the Eastern North Atlantic will be limited. ARM will continue seasonal mobile facility deployment at the Oliktok site. The Request prioritizes all ARM activities for critical observations needed to improve the E3SM model. ARM will deploy the third mobile facility to northern Norway. Subsequent to the FY 2019 procurement of a refreshed aerial capability, the new aircraft will be tested and evaluated during FY 2020 in	ARM will prioritize investments at its permanent sites in central Oklahoma and northern Alaska. A mobile unit will be deployed to northern Norway to study Arctic air mass transformations. The new ARM aircraft will be tested and evaluated in order to become available for future campaigns.

FY 2019 Enacted	FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
and subsequent retrofitting to achieve functionality for scientific instrumentation is the most cost-effective option.	limited field campaigns in order to evaluate performance.	
The FY 2019 Enacted budget for EMSL continues 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 initiates building a next generation Dynamic Transmission Electron Microscope, to support future BER science.	The Request for EMSL will continue to focus on science that exploits unique capabilities of mass spectrometry (e.g., the HRMAC and nuclear magnetic resonance), live cell imaging, Quiet Wing, and high performance computing. EMSL will continue building the Dynamic Transmission Electron Microscope, in support of BER science.	EMSL will prioritize research that focuses on environmental biogeochemistry, microbial metabolomics, aerosol chemistry, and early scientific applications of Dynamic Transmission Electron Microscope, in support of BER science. User support is reduced.
The FY 2019 Enacted budget for the Earth and Environmental Systems Sciences Data Management activity provides support to maintain existing software and data archives in support of ongoing experimental and modeling research, and for an open source distributed data and computation platform. Essential data archiving and storing protocols, capacity, and provenance are maintained.	The Request for the Earth and Environmental Sciences Data Management activity will provide support to maintain existing critical software and data archives in support of ongoing experimental and modeling research. Essential data archiving and storing protocols, capacity, and provenance will be maintained.	The Data Management effort will initiate new research on applying and demonstrating artificial intelligence and machine learning tools to observations and data from environmental field experiments.
SBIR/STTR $11,560,000	$5,991,000	-$5,569,000
In FY 2019, SBIR/STTR funding is set at 3.65% of non-capital funding.	In FY 2020, SBIR/STTR funding is set at 3.65% of non-capital funding.	The SBIR/STTR funding will be consistent with the BER total budget.

Biological and Environmental Research
Capital Summary

(dollars in thousands)

	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Capital Operating Expenses Summary						
Total Non-MIE Capital equipment (Capital Equipment > $500K)	N/A	N/A	4,500	9,300	4,500	-4,800
Major Items of Equipment [a]						
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**	**26,800**	**4,500**	**-22,300**

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

[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.

Biological and Environmental Research
Major Items of Equipment Description(s)

Earth and Environmental Systems Sciences Facilities and Infrastructure MIE(s):
Atmospheric Radiation Measurement Research Facility (ARM) – ARM Aircraft project: 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 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, was one of only 10 G-1's that remain in service worldwide, and is at the end of its service life. BER has initiated retirement and replacement of the aircraft in FY 2019. The FY 2019 Enacted Budget includes funding to replace the Battelle-owned G-1 aircraft that supported airborne data collection as part of ARM field campaigns. In FY 2020, the newly acquired aircraft will undergo testing and evaluation, including modifications to the air frame as needed to install numerous existing and new atmospheric aerosol, cloud, turbulence, and other sensors. Also, the aircraft will undergo ground-based and airborne testing, in order to prepare it for scientific studies.

Biological and Environmental Research
Funding Summary

(dollars in thousands)

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Research	500,957	516,858	360,184	-156,674
Facility Operations	172,043	170,642[a]	134,250	-36,392
Projects				
Major Items of Equipment	—	17,500	—	-17,500
Total, Projects	—	17,500	—	-17,500
Total, Biological and Environmental Research	**673,000**	**705,000**	**494,434**	**-210,566**

Scientific User Facility Operations

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.

(dollars in thousands)

	FY 2018 Enacted	FY 2018 Current	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
TYPE B FACILITIES					
Atmospheric Radiation Measurement Research Facility (ARM)	**$70,000**	**$70,000**	**$85,500[b]**	**$43,000**	**-$42,500**
Number of users	1,086	1,086	1,100	900	-200
Joint Genome Institute	**$69,401**	**$69,401**	**$70,000**	**$60,000**	**-$10,000**
Number of users	1,882	1,882	1,800	1,550	-250
Environmental Molecular Sciences Laboratory	**$45,000**	**$45,000**	**$45,000**	**$40,000**	**-$5,000**
Number of users	561	561	600	550	-50
Total Facilities	**$184,401**	**$184,401**	**$200,500**	**$143,000**	**-$57,500**
Number of users	3,529	3,529	3,500	3,000	-500

[a] Facility Operations amount less Air-ARM MIE – replacement aircraft.
[b] Includes Air-ARM MIE - replacement aircraft.

Biological and Environmental Research
Scientific Employment

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Number of permanent Ph.D.'s	1,415	1,425	1,195	-230
Number of postdoctoral associates	330	350	280	-70
Number of graduate students	475	490	405	-85
Other[a]	330	350	280	-70

[a] 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, with various types comprising 99% of the visible universe. It is the state of matter in the sun's center, corona, and solar flares. Plasma dynamics are at the heart of the formation of galactic jets and accretion of stellar material around black holes. On Earth it is the substance of lightning and flames. Plasma physics describes the processes giving rise to the aurora that illuminates the far northern and southern nighttime skies. Practical applications of plasmas are found in various forms of lighting and semiconductor manufacturing. High-temperature fusion plasmas at hundreds of millions of degrees occur in national security applications, albeit for very short times. The same fusion plasmas may be exploited in the laboratory in a controlled fashion to become the basis for a future clean nuclear power source, which could 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 a 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), the latter of which is currently down for recovery and repair, 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. The FES program 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, which will be enabled by the ITER facility, 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. Advances in plasma science 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 (R&D) budget priorities[a]. Research in fusion has the potential to contribute to American energy dominance by making available to the American people a 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 (described in a 2015 report by the Fusion Energy Sciences Advisory Committee [FESAC][b]) as well as targeted investments

[a] https://www.whitehouse.gov/wp-content/uploads/2018/07/M-18-22.pdf
[b] https://science.energy.gov/~/media/fes/fesac/pdf/2015/2101507/FINAL_FES_NonFusionAppReport_090215.pdf

(e.g., 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. Also, FES partnerships with industry will propagate scientific discoveries that could transition into the private sector. Investments in transformational technologies such as machine learning, quantum information science (QIS), microelectronics, and high-performance strategic computing could accelerate progress in several mission areas. Finally, the unique scientific challenges and rigor of fusion and plasma physics research lead to the development of a well-trained STEM 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 2020 Request

The FY 2020 Request is $402,750,000. 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,"[a] the research opportunities identified in a series of community engagement workshops held in 2015[b], and the FY 2017 FESAC report on the potential for transformative developments in fusion science and technology[c]. Priorities include keeping SC fusion user facilities world-leading, investing in high-performance computing and preparing for exascale, exploring the potential of QIS and machine learning, 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, continuing stewardship of discovery plasma science (e.g., via intermediate-scale facilities), and initiating private-public partnerships. Furthermore, research priorities for burning plasma science in FY 2020 will be informed by the 2018 report[d] of the National Academies of Sciences, Engineering, and Medicine burning plasma study commissioned by FES.

Key elements in the FY 2020 Request include:

<u>Research</u>

- *DIII-D research* – DIII-D research will utilize the facility enhancements implemented during the FY 2018–2019 Long Torus Opening. Research goals will aim at resolving predictive burning plasma physics, validation of impurity transport models, and integration of core and edge plasma solutions.
- *NSTX-U research* – The NSTX-U research budget will fund a focused effort on physics topics that directly support the recovery of robust NSTX-U plasma operations, as well as collaborative research at other facilities to support NSTX-U research program priorities.
- *Partnerships with private fusion efforts* – Private-public collaborations will leverage opportunities in critical fusion research areas (e.g., diagnostics, theory and simulation, materials science, and magnet technology).
- *Enabling technology and discovery plasma science* – Research on high-temperature superconductors, additive manufacturing, low-temperature plasmas (relevant to microelectronics), and high-energy-density plasmas lead to connections with and spinoffs for U.S. industry.
- *Scientific Discovery through Advanced Computing* – SciDAC projects will address high-priority research on tokamak disruptions and large-scale fusion data analysis challenges, including machine learning and QIS, and also 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 enables U.S. scientists to work 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 Torus (JET). Long-pulse stellarator research will allow 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.
- *Fusion nuclear science* – FES will continue to evaluate options for a neutron source that will test materials in fusion-relevant environments.

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[a] https://science.energy.gov/~/media/fes/pdf/workshop-reports/2016/FES_A_Ten-Year_Perspective_2015-2025.pdf
[b] https://science.energy.gov/fes/community-resources/workshop-reports/
[c] https://science.energy.gov/~/media/fes/fesac/pdf/2018/TEC_Report_15Feb2018.pdf
[d] https://www.nap.edu/catalog/25331/final-report-of-the-committee-on-a-strategic-plan-for-us-burning-plasma-research

- *Discovery plasma science* – Basic plasma research is partially carried out in partnership with NSF and NNSA. Research and operations will focus on the intermediate-scale plasma science facilities and on HEDLP research on the Matter in Extreme Conditions (MEC) instrument, an end station on the Linac Coherent Light Source (LCLS) facility at SLAC National Accelerator Laboratory (SLAC), stewarded by the SC Basic Energy Sciences (BES) program, and on LaserNetUS, a new national consortium of laser facilities for enhanced user access.

<u>Facility Operations</u>

- *DIII-D operations* – The funding will allow 13 weeks of facility operations, along with machine and infrastructure refurbishments and improvements needed for new research capabilities.
- *NSTX-U recovery activities* – The NSTX-U facility is down for recovery and repair, which will continue through FY 2020. The NSTX-U Operations budget will support high-priority activities to implement repairs and corrective actions required to achieve research operations, as well as to increase machine reliability.
- *Major Item of Equipment (MIE) project for world-leading fusion materials research* – The Materials Plasma Exposure eXperiment (MPEX) MIE project will be a world-leading facility for steady-state, high-heat-flux testing of fusion materials and will be a great resource for advancing the FES strategic priority in materials research. The project is expected to be baselined in FY 2020. The FY 2020 funding will maintain the required detailed design and R&D activities and allow for initiation of long-lead major procurements for the device.

<u>Projects</u>

- *Continued U.S. hardware development and delivery to ITER* – The FY 2020 Request will support the continued design and fabrication of the highest-priority “in-kind” hardware systems. This includes continued fabrication of the Central Solenoid magnet system, which consists of seven superconducting modules, structural components, and assembly tooling. The U.S. will deliver the first Central Solenoid magnet module to the ITER site and also continue design and fabrication efforts for other hardware systems.
- *High energy density laboratory plasmas* – FES will initiate a line-item construction project for a significant upgrade to the MEC instrument on the LCLS facility at SLAC.

<u>Other</u>

- *GPP/GPE* – Funding is provided for General Plant Projects/General Purpose Equipment, to support Princeton Plasma Physics Laboratory (PPPL) infrastructure improvements and repairs as well as support a study of FES infrastructure needs at Oak Ridge National Laboratory (ORNL).

FES supports the following FY 2020 Administration Priorities.

FY 2020 Administration Priorities

(dollars in thousands)

	Artificial Intelligence (AI)	**Quantum Information Science (QIS)**
Fusion Energy Sciences	7,000	7,520

Fusion Energy Sciences
Funding

	(dollars in thousands)			
	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Burning Plasma Science: Foundations				
Advanced Tokamak	121,115	130,500	88,500	-42,000
Spherical Tokamak	93,550	96,000	67,500	-28,500
Theory & Simulation	50,000	50,000	44,000	-6,000
GPE/GPP/Infrastructure	13,000	10,204	1,000	-9,204
Total, Burning Plasma Science: Foundations	**277,665**	**286,704**	**201,000**	**-85,704**
Burning Plasma Science: Long Pulse				
Long Pulse: Tokamak	15,000	14,000	9,000	-5,000
Long Pulse: Stellarators	10,069	8,500	8,500	—
Materials & Fusion Nuclear Science	27,177	38,746	32,500	-6,246
Total, Burning Plasma Science: Long Pulse	**52,246**	**61,246**	**50,000**	**-11,246**
Discovery Plasma Science				
Plasma Science Frontiers	54,000	52,050	25,000	-27,050
Measurement Innovation	7,000	8,000	4,000	-4,000
SBIR/STTR & Other	19,200	24,000	14,750	-9,250
Total, Discovery Plasma Science	**80,200**	**84,050**	**43,750**	**-40,300**
Subtotal, Fusion Energy Sciences	**410,111**	**432,000**	**294,750**	**-137,250**
Construction				
20-SC-61 Matter in Extreme Conditions Petawatt Upgrade	—	—	1,000	+1,000
14-SC-60 U.S. Contributions to ITER	122,000	132,000	107,000	-25,000
Total, Construction	**122,000**	**132,000**	**108,000**	**-24,000**
Total, Fusion Energy Sciences	**532,111**	**564,000**	**402,750**	**-161,250**

SBIR/STTR Funding:

- FY 2018 Enacted: SBIR $11,598,000 and STTR $1,631,000
- FY 2019 Enacted: SBIR $12,992,000 and STTR $1,827,000
- FY 2020 Request: SBIR $8,899,000 and STTR $1,252,000

Fusion Energy Sciences
Explanation of Major Changes

	(dollars in thousands) FY 2020 Request vs FY 2019 Enacted
Burning Plasma Science: Foundations The Request for DIII-D prioritizes funding to ensure scientific utilization of the significant facility enhancements implemented during the FY 2018–FY 2019 Long Torus Opening, with 13 weeks of research operation. Funding for the NSTX-U program will support the ongoing recovery activities and maintain collaborative research at other facilities to support NSTX-U research program priorities. SciDAC continues to make progress toward whole-device modeling; this subprogram will also explore the potential of transformative approaches to fusion science, such as machine learning and QIS. Enabling R&D will focus attention on high-temperature superconductor development. Funding is provided for General Plant Projects/General Purpose Equipment (GPP/GPE), to support critical infrastructure improvements and repairs at PPPL, as well as a study of FES infrastructure needs at ORNL.	**-85,704**
Burning Plasma Science: Long Pulse The Request will continue to provide support for high-priority international collaboration activities, both for tokamaks and stellarators. Materials research and fusion nuclear science research programs are focused on high priorities, such as advanced plasma-facing and structural materials. The Request supports design and R&D activities for the MPEX MIE project, expected to be baselined in FY 2020, and initiates long-lead major procurements.	**-11,246**
Discovery Plasma Science For General Plasma Science, the Request emphasizes research and operations of intermediate-scale scientific user facilities and participation in the NSF-DOE Partnership. 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, supporting research on medium-scale laser facilities through the new LaserNetUS network, and exploring research opportunities of QIS.	**-40,300**
Construction FES will initiate a line-item construction project for a significant upgrade to the MEC instrument. The U.S. Contributions to ITER project will continue design, fabrication, and delivery of highest-priority First Plasma hardware.	**-24,000**
Total, Fusion Energy Sciences	**-161,250**

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

Doubled efficiency of sustaining plasma pressure in spherical tokamaks. Spherical tokamaks are able to support high plasma pressures, relative to the pressure of the applied confining magnetic field. Recent experiments on the Pegasus spherical tokamak at the University of Wisconsin-Madison were able to achieve a 100% value for the beta parameter (the ratio of plasma pressure to applied magnetic pressure); the previous record for achieved beta was ~35%. Beta is an important metric in fusion science, since fusion power output increases quadratically as the value for beta goes up. The beta value represents the efficiency with which the applied magnetic field in any fusion system is utilized.

Addressing the transients challenge for tokamak fusion. DIII-D has made significant advances in the mitigation and avoidance of large-scale transient events ("disruptions") that can abruptly terminate a fusion plasma. This includes testing a new shell-pellet concept that uses a thin-walled, hollow, pea-sized diamond “pellet” filled with metallic dust to suppress the high-energy runaway electrons that are often generated during a disruption and that can damage the vacuum vessel. The experiments showed successful delivery of the dust into the current channel formed by these runaway electrons. Computer algorithms informed by modern machine-learning techniques are being developed to provide supervisory logic for comprehensive disruption avoidance and machine protection.

Massively parallel supercomputer simulations shed light on the behavior of magnetic islands. Magnetic islands, which are bubble-like structures that form in magnetically confined fusion plasmas, can grow and lead to plasma disruptions, which are among the critical challenges confronting future fusion reactors. Simulation research supported by the Scientific Discovery through Advanced Computing (SciDAC) program and carried out on the Cori supercomputer at the National Energy Research Scientific Computing Center (NERSC) showed that—contrary to long-held assumptions—the plasma profile inside the island can maintain a radial structure and the plasma flow can be strongly sheared, which is known to have a beneficial effect on plasma transport. These findings will improve the ability to predict and avoid the onset of the deleterious plasma disruptions.

Optimal magnetic fields stabilize dangerous instabilities in tokamak plasmas. Researchers have succeeded in developing a breakthrough predictive method for improving the operation of tokamaks using magnetic fields. In tokamaks, magnetic field perturbations are often used to avoid undesirable plasma instabilities; however, other unwanted side effects may occur, such as excessive leakage of heat. The research showed how to use plasma simulations and an efficient numerical method to identify the most effective fields, while keeping certain components of the field below critical thresholds. The modeling motivated experimental studies on the Korean superconducting tokamak KSTAR that validated the new methods, which are now being applied to ITER and future fusion facility designs.

U.S.-provided trim coils improve performance of Wendelstein 7-X stellarator. The recent second round of W7-X experiments demonstrated the ability of the five large copper magnetic trim coils and their sophisticated control system to measure and correct deviations of the magnetic fields from their designated configuration. Any deviation of these “error fields” can cause divertor plates to overheat and limit the performance of the plasma. Controlling such fields at the edge of the plasma enabled W7-X to produce plasma discharges lasting up to 30 seconds. Complementary experiments confirmed predictions about the power needed by the trim coils to correct the deviations—only 10% of the full power of the coils, which is a testament to the precision with which W7-X was constructed.

First-of-a-kind fusion materials irradiation experiment completed. The U.S. and Japan “PHENIX” collaboration has successfully completed an extensive, first-of-a-kind irradiation campaign to study the feasibility of tungsten-based plasma-facing materials for future fusion devices. This campaign utilized novel gadolinium shield technologies to achieve realistic displacement damage to transmutation ratios in the High Flux Isotope Reactor facility at ORNL. This was the first-ever exploration of fusion-relevant neutron damage in tungsten. The full disassembly of the irradiation experiment was completed on cost and schedule, and extensive post-irradiation examination has been initiated, after five years of experimentation. The information gleaned from this experiment is expected to provide lasting guidance for the international fusion materials community.

New discovery reveals how solar-wind electrons are heated in the Earth's magnetic shield. Analyses of observational data from the NASA Magnetospheric Multiscale spacecraft demonstrated that the solar-wind electron stream is accelerated, upon interacting with Earth's magnetic field, to such high speeds that the streaming breaks down and is transformed into heat. The discovery reveals a never-before-seen picture about how solar-wind electrons are heated when reaching Earth's magnetic shield. These ground-breaking results will stimulate further theories, simulations, and laboratory experiments to resolve a longstanding question about collisionless heating at shocks. The discovery has broad applicability to the understanding of shocks and particle acceleration in solar flares and supernovae, as well as to astrophysics in general.

Turning plastic into diamonds. Scientists at SLAC have successful produced the “diamond rain” that forms in the interior of icy giant planets. In these laboratory experiments, the environment inside these planets was recreated at the MEC instrument by the irradiation of plastic targets with a high-power optical laser. Nearly every carbon atom of the original plastic was incorporated into small diamond structures up to a few nanometers in size. This study predicts that on Uranus and Neptune, diamonds would become much larger, maybe millions of carats in weight.

Fusion Energy Sciences
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 Princeton Plasma Physics Laboratory (PPPL) and other possible DOE laboratories where fusion research is ongoing.

Research in the Burning Plasma Science: Foundations area in FY 2020 will focus on high-priority scientific issues and opportunities in the areas of transients in tokamaks, plasma-material interactions, and whole-device modeling, as identified by research needs workshops and other community-led studies. It will also support new approaches with transformational potential to advance the FES mission, such as machine learning and QIS.

<u>Advanced Tokamak</u>
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. The Request will also allow for partnership opportunities with the private sector on enabling technology research issues.

Versatile university-led small-scale advanced tokamak research is complementary to the efforts at the major user facilities, providing cost-effective development of new techniques and exploration of new concepts. These activities are often the first step in a multi-stage approach toward the extension of the scientific basis for advanced tokamaks or the maturation of new experimental techniques. 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.

<u>Spherical Tokamak</u>
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 are experimentally realized in NSTX-U, then the ST might provide a more compact fusion reactor than other plasma confinement geometries. In FY 2020, NSTX-U recovery activities will focus on the continued execution of facility repairs and corrective actions required to resume reliable plasma operations.

Small-scale ST plasma research involves focused experiments to provide data in regimes of relevance to the ST magnetic confinement program. These efforts 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 ranges from foundational analytic theory to mid- and large-scale computational work with the use of high-performance computing resources. In addition to its scientific discovery mission, the Theory element 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, seven of which are jointly supported by FES and ASCR while one is supported entirely by FES, and addresses the high-priority research directions identified in recent community workshops. A ninth project focused on the critical area of avoidance and mitigation of runaway electrons was added in FY 2018, following a competitive review. 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 support of emerging computational approaches, such as machine learning and other data-centric technologies, and the support of longer-term transformative research opportunities such as computing aspects of QIS, as identified in the 2018 FES Roundtable on QIS[a]. The Request will also allow for partnership opportunities with the private sector in theory and simulation research areas.

GPE/GPP/Infrastructure

This activity supports critical general infrastructure (e.g., utilities, roofs, roads, facilities, environmental monitoring, and equipment) at the PPPL site and other DOE laboratories where fusion research is ongoing.

[a] https://science.energy.gov/~/media/fes/pdf/workshop-reports/FES-QIS_report_final-2018-Sept14.pdf

Activities and Explanation of Changes

FY 2019 Enacted		FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
Burning Plasma Science: Foundations	**$286,704,000**	**$201,000,000**	**-$85,704,000**
Advanced Tokamak	$130,500,000	$88,500,000	-$42,000,000
DIII-D Research	*$46,000,000*	*$40,500,000*	*-$5,500,000*
DIII-D Operations	*$75,500,000*	*$44,000,000*	*-$31,500,000*
The FY 2019 Enacted budget continues numerous enhancements/improvements to the DIII-D facility, to include the neutral beam modification to add bi-directional off-axis injection capability; and supports 12 weeks of operations. Research continues 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 exploit additional heating and current drive systems added in FY 2018. Researchers utilize the new neutral beam capability to examine the physics of self-driven tokamak plasmas. Specific research goals include further integration of the core and edge conditions in high-performance plasmas and studying the role of neutral fueling and transport in determining the edge pedestal structure.		At the Request level, operations funding will support 13 weeks of research at the DIII-D facility. Facility improvements to increase auxiliary heating power, current drive, and 3D magnetic field shaping capabilities will be supported. Research will utilize new heating and current drive systems to access steady-state tokamak plasma scenarios at high pressure and low rotation, further refine techniques to avoid and mitigate transients in tokamaks, and exploit new diagnostics to improve the understanding of divertor material erosion and transport. Specific research goals will aim at resolution of predictive burning plasma physics, validation of impurity transport models, and integration of core and edge plasma solutions that extrapolate to future fusion reactors.	Research efforts will focus on highest-priority science issues, including funding for key facility collaborators and off-site users. Operations will support critical machine improvements to maintain DIII-D world-leading status.
Enabling R&D	*$7,000,000*	*$3,000,000*	*-$4,000,000*
The FY 2019 Enacted budget continues research in superconducting magnet technology and plasma fueling and heating technologies required to enhance the performance for existing and future magnetic confinement fusion devices.		The Request supports continuing research in high-temperature superconducting magnet technology and in plasma fueling and heating technologies. The Request will allow for exploration of partnership opportunities with the private sector.	Research efforts will continue to emphasize high-priority R&D. Efforts will be made to enhance research into high-temperature superconducting magnet technology.

FY 2019 Enacted		FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
Small-scale Experimental Research	*$2,000,000*	*$1,000,000*	*-$1,000,000*
The FY 2019 Enacted budget allows versatile university-led experiments to focus on improving fusion plasma control physics for advanced tokamaks.		At the Request level, university-led experiments will continue to develop innovative strategies to improve the performance of advanced tokamaks.	Highest-priority experimental research and model validation efforts will continue.
Spherical Tokamak	$96,000,000	$67,500,000	-$28,500,000
NSTX-U Research	*$25,000,000*	*$27,000,000*	*+$2,000,000*
NSTX-U Operations	*$68,000,000*	*$38,500,000*	*-$29,500,000*
The FY 2019 Enacted budget supports NSTX-U operations of high-priority activities to implement repairs and corrective actions required to obtain robust, reliable research operations. Research supports the continued analysis of high-impact data, a focused effort on physics topics that directly support the recovery of robust plasma operations, and enhanced collaborative research at other facilities to support NSTX-U research program priorities.		At the Request level, operations will support recovery procurements and construction activities that are necessary to realize robust research operations. Research will support analysis and modeling efforts at other facilities to support NSTX-U research program priorities and the installation of high-priority diagnostic instruments on the device.	Operations will support continued critical recovery activities. Research efforts will focus on high-priority science issues in preparation for return to operations.
Small-scale Experimental Research	*$3,000,000*	*$2,000,000*	*-$1,000,000*
The FY 2019 Enacted budget supports 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, continues. In addition, techniques to operate spherical tokamaks without the use of a central solenoid continue to be experimentally tested.		At the Request level, studies and experiments will focus on exploring operational scenarios without a central solenoid and model validation and detailed core turbulent transport mechanisms that elucidate experimental observations of improved confinement when the plasma is surrounded by liquid lithium.	Highest-priority experimental research and model validation efforts will continue.

FY 2019 Enacted		FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
Theory & Simulation	$50,000,000	$44,000,000	-$6,000,000
Theory	*$25,000,000*	*$18,000,000*	*-$7,000,000*
In the FY 2019 Enacted budget, theory continues 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.		At the Request level, theory will continue to address foundational problems in the science of magnetic confinement. Emphasis will be placed on research that maximizes synergy with large-scale simulation efforts and addresses recommendations from community workshops. The Request will allow for partnership opportunities with the private sector.	Research efforts will focus on the highest-priority activities.
SciDAC	*$25,000,000*	*$26,000,000*	*+$1,000,000*
In the FY 2019 Enacted budget, the SciDAC portfolio continues to emphasize high-priority areas such as plasma disruptions (including runaway electron effects), boundary physics, and plasma-materials interactions. The activities of all the partnerships are coordinated to accelerate progress toward whole-device modeling. Synergy with whole-device modeling activities supported by the DOE Exascale Computing Project is strengthened.		At the Request level, the nine FES SciDAC partnerships will continue to address challenges in burning plasma science, with emphasis on integration and whole-device modeling, as well as Exascale readiness. Progress in plasma disruptions will accelerate following the addition of a partnership focusing on runaway electron physics in FY 2018. Validation of the simulation codes against experimental data will also be emphasized. Research efforts focusing on emerging technologies with transformational potential, such as machine learning and computing aspects of QIS, will continue.	The Request will maintain the existing portfolio at the same level of effort. Research efforts focusing on emerging technologies with transformational potential, such as machine learning /artificial intelligence and computing aspects of QIS, will be strengthened.
GPE/GPP/Infrastructure	$10,204,000	$1,000,000	-$9,204,000
The FY 2019 Enacted budget supports Princeton Plasma Physics Laboratory (PPPL) infrastructure improvements, repair, and maintenance.		The Request will support PPPL infrastructure improvements, repair, monitoring, and maintenance. Funding will also support a study of FES infrastructure needs at ORNL.	The focus will be on highest-priority infrastructure needs and improvements.

Fusion Energy Sciences
Burning Plasma Science: Long Pulse

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 non-superconducting overseas 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, including the provision of a pellet fueling injector for quasi-steady-state plasma experiments. 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 improvement of the stellarator magnetic confinement 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 plasmas.

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 new materials and components suitable for fusion power plants is necessary 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 strong magnetic fields, as well as large variations of these parameters from the first wall to the vacuum vessel, and the impact of this extreme environment 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 replicate or effectively simulate various aspects of the harsh fusion environment. These experimental capabilities can lead to an increased understanding of materials and could aid in the development of new materials for use in fusion as well as other extreme environments. The Request described below will also allow for partnership opportunities with the private sector on fusion materials research.

The highest-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 enable 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 and particle fluxes on materials can be studied for the first time anywhere in the world.

Activities and Explanation of Changes

FY 2019 Enacted		FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
Burning Plasma Science: Long Pulse	**$61,246,000**	**$50,000,000**	**-$11,246,000**
Long Pulse: Tokamak	$14,000,000	$9,000,000	-$5,000,000
In the FY 2019 Enacted budget, research on the EAST and KSTAR superconducting tokamaks continues to establish the physics bases and control tools for steady-state plasma scenarios, disruption avoidance and mitigation, and control of plasma-material interfaces. On the Joint European Torus, U.S. scientists are commissioning a shattered pellet disruption mitigation system and collaborating on optimization of burning plasma scenarios with deuterium and tritium fuels.		In the Request, research on overseas superconducting tokamaks will continue to integrate new diagnostics and control tools to improve the performance and duration of a wide range of steady-state, long-pulse plasma scenarios in collaboration with international partners. Research goals will support the pursuit of robust disruption and runaway mitigation solutions, validation of theoretical tools for plasma scenario development and optimization, and refinement of power exhaust control solutions that are consistent with transient-free plasma operation.	High-priority research activities by U.S. multi-institutional teams will be maintained in areas critical to the advancement of long-pulse, steady-state plasma operation.
Long Pulse: Stellarators	$8,500,000	$8,500,000	$—
Superconducting Stellarator Research	*$5,000,000*	*$6,000,000*	*+$1,000,000*
In the FY 2019 Enacted budget, U.S. scientists are using data from the first major experimental campaign on W7-X to strengthen the basis for long-pulse operation with pellet fueling, testing the innovative island divertor concept, investigating impurity recycling, studying the effect of the U.S.-provided trim coils on fast-ion confinement and on modulation of divertor heat loads, and determining the effect of the radial electric field on impurity transport.		In the Request, on W7-X, U.S. scientists will build and install a continuous high-speed pellet system to provide fueling for quasi-steady-state plasma experiments; develop a complete set of powder droppers for boron powder injection to enable steady-state wall conditioning; examine the effect of plasma turbulence and coherent modes on energy and particle transport; and explore edge radiative cooling with an island divertor, including 3D equilibrium effects.	Research activities by U.S. multi-institutional teams will be enhanced, including deployment and utilization of U.S. experimental hardware on international stellarator facilities.

FY 2019 Enacted	FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
Compact Stellarator Research *$3,500,000*	*$2,500,000*	*-$1,000,000*
In the FY 2019 Enacted budget, research is providing experimental data in regimes of relevance to the mainline stellarator magnetic confinement efforts and helping confirm theoretical models and simulation codes in support of the goal to develop an experimentally-validated predictive capability for magnetically confined fusion plasmas.	In the Request, research will continue on experiments that are providing data in regimes relevant to mainline stellarator confinement and experimental validation of models and codes.	The highest-priority research activities will be supported.
Materials & Fusion Nuclear Science $38,746,000	$32,500,000	-$6,246,000
Fusion Nuclear Science *$14,000,000*	*$8,500,000*	*-$5,500,000*
In the FY 2019 Enacted budget, research efforts continue to focus on the priority areas of plasma-facing components, safety, tritium fuel cycle, and breeder blanket technologies. In addition, a study is being initiated to evaluate options for a neutron source to test materials in fusion-relevant environments.	In the Request, 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 expanding into high-priority research area of novel technologies for tritium fuel cycle control, as identified by the recent FESAC report on Transformative Enabling Capabilities. In addition, FES will continue to evaluate options for a near-term fusion-relevant neutron source.	Research efforts will be focused on the highest-priority activities, including novel technologies for the tritium fuel cycle and evaluation of near-term fusion-relevant neutron sources.
Materials Research *$10,000,000*	*$12,000,000*	*+$2,000,000*
In the FY 2019 Enacted budget, research efforts continue to focus on the development of materials that can withstand the extreme fusion environment expected in future fusion reactors.	In the Request, research efforts will continue to focus on the development of materials that can withstand the extreme fusion environment. Opportunities will be considered for expanding into high-priority research in the area of advanced materials and manufacturing, as identified by the recent FESAC report on Transformative Enabling Capabilities.[a]	Research efforts will focus on highest-priority activities and expansion into advanced materials and manufacturing. The Request will also allow for partnership opportunities with the private sector.

[a] https://science.energy.gov/~/media/fes/fesac/pdf/2018/TEC_Report_1Feb20181.pdf

FY 2019 Enacted	FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
Projects *$14,746,000*	*$12,000,000*	*-$2,746,000*
In the FY 2019 Enacted budget, 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. Funding is provided for project engineering and design efforts and some long-lead procurements.	The Request will support MPEX project engineering design and also preparation for baseline approval and long-lead procurements.	Critical design activities for the MPEX MIE project will continue.

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 synthesis of nanomaterials and artificial diamonds, fabrication of micro- and opto-electronic devices, energy-efficient lighting, low-heat chemical-free sterilization processes, 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 at the frontiers of basic and low temperature plasma science, including dynamical processes in laboratory, space, and astrophysical plasmas, such as magnetic reconnection, dynamo, shocks, turbulence cascade, structures, waves, flows and their interactions; behavior of dusty plasmas, non-neutral, single-component matter or antimatter plasmas, and ultra-cold neutral plasmas; plasma chemistry and processes in low-temperature plasma, interfacial plasma, synthesis of nanomaterials, and interaction of plasma with surfaces, materials or biomaterials.
- *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. Additionally, this portfolio will support HEDLP QIS priority research opportunities outlined in the 2018 Report of the Fusion Energy Sciences Roundtable on Quantum Information Science.
- *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 collaborative research 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 transformative and 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

Science: Long Pulse subprograms. The utilization of mature diagnostics systems is then supported via the research programs at major fusion facilities. The Request will also allow for partnership opportunities with the private sector on fusion diagnostics issues.

<u>SBIR/STTR & Other</u>
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; outreach programs; and support for the FESAC.

Activities and Explanation of Changes

FY 2019 Enacted		FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
Discovery Plasma Science	**$84,050,000**	**$43,750,000**	**-$40,300,000**
Plasma Science Frontiers	$52,050,000	$25,000,000	-$27,050,000
General Plasma Science	*$31,050,000*	*$13,000,000*	*-$18,050,000*
In the FY 2019 Enacted budget, core research areas of this activity continue to address questions related to plasma dynamo, magnetic reconnection, particle acceleration, turbulence, and magnetic self-organization. New efforts in low-temperature plasma are being competitively selected.		In the Request, core research areas of this activity will continue, with a focus on basic plasma science and low-temperature plasma collaborative research facilities, including support for users of these facilities.	Research efforts will focus on highest-priority scientific activities in both basic plasma science and low-temperature plasmas.
High Energy Density Laboratory Plasmas	*$18,400,000*	*$12,000,000*	*-$6,400,000*
In the FY 2019 Enacted budget, research emphasizes utilizing the MEC at LCLS for warm dense matter studies. Support continues for the MEC beam-line science team and the experimental HEDLP research groups at SLAC. With the approval of a Critical Decision-0 for Mission Need, a study is initiated to evaluate options for a MEC upgrade. Modest support is provided to make medium-scale HEDLP facilities accessible to university researchers.		In the Request, research will emphasize utilizing the MEC at LCLS. Support will continue for the MEC beam-line science team and the LaserNetUS initiative. Application of HEDLP to advance QIS will be supported.	Research efforts will focus on highest-priority science activities.
Exploratory Magnetized Plasma	*$1,000,000*	*$—*	*-$1,000,000*
In the FY 2019 Enacted budget, core research areas of this activity continue.		No funding is requested.	No funding is requested.
Projects	*$1,600,000*	*$—*	*-$1,600,000*
The FY 2019 Enacted budget provides OPC funding for the Matter in Extreme Conditions (MEC) Petawatt Upgrade project.		No funding is requested.	No funding is requested.

FY 2019 Enacted	FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
Measurement Innovation $8,000,000	$4,000,000	-$4,000,000
In the FY 2019 Enacted budget, Measurement Innovation is funding new transformative and innovative diagnostics for plasma transient instabilities, plasma-materials interactions, modeling validation, and basic plasma science identified in the community workshops.	In the Request, Measurement Innovation will support the development of transformative and innovative diagnostics for plasma transient instabilities, plasma-materials interactions, modeling validation, and basic plasma science identified in the community workshops. The Request will allow for partnership collaboration opportunities with the private sector.	Research efforts will focus on the highest-priority activities.
SBIR/STTR & Other $24,000,000	$14,750,000	-$9,250,000
The FY 2019 Enacted budget continues support 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 Request will continue support for USBPO activities, HBCUs, peer reviews for solicitations, outreach programs, and FESAC. SBIR/STTR funding is statutorily set at 3.65 percent of noncapital funding in FY 2020.	The SBIR/STTR funding will be consistent with the FES total budget.

Fusion Energy Sciences
Construction

Description
This subprogram supports all line-item construction for the entire FES program. All Total Estimated Costs (TEC) are funded in this subprogram.

Matter in Extreme Conditions (MEC) Petawatt Upgrade

The National Academies of Sciences, Engineering, and Medicine (NAS) 2017 report "Opportunities in Intense Ultrafast Lasers: Reaching for the Brightest Light[a]" recommended that "The Department of Energy should plan for at least one large-scale open-access high-intensity laser facility that leverages other major science infrastructure in the Department of Energy complex". This project is a new start in FY 2020 and will be an upgrade to MEC. The MEC Petawatt Upgrade is aimed at providing an experimental collaborative National User Facility for High-Energy-Density Science that will help address this NAS recommendation as well as helping the U.S. regain leadership in this important field of study. MEC is an experimental research end-station that utilizes the SLAC's Linac Coherent Light Source. The project received CD-0, "Approve Mission Need" on January, 4, 2019. The FY 2020 Request will support conceptual design of the MEC Petawatt Upgrade. The estimated total project cost is $50 million to $200 million.

ITER

The ITER facility, currently under construction in St. Paul-lez-Durance, France, and nearly 60% complete for First Plasma, aims to provide 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 also a financial contribution, e.g. for the installation and assembly of the components provided by the U.S. and other Members to the ITER Organization (IO). An independent review of CD-2, "Approve Performance Baseline" for the First Plasma (FP) subproject was completed in November 2016 and then subsequently approved by the Project Management Executive (PME) on January 13, 2017, with a total project cost of $2.5 billion.

The U.S. in-kind contribution represents 9% of the overall cost, but will allow access to 100% of the science and engineering associated with what will be the largest magnetically confined burning plasma experiment ever created. Recent advances in validated theory indicate that ITER will outperform its currently stated performance, including higher fusion power gain, longer plasma duration, demonstration of advanced operating scenarios, and improvements in divertor power handling.

[a] https://www.nap.edu/read/24939/chapter/1

Activities and Explanation of Changes

FY 2019 Enacted		FY 2020 Request	Explanation of Change FY 2020 Request vs FY 2019 Enacted
Construction	**$132,000,000**	**$108,000,000**	**-$24,000,000**
Matter in Extreme Conditions (MEC) Petawatt Upgrade	$—	$1,000,000	+$1,000,000
		The Request will initiate design activities for this project, which is a new start.	The Request supports the initiation of a line-item construction project for an upgrade to MEC.
U.S. Contributions to ITER	$132,000,000	$107,000,000	-$25,000,000
In the FY 2019 Enacted budget, the primary focus is on First Plasma hardware, including continued design and fabrication of the highest-priority in-kind deliverables. A financial contribution is provided.		The Request will support the continued design and fabrication of the highest priority “in-kind” hardware systems.	Work will focus on the highest-priority First Plasma hardware activities.

Fusion Energy Sciences
Capital Summary

(dollars in thousands)

	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Capital Operating Expenses Summary						
Capital Equipment	N/A	N/A	10,490	16,874	16,300	-574
Minor Construction Activities						
General Plant Projects (GPP)	N/A	N/A	12,190	9,134	380	-8,754
Total, Capital Operating Expenses	**N/A**	**N/A**	**22,680**	**26,008**	**16,680**	**-9,328**

Capital Equipment

(dollars in thousands)

	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Capital Equipment						
Major Items of Equipment[a]						
Burning Plasma Science: Long Pulse Materials Plasma Exposure eXperiment (MPEX)	40,000–60,000	—	—	14,746	12,000	-2,746
Total Non-MIE Capital Equipment	N/A	N/A	10,490	2,128	4,300	2,172
Total, Capital Equipment	**N/A**	**N/A**	**10,490**	**16,874**	**16,300**	**-574**

Minor Construction Activities

(dollars in thousands)

	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
General Plant Projects						
Total GPPs less than $5M[b]	N/A	N/A	12,190	9,134	380	-8,754

[a] Each MIE located at a DOE facility Total Estimated Cost (TEC) >$5M and each MIE not located at a DOE facility TEC >$2M.
[b] GPP activities less than $5M include design and construction for additions and/or improvements to land, buildings, replacements or additions to roads, and general area improvements.

Fusion Energy Sciences
Major Items of Equipment Description(s)

Burning Plasma Science: Long Pulse MIE:

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 that will be used to explore 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 project is expected to be baselined in FY 2020. The proposed funding will maintain the required design and R&D activities and allow for initiation of long-lead major procurements for the device. (TPC $40–$60 million)

Fusion Energy Sciences
Construction Projects Summary

(dollars in thousands)

	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
20-SC-61, Matter in Extreme Conditions (MEC) Petawatt Upgrade						
TEC	TBD	—	—	—	1,000	+1,000
OPC	TBD	—	—	1,600	—	-1,600
TPC	**TBD**	—	—	**1,600**	**1,000**	-600
14-SC-60, U.S. Contributions to ITER						
TEC	TBD	1,117,617	122,000	132,000	107,000	-25,000
OPC	TBD	70,302	—	—	—	—
TPC	**TBD**	**1,187,919**	**122,000**	**132,000**	**107,000**	**-25,000**
Total, Construction						
TEC	**TBD**	**1,117,617**	**122,000**	**132,000**	**108,000**	**-24,000**
OPC	**TBD**	**70,302**	**—**	**1,600**	**—**	**-1,600**
TPC	**TBD**	**1,187,919**	**122,000**	**133,600**	**108,000**	**-25,600**

Funding Summary

(dollars in thousands)

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Research	272,447	261,950	199,250	-62,700
Facility Operations	124,664	143,500	82,500	-61,000
Projects	122,000	148,346	120,000	-28,346
Other (GPP, GPE, and Infrastructure)	13,000	10,204	1,000	-9,204
Total, Fusion Energy Sciences	**532,111**	**564,000**	**402,750**	**-161,250**

Fusion Energy Sciences
Scientific User Facility Operations and Research

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.

(dollars in thousands)

	FY 2018 Enacted	FY 2018 Current	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
TYPE A FACILITIES					
DIII-D National Fusion Facility	**$114,915**	**$111,180**	**$121,500**	**$84,500**	**-37,000**
Number of Users	603	673	673	600	-73
Achieved operating hours	N/A	812	N/A	N/A	N/A
Planned operating hours	720	720	480	520	+40
Optimal hours	720	720	480	800	+320
Percent optimal hours	100%	112.8%	100%	65.0%	-35%
Unscheduled downtime hours	N/A	N/A	N/A	N/A	N/A

(dollars in thousands)

	FY 2018 Enacted	FY 2018 Current	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
National Spherical Torus Experiment—Upgrade	**$90,050**	**$88,590**	**$93,000**	**$65,500**	**-$27,500**
Number of Users	390	248	385	307[a]	-78
Achieved operating hours	N/A	N/A	N/A	N/A	N/A
Planned operating hours	—	—	—	—	—
Optimal hours	—	—	—	—	—
Percent optimal hours	N/A	N/A	N/A	N/A	N/A
Unscheduled downtime hours	N/A	N/A	N/A	N/A	N/A
Total Facilities	**$204,965**	**$199,770**	**$214,500**	**$150,000**	**-$64,500**
Number of Users	993	921	1,058	907	-151
Achieved operating hours	N/A	812	N/A	N/A	N/A
Planned operating hours	720	720	480	520	+40
Optimal hours	720	720	480	800	+320
Percent of optimal hours[b]	100%	112.8%	100%	65.0%	-35%
Unscheduled downtime hours	N/A	N/A	N/A	N/A	N/A

Scientific Employment

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Number of permanent Ph.D.'s (FTEs)	933	931	618	-313
Number of postdoctoral associates (FTEs)	116	115	77	-38
Number of graduate students (FTEs)	311	310	206	-104
Other[c]	1,393	1,390	923	-467

[a] While the facility is down, users are still accessing data from previous operational runs to evaluate what is seen in NSTX-U as compared to other devices both domestically and internationally.

[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.

20-SC-61, Matter in Extreme Conditions (MEC) Petawatt Upgrade
SLAC National Accelerator Laboratory
Project is for Design and Construction

1. Summary, Significant Changes, and Schedule and Cost History

Summary

The FY 2020 Request for the Matter in Extreme Conditions (MEC) Petawatt Upgrade project is $1,000,000. The MEC is an experimental research end-station that utilizes the Linac Coherent Light Source (LCLS) Office of Science (SC) User Facility at the SLAC National Accelerator Laboratory. The estimated total project range is $50 million to $200 million. SC plans for the MEC Petawatt Upgrade project to achieve CD-1, "Approve Alternative Selection and Cost Range" in FY 2020.

Significant Changes

This project is a new start in FY 2020 and will be an upgrade to MEC. The project achieved CD-0, "Approve Mission Need" on January, 4, 2019. Other Project Costs funding in FY 2019 will support conceptual design of the MEC Petawatt Upgrade and is expected to continue into FY 2020. When the project achieves CD-1, "Approve Alternative Selection and Cost Range", which is expected in early FY 2020, SC will then initiate TEC design efforts. A Federal Project Director will be assigned to the MEC Petawatt Upgrade project prior to CD-2 approval ("Approved Performance Baseline").

Critical Milestone History

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2020	1/4/2019	3Q FY 2019	1Q FY 2020	TBD	TBD	TBD	TBD	TBD

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 or will be 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

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D	OPC, D&D	OPC, Total	TPC
FY 2020	1,000	—	1,000	1,600	—	1,600	2,600

2. Project Scope and Justification

Scope

The scope of the MEC Petawatt Upgrade is still being formulated. At a minimum, it will include the design and procurement of a petawatt-class laser system and the design, construction, and installation of a new shield wall.

Justification

The FES mission is to build the scientific foundations needed to develop a fusion energy source and to expand the fundamental understanding of matter at very high temperatures and densities. To meet this mission, there is a scientific need for a petawatt or greater laser facility that is currently not available in the U.S. The National Academies of Science, Engineering, and Medicine (NAS) 2017 study titled "Opportunities in Intense Ultrafast Lasers: Reaching for the Brightest Light[a]" found that about 80 percent to 90 percent of the high-intensity laser systems are overseas, and all of the highest powered lasers currently in construction or already built are overseas as well. The report noted that the U.S. is losing ground in a second laser revolution of highly-intense, ultrafast lasers that have broad applications in manufacturing, medicine, and national security. The report makes five recommendations that would improve the nation's position in the field, including a recommendation for the U.S. Department of Energy (DOE) to plan for at least one large-scale, open-access, high-intensity laser facility that leverages other major science infrastructures in the DOE complex.

The NAS report focuses on highly-intense, pulsed petawatt-class lasers (1 petawatt is equal to 1 million billion watts). Such laser beams can drive nuclear reactions, heat and compress matter to mimic conditions found in stars, and create electron-positron plasmas. In addition to curiosity-driven science, petawatt-class lasers can generate particle beams with potential applications in cancer radiation therapy, intense neutron and gamma ray beams for homeland security applications, directed energy for Department of Defense (DOD) applications, and extreme ultraviolet lithography (EUV) radiation.

Co-location of high-intensity lasers with existing infrastructure such as particle accelerators has been recognized as a key advantage of the U.S. laboratories over the Extreme Light Infrastructure (ELI) concept in Europe. A laser facility with high-power, high-intensity beam parameters that is co-located with hard X-ray laser probing capabilities (i.e. with an X-ray wavelength that allows atomic resolution) will provide the required diagnostic capabilities for fusion discovery science and related fields. This co-location enables novel pump-probe experiments with the potential to dramatically improve our understanding of the ultrafast response of materials in extreme conditions, e.g., found in the environment of fusion plasmas, astrophysical objects, and highly stressed engineering materials. Recent research on ultrafast pump-probe experiments using the Linac Coherent Light Source (LCLS) at the SLAC National Accelerator Laboratory has demonstrated exquisite ultrafast measurements of the material structural response to radiation, but higher flux sources of deuterons, neutrons, and gamma rays are needed to properly emulate the environment and physics processes that occur in materials next to fusion plasmas. This strategy holds the potential to validate inter-atomic potentials in molecular dynamics simulations of materials to enable long-term predictions of the material behavior in fusion facilities.

FES is seeking to develop a new, world-class petawatt laser capability to address the FES mission and the recommendations from the NAS report.

The project will be conducted in accordance with the project management requirements in DOE O 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.

Performance Measure	Threshold	Objective
TBD	TBD	TBD

[a] https://www.nap.edu/catalog/24939/opportunities-in-intense-ultrafast-lasers-reaching-for-the-brightest-light

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design			
FY 2020	1,000	1,000	1,000
Total, Design	TBD	TBD	TBD
Construction			
FY 2020	—	—	—
Total, Construction	TBD	TBD	TBD
Total Estimated Costs (TEC)			
FY 2020	1,000	1,000	1,000
Total, TEC	**TBD**	**TBD**	**TBD**
Other Project Costs (OPC)			
FY 2019	1,600	1,600	1,600
FY 2020	—	—	—
Total, OPC	**TBD**	**TBD**	**TBD**
Total Project Costs (TPC)			
FY 2020	2,600	2,600	2,600
Total, TPC	**TBD**	**TBD**	**TBD**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	TBD	TBD	TBD
Contingency	TBD	TBD	TBD
Total, Design	TBD	TBD	TBD
Construction			
Site Work	TBD	TBD	TBD
Equipment	TBD	TBD	TBD
Construction	TBD	TBD	TBD
Other, as needed	TBD	TBD	TBD
Contingency	TBD	TBD	TBD
Total, Construction	TBD	TBD	TBD
Other TEC			
Cold Startup	TBD	TBD	TBD
Contingency	TBD	TBD	TBD
Total, Other TEC	TBD	TBD	TBD
Total, TEC	TBD	TBD	TBD
Contingency, TEC	*TBD*	*TBD*	*TBD*

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Other Project Costs (OPC)			
OPC except D&D			
R&D	TBD	TBD	TBD
Conceptual Planning	TBD	TBD	TBD
Conceptual Design	TBD	TBD	TBD
Other OPC Costs	TBD	TBD	TBD
Contingency	TBD	TBD	TBD
Total, OPC	TBD	TBD	TBD
Contingency, OPC	*TBD*	*TBD*	*TBD*
Total Project Costs	TBD	TBD	TBD
Total Contingency (TEC+OPC)	*TBD*	*TBD*	*TBD*

5. Schedule of Appropriation Requests

(dollars in thousands)

Request	Type	Prior	FY 2019	FY 2020	Outyears	Total
FY 2020	TEC	N/A	—	1,000	TBD	TBD
	OPC	N/A	1,600	—	TBD	TBD
	TPC	N/A	1,600	1,000	TBD	TBD

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy (fiscal quarter or date)	1Q FY 2026
Expected Useful Life (number of years)	TBD
Expected Future Start of D&D of this capital asset (fiscal quarter)	1Q FY 2045

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Previous Total Estimate	Current Total Estimate	Previous Total Estimate	Current Total Estimate
Operations and Maintenance	TBD	TBD	TBD	TBD

7. D&D Information

The new area being constructed for this project is under analysis at this time.

	Square Feet
New area being constructed by this project at SLAC National Accelerator Laboratory	TBD
Area of D&D in this project at SLAC National Accelerator Laboratory	TBD
Area at SLAC National Accelerator Laboratory to be transferred, sold, and/or D&D outside the project, including area previously "banked"	TBD
Area of D&D in this project at other sites	TBD
Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked"	TBD
Total area eliminated	TBD

8. Acquisition Approach

An Acquisition Strategy has not yet been formulated, but will be completed prior to seeking Critical Decision 2 approval.

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

1. Summary, Significant Changes, and Schedule and Cost History

Summary

The FY 2020 Request for the U.S. ITER project is $107,000,000. ITER is a major fusion research facility being constructed in Saint-Paul-lez-Durance, France by an international partnership of seven Members or Domestic Agencies: U.S., China, European Union, India, the Republic of Korea, Japan, and the Russian Federation, that comprise 34 countries. Since it will not result in a facility owned by the U.S. or located in the U.S., the U.S. ITER project is not classified as a Capital Asset Project, but is classified as a Major System Project. It is a U.S. Department of Energy (DOE) project to provide the U.S. share of ITER construction, classified as in-kind hardware (i.e., subsystems, equipment, and components), as well as financial resources to support the ITER Organization (IO), as delineated in the Joint Implementation Agreement (JIA). Sections of this Construction Project Data Sheet (CPDS) have been tailored accordingly to reflect the unique nature of the U.S. ITER project.

Critical Decision (CD) CD-0, "Approve Mission Need" was signed on July 5, 2005. CD-1, "Approve Alternative Selection and Cost Range," was approved on January 25, 2008, with a preliminary cost range of $1.45 billion to $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 was subsequently approved by the PME on January 13, 2017. The CD-1 Revised cost range is now $4.7 billion to $6.5 billion.

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) completing fabrication and delivery of the Toroidal Field (TF) superconductor; completing fabrication and delivery of the Steady-State Electrical Network (SSEN), and the Central Solenoid (CS) superconducting magnet modules, assembly tooling, and associated structures; and 3) completing the partial fabrication of and delivering seven other subsystems: Tokamak Cooling Water, Roughing Pumps, Vacuum Auxiliary, Pellet Injection, Ion Cyclotron Heating, Electron Cyclotron Heating, and two of seven Diagnostics. An independent 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 $2.5 billion, 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.

Subproject 2 (SP-2) is the second element of the U.S. ITER project, and includes the remainder of U.S. hardware contributions for Post-First Plasma operations leading up to Deuterium-Tritium Operations. SP-2 is planned to be baselined at a future timeframe (e.g., FY 2021/2022).

The financial contributions to the IO operational costs during construction are shared among the seven Members, pursuant to the ITER JIA, and is the third element of the U.S. ITER Total Project Cost.

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 (ORNL), in partnership with Princeton Plasma Physics Laboratory (PPPL) and the Savannah River National Laboratory (SRNL). The project began as a Major Item of Equipment (MIE) in FY 2006, and was changed to a Congressional control point Line-Item construction project in FY 2014. The principles and practices of DOE Order 413.3B are applied in the effective management of the U.S. ITER project, including Critical Decision approvals; establishment of Key Performance Parameters; and the application of Earned Value Management. SC applies the requirements for project documentation, monitoring and reporting, change control, and regular independent project reviews (IPRs) with the same degree of rigor as other SC line-item projects. The USIPO regularly reports progress and performance in monthly performance metrics and project status reports.

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

Significant Changes

This CPDS is an update of the FY 2019 CPDS and does not include a new start for FY 2020. The First Plasma subproject (SP-1), which includes fabrication and delivery of all hardware required for First Plasma and the completion of design for all U.S. hardware contributions, is more than 56% complete.

The FY 2020 Request will support the continued design and fabrication of the highest priority “in-kind” hardware systems. This includes continued fabrication of the Central Solenoid (CS) magnet system, which consists of seven superconducting magnet modules, structural components, and assembly tooling. In FY 2020, the U.S. will deliver the first CS magnet module (Module 1) to the ITER site, as well as continue design and fabrication efforts associated with other “in-kind” hardware systems. The U.S. ITER project has obligated $980 million through the end of FY 2018 to U.S. industry, universities, and DOE laboratories.

Critical Milestone History

Fiscal Year	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
FY 2014	7/5/2005		1/25/2008	TBD	12/10/2013[j]	TBD	N/A	2034
FY 2015	7/5/2005		1/25/2008	TBD		TBD	N/A	2036
FY 2016[k]	7/5/2005		1/25/2008	TBD		TBD	N/A	TBD
FY 2017[l]	7/5/2005		1/25/2008	TBD		TBD	N/A	TBD

CD-0 – Approve Mission Need
CD-1 – Approve Alternative Selection, and Cost Range
CD-2 – Approve Performance Baseline
CD-3 – Approve Start of Fabrication
CD-4 – Approve Project Completion

[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).
[j] CS Modules and Structures (11/18/2013); VAS Main Piping B-2, L-1, L-2 (12/10/2013).
[k] CS AT Remaining Items (12/02/2015).
[l] Roughing Pumps (03/2017); VAS 03 Supply (07/2017); Roughing Pumps I&C (04/2017); VAS 03 Supply I&C (07/2017); 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).

Fiscal Year	Performance Baseline Validation	CD-1 Cost Range Update	CD-2/3		CD-4	
			SP-1	SP-2	SP-1	SP-2
FY 2018[a]	7/5/2005	1/13/17	1/13/17	2019	1Q FY 2027	2034–2038
FY 2019	7/5/2005	1/13/17	1/13/17	2019	1Q FY 2027	2034–2038
FY 2020	7/5/2005	1/13/17	1/13/17	2021/2022	1Q FY 2028	2034–2038

Project Cost History

At the time of CD-1 approval in January 2008, the preliminary cost range was $1.45 to $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 poor project management and leadership issues in the ITER Organization) have affected the project cost and schedule. 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 $6.5 billion would likely encompass the final total TPC. This range, recommended in 2013, was included in subsequent President's Budget Requests. In May 2016, DOE provided a "Report on the Continued U.S. Participation in the ITER Project" to Congress, which stated that the First Plasma part of the U.S. ITER project would be baselined in FY 2017. In preparation for baselining SP-1, based on the results of the IPR, a decision was made by the acting SC-1 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 $6.5 billion. 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 $2.5 billion.

Subproject 1 (First Plasma Hardware for US ITER)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D	OPC, D&D	OPC, Total	TPC
FY 2017[b]	696,025	1,723,334	2,419,359	80,641	N/A	80,641	2,500,000
FY 2018	696,025	1,723,334	2,419,359	80,641	N/A	80,641	2,500,000
FY 2019	696,025	1,723,334	2,419,359	80,641	N/A	80,641	2,500,000
FY 2020	696,025	1,733,673	2,429,698	70,302	N/A	70,302	2,500,000

2. Project Scope and Justification

Introduction

ITER is an international partnership among seven Members (China, the European Union, India, Japan, the Republic of Korea, the Russian Federation, and the U.S.) 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 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.

[a] VAS 02 Supply Part 1 (05/2018); ICH RF Building and I&C (11/2017); TCWS Captive Piping and First Plasma (11/2017); ICH RF components supporting INDA/IO testing (01/2018).
[b] Prior to FY2017 the TPC for U.S. ITER was reported as "TBD"; estimates reported beginning in FY 2017 represent the validated baseline values for Subproject 1 First Plasma Hardware. These values for the SP-1 baseline have not been updated to reflect impacts from FY 2017 and FY 2018 funding reductions and allocations.

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 hardware to ITER, the technical components of which are split between SP-1 (First Plasma) and SP-2 (Post-First Plasma). The percentage of hardware components to be delivered in each system for SP-1 are indicated for each system:

- Tokamak Cooling Water System (TCWS): manages the thermal energy generated during the operation of the tokamak. (58% of system for SP-1)
- 15% of ITER Diagnostics: provides the measurements necessary to control, evaluate, and optimize plasma performance and to further the understanding of plasma physics. (6% for SP-1)
- Disruption Mitigation (DM) Systems: limits the impact of plasma disruptions to the tokamak vacuum vessel, blankets, and other components. All of DM design is done in SP-1.
- 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. (55% for SP-1)
- Tokamak Exhaust Processing (TEP) System: separates hydrogen isotopes from tokamak exhaust. (All of TEP design is done in SP-1)
- Tokamak Fueling System (Pellet Injection): injects fusion fuels in the form of deuterium-tritium ice pellets into the vacuum chamber. (9% for SP-1)
- Ion Cyclotron Heating (ICH) Transmission Lines: bring additional power to the plasma. (15% for SP-1)
- 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. (85% for SP-1)
- Roughing Pumps: evacuate the tokamak, cryostat, and auxiliary vacuum chambers prior to and during operations. (56% for SP-1)

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.

Key Performance Parameters (KPPs)

The U.S. ITER project will not deliver an integrated operating facility, but rather in-kind hardware contributions, which represent a portion of the subsystems for the international ITER facility. Therefore, typical KPPs are not practical for this type of project. The U.S. ITER project defines project completion as delivery and IO acceptance of the U.S. in-kind hardware. For SP-1, in some cases (e.g., Tokamak Exhaust Processing and Disruption Mitigation), only the completion of the design is required, which requires IO approval of the final designs. Below is the list of SP-1 deliverables that were approved when the SP-1 baseline was approved.

Table 1. SP-1 In-Kind Hardware Description

System/Subsystem	Description
Central Solenoid Magnet System	Provide 7 (including spare) independent coil packs made of superconducting niobium-tin providing 13 Tesla at 45 kA, the vertical pre- compression structure, and assembly tooling.
Toroidal Field Magnet Conductor	Provide 9 active lengths (~765m), 1 dummy length (~765m) for winding trials and 2 active lengths (~100m each) for superconducting qualification.
Steady State Electrical Network	Provide components for a large AC power distribution system (transformers, switches, circuit breakers, etc.) at high-voltage (400kV) and medium-voltage (22kV) levels.
Tokamak Cooling Water System	Provide Final Designs for major industrial components (heat exchangers, pumps, valves, pressurizers, etc.) capable of removing 1 GW of heat. Among those components, also fabricate and deliver certain IO-designated items.
Diagnostics	Provide Final Designs for 4 diagnostic port plugs and 7 instrumentation systems (Core Imaging X-ray Spectrometer, Electron Cyclotron Emission Radiometer, Low Field Side Reflectometer, Motional Stark Effect Polarimeter, Residual Gas Analyzer, Toroidal Interferometer/Polarimeter, and Upper IR/Visible Cameras). Among those components, also fabricate and deliver certain IO-designated items.
Electron Cyclotron Heating Transmission Lines	Provide Final Designs for approximately 4 km of aluminum waveguide lines (24 lines) capable of transmitting up to 1.5 MW per line. Among those components, also fabricate and deliver certain IO-designated items.
Ion Cyclotron Heating Transmission Lines	Provide Final Designs for approximately 1.5 km of coaxial transmission lines (8 lines) capable of transmitting up to 6 MW per line. Among those components, also fabricate and deliver certain IO-designated items.
Pellet Injection System	Provide Final Designs for injector system capable of delivering deuterium/tritium fuel pellets up to 16 times per second. Among those components, also fabricate and deliver certain IO-designated items.
Vacuum Roughing Pumps	Provide Final Designs for a matrix of pump trains consisting of approximately 400 vacuum pumps. Among those components, also fabricate and deliver certain IO-designated items.
Vacuum Auxiliary Systems	Provide Final Designs for vacuum system components (valves, pipe manifolds, auxiliary pumps, etc.) and approximately 6 km of vacuum piping. Among those components, also fabricate and deliver certain IO-designated items.
Tokamak Exhaust Processing System	Provide Final Designs for an exhaust separation system for hydrogen isotopes and non-hydrogen gases.
Disruption Mitigation System	Provide design, and research and development (R&D) (up to a limit of $25M*[a]) for a system to mitigate plasma disruptions that could cause damage to the tokamak inner walls and components.

[a] Any additional costs would be funded by the ITER organization.

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC) [a]			
Hardware			
FY 2006	13,754	13,754	6,169
FY 2007	36,588	36,588	24,238
FY 2008	23,500	23,500	24,121
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]	91,453	91,441	99,249
FY 2013	107,635	107,669	110,074
FY 2014[c]	166,605	166,605	153,995
FY 2015	134,043	134,043	114,129
FY 2016[d]	115,000	115,000	106,519
FY 2017	50,000	50,000	123,117
FY 2018	122,000	122,000	98,185
FY 2019	117,000	117,000	107,435
FY 2020	107,000	107,000	117,182
Subtotal	1,319,120	1,319,142	1,241,064
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[f]	13,214	13,214	13,214
FY 2013	13,805	13,805	13,805
FY 2014[c]	32,895	32,895	32,895
FY 2015	15,957	15,957	15,957
FY 2016	—	—	—
FY 2017	—	—	—
FY 2018	—	—	—
FY 2019	15,000	15,000	15,000
FY 2020	—	—	—
Subtotal	159,497	159,497	159,497
Total, Cash Contributions	TBD	TBD	TBD

[a] Costs through FY 2017 reflect actual costs; costs for FY 2019 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] Prior actuals adjusted to incorporate project funds utilized at PPPL and DOE. Obligation adjusted to reflect year-end PPPL settlement funding.

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Hardware and Cash Contributions			
FY 2006	15,866	15,866	8,281
FY 2007	44,000	44,000	31,650
FY 2008	26,144	26,144	26,765
FY 2009	109,000	109,000	49,877
FY 2010	115,000	115,000	75,786
FY 2011	67,000	67,000	87,446
FY 2012	104,667	104,655	112,463
FY 2013	121,440	121,474	123,879
FY 2014	199,500	199,500	186,890
FY 2015	150,000	150,000	130,086
FY 2016	115,000	115,000	106,519
FY 2017	50,000	50,000	123,117
FY 2018	122,000	122,000	98,185
FY 2019	132,000	132,000	122,435
FY 2020	107,000	107,000	117,182
Subtotal	1,478,617	1,478,639	1,400,561
Total, TEC	**TBD**	**TBD**	**TBD**
Other Project Costs (OPC)[a]			
FY 2006	3,449	3,449	1,110
FY 2007	16,000	16,000	7,606
FY 2008	-74	-74	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[b]	333	311	22,302
FY 2013	2,560	2,560	5,984
FY 2014[c]	—	—	2,090
FY 2015	—	—	600
FY 2016	34	34	–
FY 2017	—	-50	58
FY 2018	—	—	2
Subtotal	70,302	70,230	70,123
Total, OPC	**TBD**	**TBD**	**TBD**
Total Project Costs (TPC) [d]			
FY 2006	19,315	19,315	9,391
FY 2007	60,000	60,000	39,256
FY 2008	26,070	26,070	34,278
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[b]	105,000	104,966	134,765

[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] Costs through FY 2017 reflect actual costs; costs for FY 2018 and the outyears are estimates.

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
FY 2013	124,000	124,034	129,863
FY 2014[c]	199,500	199,500	188,980
FY 2015	150,000	150,000	130,686
FY 2016	115,034	115,034	106,519
FY 2017	50,000	49,950	123,175
FY 2018	122,000	122,000	98,187
FY 2019	132,000	132,000	122,435
FY 2020	107,000	107,000	117,182
Subtotal	1,548,919	1,548,869	1,470,684
Total, TPC	**TBD**	**TBD**	**TBD**

4. Details of Project Cost Estimate

The project has an approved updated CD-1 Cost Range, and DOE has chosen to divide the project hardware scope into two distinct subprojects (FP SP-1, and Post-FP SP-2). The baseline for SP-1 was approved in January 2017. Baselining of SP-2 will follow when the Administration has made a decision about whether the U.S. commitment to ITER. No procurements for SP-2 scope are anticipated until FY 2022 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 for 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 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 ($4.0 to $6.5 billion) 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 billion to $6.5 billion.

Subproject – 1 First Plasma Hardware Only

(dollars in thousands)

	Current Total Estimate[a]	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	573,660	—	573,660
Contingency	122,365	—	122,365
Total, Design	696,025	—	696,025
Construction			
Equipment	1,362,521	—	1,362,521
Contingency	371,152	—	371,152
Total, Construction	1,733,673	—	1,733,673
Total, TEC	2,429,698	—	2,429,698
Contingency, TEC	*493,517*	—	*493,517*

[a] The estimate value reflected here has not been adjusted to reflect the FY 2017 and FY 2018 appropriations.

Subproject – 1 First Plasma Hardware Only

(dollars in thousands)

	Current Total Estimate[a]	Previous Total Estimate	Original Validated Baseline
Other Project Cost (OPC)			
OPC except D&D			
Other OPC Costs	70,302	—	70,302
Total, OPC	70,302	—	70,302
Total Project Cost[a]	**2,500,000**	**—**	**2,500,000**
Total, Contingency (TEC+OPC)	***493,517***	**—**	***493,517***

5. Schedule of Appropriation Requests

(dollars in thousands)

Request	Type	Prior	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2006	TEC	1,038,000	—	—	—	—	—	—	—	1,038,000
	OPC	84,000	—	—	—	—	—	—	—	84,000
	TPC	1,122,000	—	—	—	—	—	—	—	1,122,000
FT 2007	TEC	1,077,051	—	—	—	—	—	—	—	1,077,051
	OPC	44,949	—	—	—	—	—	—	—	44,949
	TPC	1,122,000	—	—	—	—	—	—	—	1,122,000
FY 2008	TEC	1,078,230	—	—	—	—	—	—	—	1,078,230
	OPC	43,770	—	—	—	—	—	—	—	43,770
	TPC	1,122,000	—	—	—	—	—	—	—	1,122,000
FY 2009[b]	TEC	266,366	—	—	—	—	—	—	—	TBD
	OPC	38,075	—	—	—	—	—	—	—	TBD
	TPC	304,441	—	—	—	—	—	—	—	TBD
FY 2010	TEC	294,366	—	—	—	—	—	—	—	TBD
	OPC	70,019	—	—	—	—	—	—	—	TBD
	TPC	364,385	—	—	—	—	—	—	—	TBD
FY 2011	TEC	379,366	—	—	—	—	—	—	—	TBD
	OPC	65,019	—	—	—	—	—	—	—	TBD
	TPC	444,385	—	—	—	—	—	—	—	TBD
FY 2012[c]	TEC	394,366	—	—	—	—	—	—	—	TBD
	OPC	75,019	—	—	—	—	—	—	—	TBD
	TPC	469,385	—	—	—	—	—	—	—	TBD
FY 2013[d]	TEC	617,261	—	—	—	—	—	—	—	TBD
	OPC	82,124	—	—	—	—	—	—	—	TBD
	TPC	699,385	—	—	—	—	—	—	—	TBD

[a] The TPC reported here is only for Subproject 1 (and does not include Subproject 2 or cash contributions estimates), prior to FY 2017 the Total Project Cost for US ITER was identified as "TBD".

[b] 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.

[c] 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.

[d] 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.

(dollars in thousands)

Request	Type	Prior	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2014[a]	TEC	806,868	—	—	—	—	—	—	—	TBD
	OPC	73,159	—	—	—	—	—	—	—	TBD
	TPC	880,027	—	—	—	—	—	—	—	TBD
FY 2015	TEC	942,578	—	—	—	—	—	—	—	TBD
	OPC	80,341	—	—	—	—	—	—	—	TBD
	TPC	1,022,919	—	—	—	—	—	—	—	TBD
FY 2016	TEC	1,092,544	—	—	—	—	—	—	—	TBD
	OPC	80,341	—	—	—	—	—	—	—	TBD
	TPC	1,172,885	—	—	—	—	—	—	—	TBD
FY 2017	TEC	1,182,578	—	—	—	—	—	—	—	TBD
	OPC	80,341	—	—	—	—	—	—	—	TBD
	TPC	1,262,919	—	—	—	—	—	—	—	TBD
FY 2018	TEC	1,107,244	63,000	—	—	—	—	—	—	TBD
	OPC	80,641	—	—	—	—	—	—	—	TBD
	TPC	1,187,885	63,000	—	—	—	—	—	—	TBD
FY 2019	TEC	1,107,244	63,000	75,000	—	—	—	—	—	TBD
	OPC	80,641	—	—	—	—	—	—	—	TBD
	TPC	1,187,885	63,000	75,000	—	—	—	—	—	TBD
FY 2020	TEC	1,117,617	122,000	132,000	107,000	—	—	—	—	TBD
	OPC	70,302	—	—	—	—	—	—	—	TBD
	TPC	1,187,919	122,000	132,000	107,000	—	—	—	—	TBD

6. 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

7. D&D Information

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.

8. Acquisition Approach

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

[a] Prior to FY 2015, the requests were for a major item of equipment broken out by TEC, OPC, and TPC.

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.

An international enterprise 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 report, which 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, 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 Experimental Physics, 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 Experimental Physics, 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 Experimental Physics, 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.

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[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

HEP's Theoretical, Computational, and Interdisciplinary Physics (formerly Theoretical and Computational Physics) and Advanced Technology Research and Development (R&D) subprograms formulate and enable scientific discovery. The Theoretical, Computational, and Interdisciplinary 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 in high performance computing and Artificial Intelligence (AI)-Machine Learning (ML). Quantum Information Science (QIS) is a rapidly-developing, inter-disciplinary field, and HEP QIS efforts are aligned with the National Quantum Initiative and DOE priorities in this area. The HEP QIS research program promotes the co-development of quantum information, theory, and technology with the science drivers and opens prospects for new capabilities in sensing, simulation, and computing. In support of the National Quantum Initiative, at least one SC QIS Center will be established through a partnership between the HEP, Advanced Scientific Computing Research (ASCR), and Basic Energy Sciences (BES) programs. This partnership will be coupled with a robust core research portfolio stewarded by the individual SC programs including HEP, and will create the ecosystem across universities, national laboratories, and industry that is needed to developments in QIS and related technology.

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 Accelerator 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 2020 Request
The HEP FY 2020 Request for $768,038,000 focuses resources toward the highest priorities in fundamental research, operation and maintenance of scientific user facilities, facility upgrades, and projects identified in the P5 report.

Key elements in the FY 2020 Request include:

Research supports university and laboratory researchers to preserve critical core competencies, enable high priority theoretical and experimental activities in pursuit of discovery science, explore the potential of QIS and AI-ML, and invest in high-performance computing and preparing for exascale, and world-leading R&D that requires long-term investments. These include:

- U.S. responsibilities and leadership roles in the A Toroidal LHC Apparatus (ATLAS) and Compact Muon Solenoid (CMS) experiments at the LHC. To prepare for a ramp up to higher particle collision energy, the installation and commissioning of the upgrades to the ATLAS and CMS detectors will continue during the scheduled two-year long LHC technical stop from January 2019 to December 2020;
- U.S.-hosted, world-leading neutrino and muon physics experiments at Fermi National Acceleratory Laboratory (Fermilab), consisting of the Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment (LBNF/DUNE), the related Short-Baseline Neutrino (SBN) program, Muon g-2, and the Muon to Electron Conversion Experiment (Mu2e);

- U.S. responsibilities and leadership roles in world-leading, next-generation experiments to advance our understanding of the nature of dark energy and cosmic acceleration during inflation in the early universe, and the search for dark matter particles;
- Theoretical research, intertwining the physics of the Higgs boson, neutrino masses, the dark universe, and exploring the unknown;
- QIS R&D to accelerate discovery in particle physics while advancing the national effort;
- HEP, in partnership with SC's ASCR and BES programs, will establish at least one multi-disciplinary QIS center to accelerate the advancement of QIS through vertical integration between systems and theory, and hardware and software. The scope of the QIS Center will include work on sensors, quantum emulators/simulators, and enabling technologies that will pave the path to exploit quantum computing and qubit technology in the longer term;
- Artificial Intelligence (AI)-Machine Learning (ML) research to tackle the challenges of managing increasingly high volumes and complexity of experimental and simulated data across the HEP experimental frontiers, theory, and technology thrusts, and to address cross-cutting challenges across the HEP program in coordination with DOE investments in exascale computing and associated AI efforts;
- World-leading Advanced Technology R&D that will enable transformative technology for the next-generation of accelerators and particle detectors and the training of experts who build them. The HEP General Accelerator R&D (GARD) activity will increase support for the Traineeship Program for Accelerator Science and Technology 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; and,
- Accelerator Stewardship 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.

Facility Operations includes funding for the operations of the HEP scientific user facilities and other facility operation costs. Requested funding directs efforts to enable world-class science and the optimization of existing capabilities. This includes:

- Operation of the Fermilab Accelerator Complex for 4,200 hours (88% of optimal);
- Operation of the Brookhaven National Laboratory (BNL) Accelerator Test Facility (ATF) for 1,845 hours (74% of optimal);
- Commissioning, installation, and 1,500 hours of initial operation (50% of optimal) for Facility for Advanced Accelerator Experimental Tests II (FACET-II);
- New Fermilab Kautz Road Sub-Station General Plant Project (GPP), which will replace or upgrade existing electrical feeders that serve the Main Ring area of the site;
- Sanford Underground Research Facility (SURF) services to enable commissioning of the Large Underground Xenon (LUX)-ZonED Proportional Scintillation in Liquid Noble gases (Zeplin) (LUX-ZEPLIN) (LZ) dark matter experiment, to continue operations of the neutrino-less double beta decay Majorana Demonstrator, and to make investments to enhance SURF infrastructure;
- Refresh of computing resources at the U.S. Tier 1 centers at Fermilab and BNL; and,
- Commissioning, facilities, and pre-operations activities at the Large Synoptic Survey Telescope (LSST) telescope facility in Chile, and science operations of Dark Energy Spectroscopic Instrument (DESI), installed on the Mayall telescope in Arizona.

Construction, Major Items of Equipment (MIEs), and Future Project R&D includes:

- Continued investments in the LHC by contributing to the U.S. share of the High-Luminosity (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 its current reach;
- Support for LBNF/DUNE, which will enable the Critical Decision (CD)-3A approved scope for the pre-construction activities: the Far Site excavation of the underground equipment caverns and connecting drifts (tunnels); design and procurement activities for the Far Site cryogenics systems; LBNF Near Site (Fermilab) beamline and conventional facilities design; and a site-preparation construction subcontract at the Near Site for relocation of existing service roads and utilities, including communications, power and water systems;
- Support for Proton Improvement Plan II (PIP-II), which will enable engineering design work for conventional facilities and technical systems, continuation of site-preparation activities, and initiation of construction for cryogenic plant support systems, and continued fabrication of prototype accelerator system components; and

- Technology R&D and pre-conceptual design studies for the next generation Cosmic Microwave Background (CMB S4) experiment

High Energy Physics supports the following FY 2020 Administration Priorities.

FY 2020 Administration Priorities

	(dollars in thousands)	
	Artificial Intelligence (AI)	**Quantum Information Science (QIS)**
High Energy Physics	15,000	38,308

High Energy Physics
Funding

	(dollars in thousands)			
	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Energy Frontier Experimental Physics				
Research	79,530	76,530	52,510	-24,020
Facility Operations and Experimental Support	54,340	52,000	44,480	-7,520
Projects	51,000	105,000	96,935	-8,065
SBIR/STTR	6,068	5,390	3,674	-1,716
Total, Energy Frontier Experimental Physics	**190,938**	**238,920**	**197,599**	**-41,321**
Intensity Frontier Experimental Physics				
Research	60,700	61,646	41,370	-20,276
Facility Operations and Experimental Support	153,385	155,035	136,681	-18,354
Projects	24,100	16,000	9,000	-7,000
SBIR/STTR	8,583	8,299	6,631	-1,668
Total, Intensity Frontier Experimental Physics	**246,768**	**240,980**	**193,682**	**-47,298**
Cosmic Frontier Experimental Physics				
Research	49,892	50,741	31,140	-19,601
Facility Operations and Experimental Support	16,310	20,076	23,230	+3,154
Projects	52,400	27,350	1,000	-26,350
SBIR/STTR	2,644	2,869	2,098	-771
Total, Cosmic Frontier Experimental Physics	**121,246**	**101,036**	**57,468**	**-43,568**
Theoretical, Computational, and Interdisciplinary Physics (formerly Theoretical and Computational Physics)				
Research				
Theory	47,803	45,760	32,650	-13,110
Computational HEP	9,500	13,351	20,290	+6,939
Quantum Information Science	18,000	27,500	38,308	+10,808
Total, Research	75,303	86,611	91,248	+4,637
SBIR/STTR	2,853	3,223	3,457	+234
Total, Theoretical, Computational, and Interdisciplinary Physics (formerly Theoretical and Computational Physics)	**78,156**	**89,834**	**94,705**	**+4,871**

	(dollars in thousands)			
	FY 2018 Enacted	**FY 2019 Enacted**	**FY 2020 Request**	**FY 2020 Request vs FY 2019 Enacted**
Advanced Technology R&D				
Research				
HEP General Accelerator R&D	46,500	48,447	40,873	-7,574
HEP Directed Accelerator R&D	5,000	—	—	—
Detector R&D	19,257	23,694	16,700	-6,994
Total, Research	70,757	72,141	57,573	-14,568
Facility Operations and Experimental Support	30,500	27,625	30,878	+3,253
Projects	10,000	10,000	—	-10,000
SBIR/STTR	3,705	3,740	3,256	-484
Total, Advanced Technology R&D	**114,962**	**113,506**	**91,707**	**-21,799**
Accelerator Stewardship				
Research	9,000	9,083	7,930	-1,153
Facility Operations and Experimental Support	6,000	6,067	4,477	-1,590
SBIR/STTR	530	574	470	-104
Total, Accelerator Stewardship	**15,530**	**15,724**	**12,877**	**-2,847**
Subtotal, High Energy Physics	**767,600**	**800,000**	**648,038**	**-151,962**
Construction				
18-SC-42 Proton Improvement Plan II, FNAL	1,000	20,000	20,000	—
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment, FNAL	95,000	130,000	100,000	-30,000
11-SC-41, Muon to Electron Conversion Experiment, FNAL	44,400	30,000	—	-30,000
Total, Construction	**140,400**	**180,000**	**120,000**	**-60,000**
Total, High Energy Physics	**908,000**	**980,000**	**768,038**	**-211,962**

SBIR/STTR Funding:

- FY 2018 Enacted: SBIR $21,377,000 and STTR $3,006,000
- FY 2019 Enacted: SBIR $21,124,000 and STTR $2,971,000
- FY 2020 Request: SBIR $17,171,000 and STTR $2,415,000

High Energy Physics
Explanation of Major Changes

	(dollars in thousands) FY 2020 Request vs FY 2019 Enacted
Energy Frontier Experimental Physics The Request will continue support for the HL-LHC ATLAS and HL-LHC CMS Detector Upgrade Projects and will continue preparing for project baseline approval, and the HL-LHC Accelerator Upgrade Project will continue magnet fabrication and production of radio-frequency cavities. The Request will prioritize support to Research activities that address the Higgs boson, new directions in dark matter, and will continue the participation of U.S. research contributions to the HL-LHC ATLAS and HL-LHC CMS Detector upgrades. The Request will support completing the commissioning of the LHC ATLAS and CMS Detector Upgrade projects in FY 2020.	**-41,321**
Intensity Frontier Experimental Physics The Request will support the Fermilab Accelerator Complex (88% of optimal) to deliver particle beams and provide experimental operations. The FY 2019 Appropriation provided sufficient funding to complete the Fermilab NuMI Target Systems AIP and Utility Corridor GPP, which results in a decrease in the request for FY 2020. This will be partially offset by support for the Kautz Road Sub-Station GPP starting in FY 2020, and the conclusion of operations of mature experiments that have achieved their science goals. The Request will support work with international partners to reduce technical risks for the PIP-II project and funding for SURF that will support LBNF/DUNE construction. Other Project Costs (OPC) for PIP-II will decrease in FY 2020 since CD-1 was approved in FY 2018 and funding shifts to preliminary design accounted as Total Estimated Costs. The Request will prioritize support for postdoctoral researchers and graduate students engaged in research at the national laboratories and universities with a focus on delivering the final results of completed experiments, and preparing for physics on new experiments.	**-47,298**
Cosmic Frontier Experimental Physics The Request will support an increase for the installation, commissioning, and pre-operations activities for LSSTcam, DESI, LZ, and SuperCDMS-SNOLAB, offset by a decrease in major item of equipment (MIE) projects as the FY 2019 Appropriation provided sufficient funds to complete all remaining deliverables for DESI, LZ, and the Super Cryogenic Dark Matter Search at Sudbury Neutrino Observatory Laboratory (SuperCDMS-SNOLAB) MIEs. The Request will provide a small increase for new support of technology R&D and planning for a future CMB-S4 project. The Request will prioritize research support for postdoctoral researchers and graduate students at the national laboratories and universities with a focus on delivering the final results of completed experiments and preparing for physics on new experiments.	**-43,568**

	(dollars in thousands) FY 2020 Request vs FY 2019 Enacted
Theoretical, Computational, and Interdisciplinary Physics (formerly Theoretical and Computational Physics) The Request will prioritize support to postdoctoral researchers and graduate students who are engaged in theoretical physics research at the national laboratories and universities with a focus on understanding the results of current experiments, supporting new initiatives in neutrino and dark matter physics, and connecting fundamental theory to the development of quantum information science. Computational physics research will increase with a focus on advancing techniques in AI-ML across the HEP experimental frontiers, theory, and technology thrusts, and accelerating HEP access to high performance computing and future exascale computer systems. In the Request, foundational HEP QIS research, quantum simulation experiments, and quantum computing, controls, and sensors will receive increased support. In addition, the FY 2020 Request will enable the establishment of at least one Quantum Information Science Center in partnership with the ASCR and BES programs. This new center's mission will be to apply concepts and technology from relevant foundational core research in each program and foster broader partnerships in support of the SC mission related to QIS.	**+4,871**
Advanced Technology R&D The Request will prioritize support for research activities in superconducting magnet development and ultrafast lasers. The Request also will prioritize support of cross-cutting Accelerator R&D, which leverages synergistic efforts at the national laboratories and Detector R&D which exploits collaborative opportunities between the national laboratories and the universities. The FY 2019 Appropriation provided final funding for the FACET-II MIE. The decrease in project support in FY 2020 will be slightly offset by an increase to support the commissioning and installation of the electron beam systems, 1,500 hours of FACET-II operations, and to improve superconducting radio-frequency (SRF) facilities and capabilities. The Request also includes an increase for the HEP Graduate Traineeship Program for Accelerator Science and Technology.	**-21,799**
Accelerator Stewardship The Request will prioritize support for transformative R&D for security applications and implementing priority R&D topics identified by a Basic Research Needs workshop planned for the spring of 2019. ATF Operations in FY 2020 will be 88% of optimal.	**-2,847**
Construction The Request will continue support for LBNF/DUNE for completion of the pre-excavation activities such as systems to remove the excavated rock to its nearby disposal site; the start of design and procurement activities for cryogenics systems, Near Site beamline and conventional facilities; and U.S. contributions to design and construction of the DUNE detectors. The Request will continue support for PIP-II engineering design work for conventional facilities and technical systems, continuation of site-preparation activities and initiation of construction for cryogenic plant support systems, as well as continued fabrication of prototype accelerator system components. These increases are offset by the conclusion of construction funding for the Muon to Electron Conversion Experiment (Mu2e); the FY 2019 Appropriation provided final funding for this project.	**-60,000**
Total, High Energy Physics	**-211,962**

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 subprogram 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 in the Countering Weapons of Mass Destruction Office (DHS/CWMD), 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 have led to a Basic Research Needs Workshop on Compact Accelerators for Security and Medicine, to be held in May 2019 to establish research priorities for accelerator R&D in this critical area.

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 agencies 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 General Atomics), and technical design studies for high power accelerators for wastewater treatment (joint with Metropolitan Water Reclamation District of Greater Chicago and the Air Force Research Laboratory). Funded R&D awards have drawn an average of 20% of voluntary cost sharing over the first three years of the subprogram, providing evidence of the potential impact.

The HEP QIS research program has coordinated partnerships with the Department of Defense's Office of Basic Research (DOD/OBR), as well as the Air Force's Office of Scientific Research (AFOSR) on synergistic research connecting cosmic black holes with quantum error correction in qubit devices and a partnership with the Department of Commerce's National Institute of Standards and Technology (NIST) on quantum metrology and quantum sensor development for experimental discovery along HEP science drivers and better understanding fundamental constants. These interdisciplinary QIS activities are aligned with the National Quantum Initiative and Office of Science QIS priorities.

Program Accomplishments
Continued record-breaking LHC performance enables first observation of the Higgs boson decaying to quarks (Energy Frontier Experimental Physics). The LHC continued to improve in its delivery of the highest energy particle collisions in the world, again setting new performance records and exceeding its annual goals. Using the LHC, scientists from the ATLAS and CMS collaborations have observed Higgs bosons interacting with the heaviest quarks for the first time. Using AI-ML techniques to enhance their sensitivity, each collaboration observed the Higgs boson decaying to pairs of top quarks and to pairs of bottom quarks. So far, all Higgs boson production and decay mechanisms measured by LHC experiments are in agreement with predictions from the Standard Model. These measurements support the idea that particle interactions with the Higgs boson generate the mass of elementary particles and that the Higgs boson plays a fundamental role in our universe. During the scheduled two-year long LHC technical stop from January 2019 to December 2020, accelerator and detector upgrades will be installed to enable more detailed measurements of the Higgs boson and more sensitive searches for new physics.

First apparatus provided by international partners for the U.S.-hosted international neutrino program is installed at Fermilab (Intensity Frontier Experimental Physics). The largest liquid-argon based neutrino detector in the world, ICARUS, was successfully transported from Europe to Fermilab, where it was installed as the Far Detector for the Short-Baseline Neutrino (SBN) program. The 65 foot long, 760 ton detector was originally installed in the Gran Sasso National Laboratory in Italy then refurbished at CERN, in Switzerland, before beginning a journey by barge, ship, and truck to Fermilab, in Illinois. As part of SBN, scientists will use it in an effort to definitively resolve experimental anomalies in the measured neutrino energy spectrum and search for "sterile" neutrinos that do not directly interact with other forms of matter. SBN also serves to develop and demonstrate the liquid-argon based neutrino detector technology that serves as the basis for the international Deep Underground Neutrino Experiment at the U.S.-hosted Long-Baseline Neutrino Facility now under construction.

Theorists make most precise prediction of how muons wobble as they travel in a powerful magnetic field (Theoretical, Computational, and Interdisciplinary Physics (formerly Theoretical and Computational Physics)). Like their lighter cousin the electron, muons have an intrinsic spin, somewhat analogous to a spinning top. The magnetic moment of a muon determines the amount its spin will wobble as it circulates in a magnetic field. A precise comparison between the prediction and the measurement of this wobble provides a stringent test of the Standard Model where a discrepancy may point to the existence of new particles. A team of physicists has improved this prediction using Lattice Quantum Chromodynamics (QCD), modeling all the possible particle interactions on supercomputers at the Leadership Computing Facility at Argonne National Laboratory and Brookhaven's Computational Sciences Initiative. They combined the simulations with related experimental measurements to produce the highest overall precision prediction to date. To test the Standard Model and search for new physics, the new high-precision prediction will be compared to the results of the ongoing Fermilab Muon g-2 experiment.

Belle II experiment receives first particle collisions from the SuperKEKB accelerator in Japan (Intensity Frontier Experimental Physics). The Belle II experiment will explore the unknown by precisely measuring the properties of particles called B-mesons, which contain bottom quarks. The B-mesons are created by colliding intense beams of electrons and positrons at the SuperKEKB accelerator at the High Energy Accelerator Research Organization (KEK) laboratory in Japan. While the Belle II detector was under fabrication, upgrades transformed the previous KEKB accelerator into SuperKEKB, which will provide 40 times more collisions per second. Belle II recorded the first collisions of the new SuperKEKB collider in April 2018. Scientists will use data from Belle II to study rare B-meson decays, search for new particles, and look for potential differences between matter and antimatter that may explain how the hot, early universe turned into the matter-dominated universe we live in today.

International partnerships continue to grow for LBNF/DUNE (Intensity Frontier Experimental Physics). The U.S.-hosted international LBNF will host massive experiments that may change our understanding of the universe. The international partnerships that support LBNF/DUNE and enable its science continue to grow. The first major project under the United Kingdom (UK)-U.S. Science and Technology Agreement, signed in September 2017, is a UK investment in LBNF/DUNE and the PIP-II accelerator at Fermilab that will enhance the intensity of the LBNF neutrino beam. Project Annex II on Neutrino Research, the signed agreement by DOE and India's Department of Atomic Energy in April 2018, expands previous collaboration on accelerator science to include science for neutrinos. When complete, LBNF/DUNE will be the largest experiment ever built in the U.S. to study the properties of neutrinos and will enable transformative discoveries about their role in the universe.

Description

The Energy Frontier Experimental Physics 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:

- *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. 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 Experimental Physics subprograms.

<u>Research</u>

The Energy Frontier Experimental Physics subprogram's Research activity supports 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 is planned in FY 2019; the next review is planned for FY 2023. In FY 2018, HEPAP evaluated the currently operating portfolio of experiments on the Energy Frontier and assessed the priority of their science output in the context of the science drivers. In early FY 2019, HEP conducted a Basic Research Needs workshop to assess the science landscape and new opportunities for dark matter particle searches and to identify which areas would be suitable for small projects in the HEP program. The findings from these reviews, in combination with input on strategic directions from regular, open community workshops will inform funding decisions in subsequent years.

<u>Facility Operations and Experimental Support</u>

U.S. LHC Detector Operations 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 BNL and Fermilab. 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. Long-term development to analyze large datasets anticipated during future LHC operations are supported, including innovative AI-ML computational techniques.

<u>Projects</u>

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 its current reach. 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 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 2019 Enacted		FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Energy Frontier Experimental Physics	**$238,920,000**	**$197,599,000**	**-$41,321,000**
Research	$76,530,000	$52,510,000	-$24,020,000
The FY 2019 Enacted budget supports U.S. leadership roles in all aspects of the ATLAS and CMS experiments.		The Request will support U.S. scientists leading high profile analysis topics using the large datasets collected by the ATLAS and CMS experiments.	The Request prioritizes ATLAS and CMS research efforts with the highest scientific merit and potential impact based on a competitive peer-review process while continuing participation of U.S. contributions to the HL-LHC ATLAS and HL-LHC CMS Detector upgrades.
Facility Operations and Experimental Support	$52,000,000	$44,480,000	-$7,520,000
The FY 2019 Enacted budget supports 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 begins in 2019.		The Request will support ATLAS and CMS detector maintenance and operations at CERN; the U.S.-based computing infrastructure and resources necessary to store and analyze LHC data; and commissioning activities of U.S.-built detector components.	Support will focus on the completion of the commissioning activities following the installation of the LHC ATLAS and CMS Detector Upgrade projects while demands on the U.S.-based computing infrastructure are reduced during the technical stop as the experiments prepare for the next LHC run that will resume in 2021.
Projects	$105,000,000	$96,935,000	-$8,065,000
The FY 2019 Enacted budget supports 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.		The Request will support baselining the detector upgrades projects, and continue procurement of components for the HL-LHC ATLAS and HL-LHC CMS Detector Upgrades, and production of focusing magnets and radio-frequency cavities for the HL-LHC Accelerator Upgrade Project.	The Request supports fabrication and production activities for the HL-LHC Accelerator Upgrade project. Each of the HL-LHC ATLAS and HL-LHC CMS Detector Upgrade projects continue to prepare for project baseline approval.
SBIR/STTR	$5,390,000	$3,674,000	-$1,716,000
In FY 2019, SBIR/STTR funding is at 3.65% of non-capital funding.		In FY 2020, 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 Experimental Physics 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 are not directly observable at the Energy Frontier, either because they occur at much higher energies and their effects may only be seen indirectly, or because their interactions are too weak for detection 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:

- *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 may reveal information about what new particles and forces might 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 connect 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 Physics subprogram's Research activity supports groups at U.S. academic and research institutions and national laboratories. 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. 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 was conducted in FY 2018; the next review is planned for FY 2022. In FY 2018, HEPAP evaluated the currently operating portfolio of experiments on the Intensity Frontier and assessed the priority of their science output in the context of the science drivers. In early FY 2019, HEP conducted a Basic Research Needs workshop to assess the science landscape and new opportunities for dark matter particle searches and to identify which areas would be suitable for small projects in the HEP program. The findings from these reviews, in combination with input on strategic directions from regular, open community workshops will inform 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. The Booster Neutrino Beam (BNB) is used to study different aspects of neutrino physics. The SBN program, which includes a Near Detector (SBN-ND) and a Far Detector (SBN-FD) separated by about 1,600 feet, uses the BNB to definitively address hints of additional neutrinos types beyond the three currently described in the Standard Model. LBNF/DUNE will be the centerpiece of a U.S.-hosted world-leading neutrino research activities, using the world's most intense neutrino beam and large, sensitive underground detectors to make transformative discoveries.

The Research activity also supports efforts to search for rare processes in muons to detect physics beyond the reach of the LHC. A new Muon g-2 experiment at Fermilab, with four times better precision than previously achieved, is following up on hints of new physics from an earlier experiment, while the Mu2e experiment will search for extremely rare muon decays that, if detected, will provide clear evidence of new physics. The Intensity Frontier subprogram also supports U.S. physicists to participate in select experiments at other facilities, including neutrino experiments in China and Japan. In particular, the Tokai-to-Kamioka (T2K) long-baseline neutrino experiment in Japan is complementary to NOvA, and together they will offer the best available information on neutrino oscillations prior to LBNF/DUNE. There is also a U.S. contingent searching for new physics using the Belle II experiment at the KEK in Japan.

Facility Operations and Experimental Support

There are several distinct facility operations and experimental support efforts in the Intensity Frontier Experimental Physics 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. 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) have been identified for SURF plant support costs provided by SDSTA.

PIP-II will upgrade the Fermilab linear accelerator to increase beam power and sustain high reliability of the Fermilab Accelerator Complex, ultimately providing the world's highest proton beam intensity of greater than 1.2 megawatts for LBNF/DUNE. CD-1 was approved July 23, 2018, and the project is now completing its preliminary design. Two French institutions with expertise in superconducting radio-frequency (SRF) technology have joined the effort, expanding the list of partners that already includes institutions in India, Italy, and the United Kingdom.

Activities and Explanation of Changes

FY 2019 Enacted	FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Intensity Frontier Experimental Physics $240,980,000	**$193,682,000**	**-$47,298,000**
Research $61,646,000	$41,370,000	-$20,276,000
The FY 2019 Enacted budget supports 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. Belle II is anticipated to produce its first physics data results.	The Request will prioritize support for world-leading research efforts on short- and long-baseline neutrino experiments, muon experiments, and technology studies and science planning for LBNF/DUNE. The SBN program is expected to produce its first physics results. The Muon g-2 experiment will achieve the world's most sensitive measurement of the anomalous magnetic dipole moment of a muon.	Funding will be prioritized to support postdoctoral researchers and graduate students who are engaged in intensity frontier research at the national laboratories and universities with the highest scientific merit and potential impact as based on a competitive peer-review process with a focus on delivering the final results of completed experiments (e.g., Daya Bay), and preparing for physics on new experiments (e.g., SBN, Belle II).
Facility Operations and Experimental Support $155,035,000	$136,681,000	-$18,354,000
The FY 2019 Enacted budget supports the optimal operation of the Fermilab Accelerator Complex and the neutrino and muon experiments, the Fermilab NuMI Target Systems accelerator improvement project (AIP), and the Fermilab Utility Corridor general plant project (GPP). Based upon recommendations from reviews conducted by SC in FY 2018, HEP provides increased funding to address the aging infrastructure at the Sanford Underground Research Facility (SURF) to meet DOE expectations of reliable, efficient, and safe operations during the construction of LBNF/DUNE.	The Request will support the Fermilab Accelerator Complex and the neutrino and muon experiments at 88% of optimal operations. The Fermilab Kautz Road Sub-Station Radial Feed Electrical Upgrade GPP will begin. SURF operations will continue to enable operation of the LZ experiment and Majorana Demonstrator. The Request will support additional investments to enhance SURF infrastructure for reliable and efficient operation of the facility during the construction of LBNF/DUNE.	Support will focus on delivering particle beams at peak power and providing detector and computing operations for ongoing experiments (e.g., NOvA, Muon g-2) and new experiments (e.g., SBN) at the Fermilab Accelerator Complex; with operations at 88% of optimal. The FY 2019 Appropriation provided sufficient funding to complete the Fermilab NuMI Target Systems AIP and Utility Corridor GPP, which will result in a decrease in FY 2020. This will be partially offset by the Kautz Road Sub-Station GPP starting in FY 2020, and by the ramp down or conclusion of operations of mature experiments that have achieved their science goals (e.g. MicroBooNE).

FY 2019 Enacted	FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Projects $16,000,000	$9,000,000	-$7,000,000
The FY 2019 Enacted budget supports 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.	The Request will support OPC for R&D for the PIP-II Injector Test Facility and a prototype for the front-end injector, and OPC for plant support costs at SURF during LBNF/DUNE construction.	The OPC for PIP-II will decrease since CD-1 was approved on July 23, 2018. The OPC shifts to preliminary design, which is part of the Total Estimated Costs (TEC). SURF plant support costs will continue as OPC for LBNF/DUNE.
SBIR/STTR $8,299,000	$6,631,000	-$1,668,000
In FY 2019, SBIR/STTR funding is at 3.65% of non-capital funding.	In FY 2020, SBIR/STTR funding will be at 3.65% of non-capital funding.	The decrease in funding will represent mandated percentages for non-capital funding.

High Energy Physics
Cosmic Frontier Experimental Physics

Description

The Cosmic Frontier Experimental Physics 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:

- *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*
  The nature of dark energy, which drives the accelerating expansion of the universe, continues as 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 observable 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*
  The study of the largest physical structures in the Universe may 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 may 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 Physics subprogram's Research activity supports 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 FY 2016; the next review will occur in FY 2020. In FY 2018, HEPAP evaluated the currently operating portfolio of experiments in the Cosmic Frontier and assessed the priority of their science output in the context of the science drivers. In early FY 2019, HEP conducted a Basic Research Needs workshop to assess the science landscape and new opportunities for dark matter particle searches and to identify which areas would be suitable for small projects in the HEP program. The findings from these reviews, in combination with input on strategic directions from regular, open community workshops, will inform funding decisions in subsequent years.

Facility Operations and Experimental Support

This activity supports the DOE share of personnel and expenses necessary for the successful pre-operations planning activities and maintenance, operations, and data collection and processing 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 all Cosmic Frontier operating experiments in FY 2015. HEP continues its series of reviews of each experiment to ensure readiness from fabrication to the science operations phase. 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

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 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 will combine to provide the largest search currently feasible. Technology R&D and pre-conceptual design studies for the next generation Cosmic Microwave Background (CMB-S4) experiment will begin.

Activities and Explanation of Changes

FY 2019 Enacted		FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Cosmic Frontier Experimental Physics	**$101,036,000**	**$57,468,000**	**-$43,568,000**
Research	$50,741,000	$31,140,000	-$19,601,000
The FY 2019 Enacted budget supports 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.		The Request will prioritize support for world-leading research efforts on all phases of dark matter and dark energy experiments, as well as technology studies and planning for a CMB-S4 experiment. The Dark Energy Survey (DES) imaging experiment will release all its data from its 5-year survey.	Support prioritizes postdoctoral researchers and graduate students who are engaged in cosmic frontier research at the national laboratories and universities with the highest scientific merit and potential impact based on a competitive peer-review process, with a focus on delivering the final results of completed experiments (e.g., DES), and preparing for physics on new experiments (e.g., LZ, DESI).
Facility Operations and Experimental Support	$20,076,000	$23,230,000	+$3,154,000
The FY 2019 Enacted budget supports the start of installation and commissioning activities for the LSSTcam, and early planning for the LSST facility and science operations. Planning, commissioning, and pre-operations activities begins for DESI, LZ, and SuperCDMS-SNOLAB. Support for the currently operating experiments continues.		The Request will support experiments in various phases: DESI will start science operations; LSSTcam will continue commissioning and integration on to the telescope; the full LSST facility will ramp up pre-operations planning; LZ will start full commissioning efforts; and SuperCDMS-SNOLAB will continue commissioning and pre-operations activities.	The increase will support the LSSTcam, DESI, LZ, and SuperCDMS-SNOLAB projects as they transition to experimental operations, installation, commissioning, and pre-operations activities, which will be partially offset by the ramp down or conclusion of operations of mature experiments that have achieved their science goals (e.g. High Altitude Water Cherenkov (HAWC) Observatory).
Projects	$27,350,000	$1,000,000	-$26,350,000
The FY 2019 Enacted budget supports the completion of fabrication and installation of the LZ dark matter project, and supports the fabrication of the DESI dark energy project and the SuperCDMS-SNOLAB dark matter project, as well as support for technology R&D and planning for a future CMB-S4 project.		The Request will support technology R&D and planning for a future CMB-S4 project.	The FY 2019 Appropriation provided sufficient funding to complete the TEC funding for the LZ, SuperCDMS-SNOLAB, and DESI projects.

FY 2019 Enacted		FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
SBIR/STTR	$2,869,000	$2,098,000	-$771,000
In FY 2019, SBIR/STTR funding is at 3.65% of non-capital funding.		In FY 2020, SBIR/STTR funding will be at 3.65% of non-capital funding.	The decrease in funding will represent mandated percentages for non-capital funding.

High Energy Physics
Theoretical, Computational, and Interdisciplinary Physics (formerly Theoretical and Computational Physics)

Description

The Theoretical, Computational, and Interdisciplinary Physics (formerly Theoretical and Computational Physics) subprogram provides the mathematical, phenomenological, computational and technological 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, and cuts across all five 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 was conducted in FY 2018; the next review is planned for FY 2022. The findings from this review, in combination with input on strategic directions from regular, open community workshops as well as a planned, future Basic Research Needs workshop, will inform funding decisions in subsequent years.

Computational HEP

The Computational HEP activity supports advanced simulations and computational science that extends the boundaries of scientific discovery to regions not directly accessible by experiments, observations, or traditional theory. 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 promote computing research for HEP future needs, by exploiting latest architectures like massively-parallel high performance computing platforms and future exascale computer systems, and developing advanced AI-ML techniques for new tracking and analysis algorithms. Computational HEP partners with the Advanced Scientific Computing Research (ASCR) program, including via the Scientific Discovery through Advanced Computing (SciDAC) activity, and with ASCR facilities and projects to optimize the HEP computing ecosystem for the near and long term future.

Quantum Information Science

The HEP QIS activity supports foundational research on connections between cosmological black holes and qubit research as well as quantum field theory techniques and algorithms, quantum computing for HEP experiments, development and use of specialized quantum controls, and precision sensors that may yield information on fundamental physics beyond the Standard Model, and applications of HEP research to advance QIS. At least one new Quantum Information Science Center (QIS Center), jointly supported with ASCR and BES programs, will apply concepts and technology from the relevant foundational core research in the corresponding programs and foster partnerships in support of the SC mission. The HEP QIS research activity is part of a broader SC initiative that is conducted in coordination with SC programs, other federal agencies, and the private sector where relevant.

Activities and Explanation of Changes

FY 2019 Enacted		FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Theoretical, Computational, and Interdisciplinary Physics (formerly Theoretical and Computational Physics)	**$89,834,000**	**$94,705,000**	**+$4,871,000**
Theory	$45,760,000	$32,650,000	-$13,110,000
The FY 2019 Enacted budget supports world-leading theoretical research program at universities and national laboratories.		The Request will support world-leading research that addresses the neutrino mass, the interpretation of experimental results, the development of new ideas for future projects, and the advancement of the theoretical understanding of nature.	Support prioritizes postdoctoral researchers and graduate students who are engaged in theoretical physics research at the national laboratories and universities, with a focus on understanding the results of current experiments, supporting new initiatives in neutrino and dark matter physics, and connecting fundamental theory to the development of quantum information science.
Computational HEP	$13,351,000	$20,290,000	+$6,939,000
The FY 2019 Enacted budget supports transformative computational science and SciDAC 4 activities including use of current and future high performance computing platforms and machine learning/deep learning applications across the program and coordinated with other DOE investments.		The Request will support transformative computational science, AI-ML, high performance computing, and SciDAC 4 activities to provide cross cut computational science tools for HEP science.	The increased funding will support new AI-ML research to explore how DOE high performance computing resources can scale up the optimization, performance, and validation studies of AI-ML tracking models, use pattern recognition to develop production-quality tracking for online triggering systems for HEP experiments, and use statistics and AI-ML to better analyze simulated data.
Quantum Information Science	$27,500,000	$38,308,000	+$10,808,000
The FY 2019 Enacted budget supports new foundational QIS research and supporting research technology. HEP employs the latest developments in QIS, and contribute to the national effort, and promote American competitiveness.		The Request will support interdisciplinary HEP-QIS consortia and exploratory Pioneering Pilots to strengthen foundational HEP-QIS research, quantum computing, and quantum research technology.	The increased funding will support at least one multi-disciplinary, multi-institutional QIS center in collaboration with ASCR and BES via a merit reviewed process, which will be conducted early in FY 2020.

FY 2019 Enacted		FY 2020 Request		Explanation of Changes FY 2020 Request vs FY 2019 Enacted
		The Request also will support at least one new QIS Center in partnership with ASCR and BES.		
SBIR/STTR	$3,223,000		$3,457,000	+$234,000
In FY 2019, SBIR/STTR funding is at 3.65% of non-capital funding.		In FY 2020, SBIR/STTR funding will be at 3.65% of non-capital funding.		The 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. Long-term multi-purpose accelerator research, applicable to fields beyond HEP, is carried out under the Accelerator Stewardship subprogram.

HEP General Accelerator R&D

The HEP General Accelerator R&D (GARD) activity supports 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 activity supports groups at U.S. academic and research institutions and national laboratories performing research activity categorized into five areas: accelerator and beam physics; advanced acceleration concepts; particle sources and targetry; radio-frequency acceleration technology; and superconducting magnet and materials. 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 was conducted in FY 2018; the next review is planned for FY 2022. The findings from this review, in combination with input on strategic directions from regular, open community workshops as well as future Basic Research Needs workshops, will inform funding decisions in subsequent years.

The GARD activity also supports the Traineeship Program for Accelerator Science and Technology 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. The Traineeship Program is aimed at university and national laboratory consortia to provide the academic training and research experience needed to meet DOE's anticipated workforce needs. HEP holds a competition for traineeship awards for graduate level students to increase workforce development in areas of critical need. These traineeships leverage existing GARD research activities as well as the capabilities and assets of DOE laboratories.

Detector R&D

The Detector R&D activity supports the development of the next generation instrumentation and particle detectors necessary to maintain scientific leadership in a worldwide experimental endeavor that is broadening into new research areas. To meet this challenge, HEP aims to foster an appropriate balance 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 activity 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. This activity also supports technology development that turns 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 FY 2016; the next review will occur in FY 2020. The findings from this review, in combination with input on strategic directions from regular, open community workshops as well as a planned, future Basic Research Needs workshop, will inform funding decisions in subsequent years.

Facility Operations and Experimental Support

This activity supports GARD laboratory experimental and test facilities: BELLA, the laser-driven plasma wakefield acceleration facility at LBNL; FACET-II, the beam-driven plasma wakefield acceleration facility at SLAC National Accelerator Laboratory (SLAC); and superconducting radio-frequency accelerator and magnet facilities at Fermilab. This activity supports the test beam at Fermilab, and detector test and fabrication facilities such as the Microsystems Laboratory at LBNL and the Silicon Detector Facility at Fermilab. Accelerator Improvement Projects (AIP) support 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 be the world's premier beam driven plasma wakefield acceleration facility and provide intense ultra-short electron beams for other applications in accelerator and related sciences.

Activities and Explanation of Changes

FY 2019 Enacted		FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Advanced Technology R&D	**$113,506,000**	**$91,707,000**	**-$21,799,000**
HEP General Accelerator R&D	$48,447,000	$40,873,000	-$7,574,000
The FY 2019 Enacted budget supports world-leading research activities including laser and electron-beam driven plasma acceleration, high intensity beam studies, beam manipulation and control techniques, high-power targets, high-gradient accelerator structures, superconducting radio-frequency cavities with high quality factors and high accelerating gradients, and low temperature and high temperature superconductors for high-field magnet application. The Traineeship Program for Accelerator Science and Technology is supported.		The Request will support world-leading General Accelerator R&D that will enable transformative technologies for the next-generation of accelerators for High Energy Physics. The Request also provides support for the Traineeship Program for Accelerator Science and Technology.	Support will be prioritized to focus on research activities in superconducting magnet development and ultrafast lasers, and on cross-cutting Accelerator R&D which leverages synergistic efforts at the national laboratories. Also, includes an increase for the Traineeship Program for Accelerator Science and Technology.
Detector R&D	$23,694,000	$16,700,000	-$6,994,000
The FY 2019 Enacted budget supports world-leading Detector R&D activities at universities and national laboratories, with emphasis on long-term, high-risk, and high potential impact R&D efforts.		The Request will support cutting-edge Detector R&D activities at universities and national laboratories, targeted at the most promising, high-impact directions led by U.S. efforts.	Support will prioritize Detector R&D that exploits collaborative opportunities between the national laboratories and the universities.
Facility Operations and Experimental Support	$27,625,000	$30,878,000	+$3,253,000
The FY 2019 Enacted budget supports the operation of accelerator, test beam, and detector facilities at Fermilab, LBNL, and SLAC. Commissioning activities for FACET-II installation will begin.		The Request will support the operation of accelerator, test beam, and detector facilities at Fermilab, LBNL and SLAC and improvements to superconducting radio-frequency facilities. The Request also includes support for final commissioning, installation, and 1,500 hours (50% of optimal) for initial operations for FACET-II.	The increased funding will support the commissioning and installation of the electron beam systems, 1,500 hours of FACET-II operations, and improving superconducting radio-frequency (SRF) facilities and capabilities. This will be partially offset by reduced support to detector test facilities at SLAC and LBNL.

FY 2019 Enacted	FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Projects $10,000,000	$—	-$10,000,000
The FY 2019 Enacted budget supports the completion of fabrication and installation of FACET-II.	No funding is requested for this activity. The FY 2019 Appropriation provided sufficient funding to complete the FACET-II project.	FACET-II project receives final funding in FY 2019.
SBIR/STTR $3,740,000	$3,256,000	-$484,000
In FY 2019, SBIR/STTR funding is at 3.65% of non-capital funding.	In FY 2020, SBIR/STTR funding will be at 3.65% of non-capital funding.	The 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 subprogram as a coordinated interagency initiative, consulting with other SC programs (principally NP, BES, and FES), other DOE program offices (principally EM and NNSA), and other federal stakeholders[a] of accelerator technology, most notably NIH, DOD, NSF, and DHS. Ongoing interagency consultation guides R&D investments, ensuring agency priorities are addressed, exploiting synergies where possible, and identifying new cross-cutting areas of research.

<u>Research</u>

The Research activity supports both near-term translational R&D and long-term basic accelerator R&D, which is conducted at national laboratories, universities, and in the private sector. The needs for applications 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 may 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.

<u>Facility Operations and Experimental Support</u>

The Facility Operations and Experimental Support activity 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 ongoing facility R&D. Accelerator Improvement Projects (AIP) support improvements to Accelerator Stewardship facilities.

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[a] Partner agencies for the Accelerator Stewardship subprogram 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.

High Energy Physics
Accelerator Stewardship

Activities and Explanation of Changes

FY 2019 Enacted	FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Accelerator Stewardship $15,724,000	**$12,877,000**	**-$2,847,000**
Research $9,083,000	$7,930,000	-$1,153,000
The FY 2019 Enacted budget supports 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.	The 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, medical and security uses, and advanced laser technology R&D.	Support will emphasize transformative R&D for security applications and implementing priority R&D topics identified by a Basic Research Needs workshop planned for the spring of FY 2019.
Facility Operations and Experimental Support $6,067,000	$4,477,000	-$1,590,000
The FY 2019 Enacted budget supports the BNL ATF operations at optimal levels.	The Request will support the BNL ATF operations at 74% of optimal levels and support facility refurbishments to provide increased reliability and expanded capability to users.	Operating hours will be slightly reduced to 74% of optimal and approximately 30 less users are estimated as compared to FY 2019 estimates.
SBIR/STTR $574,000	$470,000	-$104,000
In FY 2019, SBIR/STTR funding is at 3.65% of non-capital funding.	In FY 2020, SBIR/STTR funding will be at 3.65% of non-capital funding.	The decrease in funding will represent mandated percentages for non-capital funding.

High Energy Physics
Construction

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.

Proton Improvement Plan II (PIP-II)

The PIP-II project will enhance the Fermilab accelerator complex to enable it to deliver higher-power proton beams to the neutrino-generating target for groundbreaking discovery in neutrino physics. The project will design and construct an 800 MeV superconducting radio-frequency (SRF) proton linear accelerator, beam transfer line and infrastructure. PIP-II will modify the existing Fermilab Booster, Recycler and Main Injector accelerators to accept the increased beam intensity. Some of the new components and the cryoplant will provide through international, in-kind contributions.

The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-1 (Approve Alternative Selection and Cost Range), approved on July 23, 2018. The TPC cost range is $653,000,000 to $928,000,000. The funding profile supports the currently estimated TPC of $721,000,000. The CD-4 milestone is 1Q FY 2030. CD-0 established the mission need in FY 2015.

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. 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 imbalance of matter and antimatter 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 U.S. 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. DUNE is an international scientific collaboration responsible for defining the scientific goals and technical requirements for the beam and detectors, as well as the design, construction and commissioning of the detectors and subsequent research.

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 1,160 scientists and engineers from 175 institutions in 32 countries. DOE will fund less than a third of DUNE.

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. The preliminary Total Project Cost (TPC) range is $1,260,000,000 to $1,860,000,000, as approved on September 1, 2016 with a preliminary CD-4 date of 4Q FY 2030. Updated planning and analysis has the TPC point estimate for LBNF/DUNE of $1,850,000,000 and was reviewed by an Independent Project Review held January 8-10, 2019.

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 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 CD-4 milestone is 1Q FY 2023.

Activities and Explanation of Changes

FY 2019 Enacted		FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Construction	**$180,000,000**	**$120,000,000**	**-$60,000,000**
18-SC-42, Proton Improvement Plan II, FNAL	$20,000,000	$20,000,000	$—
The FY 2019 Enacted budget supports the development of the preliminary design, the fabrication of prototype components, and early site preparation that is designed to mitigate environmental impacts.		The Request will support engineering design work for conventional facilities and technical systems, continuation of site-preparation activities and initiation of construction for cryogenic plant support systems, as well as continued fabrication of prototype accelerator system components.	Activities started in FY 2019 will continue as planned through FY 2020.
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment, FNAL	$130,000,000	$100,000,000	-$30,000,000
The FY 2019 Enacted budget supports the Far Site pre-construction activities to support the eventual 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.		The Request will support: continuation of pre-construction activities to support the Far Site cavern excavation; design and procurement activities for Far Site cryogenics systems; and beamline and conventional facilities design and site preparation at the Near Site. The Request will also support start of construction and fabrication for technical systems where design is final and authorized by CD-3, including U.S. contributions to the DUNE detectors.	Support will focus on the completion of the pre-excavation activities such as the systems to remove the excavated rock to its nearby disposal site; the start of design and procurement activities for cryogenics systems, Near Site beamline and conventional facilities; and U.S. contributions to design and construction of the DUNE detectors.
11-SC-41, Muon to Electron Conversion Experiment, FNAL	$30,000,000	$—	-$30,000,000
The FY 2019 Enacted budget supports the completion of the procurements and the beginning of equipment installation.		No funding is requested for this activity. The FY 2019 Appropriation provided final funding for the project. In FY 2020, fabrication will continue for the particle detectors and accelerator components including superconducting solenoid magnets and the muon stopping target.	The Mu2e project receives final funding in FY 2019.

High Energy Physics
Capital Summary

(dollars in thousands)

	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Capital Operating Expenses Summary						
Capital Equipment	N/A	N/A	91,556	125,260	101,935	-23,325
Minor Construction Activities						
General Plant Projects (GPP)	N/A	N/A	3,938	8,000	7,500	-500
Accelerator Improvement Projects (AIP)	N/A	N/A	4,445	5,600	—	-5,600
Total, Capital Operating Expenses	**N/A**	**N/A**	**99,939**	**138,860**	**109,435**	**-29,425**

Capital Equipment

(dollars in thousands)

	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Capital Equipment						
Major Items of Equipment (MIE)[a]						
Energy Frontier Experimental Physics						
HL-LHC Accelerator Upgrade Project[b]	236,672	—	21,572	50,000	50,000	—
HL-LHC ATLAS Detector Upgrade[c]	133,850	—	—	27,500	23,460	-4,040
HL-LHC CMS Detector Upgrade[d]	121,800	—	—	13,750	23,475	+9,725
Cosmic Frontier Experimental Physics						
Large Synoptic Survey Telescope Camera (LSSTcam)[e]	150,300	140,500	9,800	—	—	—
Dark Energy Spectroscopic Instrument[f] (DESI)	45,250	22,300	17,500	5,450	—	-5,450

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

[b] Critical Decision CD-2/3b for HL-LHC Accelerator Upgrade project was approved on February 11, 2019. The TPC is $242,720,000.

[c] Critical Decision CD-1 for HL-LHC ATLAS Detector Upgrade Project was approved September 21, 2018. The estimated cost range was $149,000,000 to $181,000,000.

[d] 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.

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

[f] Critical Decision CD-3 for DESI project was approved on June 22, 2016. The TPC is $56,328,000.

(dollars in thousands)

	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
LUX-ZEPLIN[a] (LZ)	52,050	23,500	14,100	14,450	—	-14,450
SuperCDMS-SNOLAB[b]	15,725	5,775	7,400	2,550	—	-2,550
Advanced Technology R&D						
FACET II[c]	20,500	500	10,000	10,000	—	-10,000
Total MIEs	N/A	N/A	80,372	123,700	96,935	-26,765
Total Non-MIE Capital Equipment	N/A	N/A	11,184	1,560	5,000	+3,440
Total, Capital Equipment	**N/A**	**N/A**	**91,556**	**125,260**	**101,935**	**-23,325**

Minor Construction Activities

(dollars in thousands)

	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
General Plant Projects (GPP)						
Greater than or equal to $5M and less than $20M						
Industrial Center Building addition	8,428	6,500	1,928	—	—	—
Utility Corridor	8,000	—	—	8,000	—	-8,000
Kautz Road Sub-Station	7,500	—	—	—	7,500	+7,500
Total GPPs (greater than or equal to $5M and less than $20M)	N/A	N/A	1,928	8,000	7,500	-500
Total GPPs less than $5M[d]	N/A	N/A	2,010	—	—	—
Total, General Plant Projects (GPP)	**N/A**	**N/A**	**3,938**	**8,000**	**7,500**	**-500**

[a] Critical Decision CD-3 for LZ project was approved February 9, 2017. The TPC is $55,500,000.

[b] Critical Decisions CD-2/3 for SuperCDMS-SNOLAB project were approved May 2, 2018. The TPC is $18,600,000.

[c] Critical Decisions CD-2/3 for FACET-II project were approved June 8, 2018. The TPC is $25,600,000.

[d] GPP activities less than $5M include design and construction for additions and/or improvements to land, buildings, replacements or additions to roads, and general area improvements.

(dollars in thousands)

	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Accelerator Improvement Projects (AIP)						
Greater than or Equal to $5M and less than $20M						
Section 10 Injector Infrastructure	5,000	3,955	1,045	—	—	—
NuMI Target Systems	5,600	—	—	5,600	—	-5,600
Total AIPs (greater than or equal to $5M and less than $20M)	N/A	N/A	1,045	5,600	—	—
Total AIPs less than $5M[a]	N/A	N/A	3,400	—	—	—
Total, Accelerator Improvement Projects (AIP)	**N/A**	**N/A**	**4,445**	**5,600**	**—**	**-5,600**
Total, Minor Construction Activities	**N/A**	**N/A**	**8,383**	**13,600**	**7,500**	**-6,100**

[a] AIP activities less than $5M include minor construction at an existing accelerator facility.

High Energy Physics
Major Items of Equipment Description(s)

Energy Frontier Experimental Physics MIEs:
The *High Luminosity Large Hadron Collider Accelerator Upgrade Project (HL-LHC Accelerator Upgrade Project)* received CD-2/3b approval on February 11, 2019 with a TPC of $242,720,000. 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 its current reach. This 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 2020 Request of TEC funding of $50,000,000 will support the production of quadrupole magnets and crab cavities.

The *High Luminosity Large Hadron Collider ATLAS Detector Upgrade Project (HL-LHC ATLAS)* received CD-1 approval on September 21, 2018 with an estimated cost range of $149,000,000 to $181,000,000, and CD-2 is planned for FY 2020. The ATLAS detector will 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 2020 Request of TEC funding of $23,460,000 will support further procurement of components and baselining of the project.

The *High Luminosity Large Hadron Collider CMS Detector Upgrade Project (HL-LHC CMS)* received CD-0 approval on April 13, 2016 with an estimated cost range of $125,000,000 to $155,000,000. The project is expected to obtain CD-1 approval in the spring of 2019, and CD-2 is planned for FY 2020. The CMS detector will 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, the trigger and data acquisition systems and the addition of a novel timing detector. 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 2020 Request of TEC funding of $23,475,000 will support further procurement of components and baselining of the project.

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. The project 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 will complete its camera components, including testing and integration, in FY 2020. It will then be shipped to Chile for installation and commissioning on the LSST telescope facility in Chile. The FY 2018 Appropriation provided sufficient funds to complete all remaining LSSTcam project 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 for operation on NSF's 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 Appropriation provided sufficient funds to complete all remaining project deliverables. In FY 2020, the project will finish installation of the focal plane and spectrograph and complete commissioning.

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 Appropriation provided sufficient funds to complete all remaining project deliverables. In FY 2020, the project will finish underground installation, functional testing, and filling of the detector's chambers with liquid xenon, liquid scintillator, and water.

The *Super Cryogenic Dark Matter Search at Sudbury Neutrino Observatory Laboratory (SuperCDMS-SNOLAB)* project received CD-2/3 approval on May 2, 2018 with a TPC of $18,600,000. 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 optimize 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 Appropriation provided sufficient funds to complete all remaining project deliverables in FY 2020, including installation of the seismic platform and assembly of the shielding, cryostat, and calibration system.

<u>Advanced Technology R&D MIE:</u>
The *Facility for Accelerator and Experimental Tests II (FACET-II)* project received CD-2/3 on June 8, 2018 with a TPC of $25,600,000. FACET-II will be the world's premier beam driven plasma wakefield acceleration facility. FACET-II is being designed to deliver beams using only one third of the SLAC linear accelerator. FACET-II installation and commissioning work in the SLAC accelerator housing will be constrained by the installation of the Linac Coherent Light Source II (LCLS-II). The FY 2019 Appropriation provided sufficient funds to complete all remaining deliverables. In FY 2020, the project will be completing its Accelerator Readiness Review and final checks of its electronic control systems.

High Energy Physics
Minor Construction Description(s)

General Plant Projects $5 Million to less than $10 Million

Kautz Road Sub-Station
General Plant Project Details

Project Name:	Kautz Road Sub-Station Radial Feed Electrical Upgrade
Location/Site:	Fermilab Accelerator Complex, Main Ring
Type:	GPP
Total Estimated Cost:	$7,500,000
Construction Design:	$500,000
Project Description:	The KRSS Radial Feed Electrical Upgrade project will replace/upgrade existing electrical feeders that serve the Main Ring area of the site to improve reliability, increase the capacity of the Fermilab site wide electrical system and bring the service up to modern standards.

High Energy Physics
Construction Project Summary

(dollars in thousands)

	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
18-SC-42, Proton Improvement Plan II, FNAL[a]						
TEC	638,965	—	1,000	20,000	20,000	—
OPC	82,035	33,935	23,100	15,000	5,000	-10,000
TPC	**721,000**	**33,935**	**24,100**	**35,000**	**25,000**	**-10,000**
11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment, FNAL						
TEC	1,755,000	111,781	95,000	130,000	100,000	-30,000
OPC	95,000	85,625	1,000	1,000	4,000	+3,000
TPC	**1,850,000**	**197,406**	**96,000**	**131,000**	**104,000**	**-27,000**
11-SC-41, Muon to Electron Conversion Experiment, FNAL						
TEC	250,000	175,600	44,400	30,000	—	-30,000
OPC	23,677	23,677	—	—	—	—
TPC	**273,677**	**199,277**	**44,400**	**30,000**	**—**	**-30,000**
Total, Construction						
TEC	**N/A**	**N/A**	**140,400**	**180,000**	**120,000**	**-60,000**
OPC	**N/A**	**N/A**	**24,100**	**16,000**	**9,000**	**-7,000**
TPC	**N/A**	**N/A**	**164,500**	**196,000**	**129,000**	**-67,000**

[a] The Proton Improvement Plan II was not included in the Construction Project Summary table in the FY 2019 President's Budget Request as TEC funding was not requested for FY 2019.

High Energy Physics
Funding Summary

	(dollars in thousands)			
	FY 2018 Enacted	**FY 2019 Enacted**	**FY 2020 Request**	**FY 2020 Request vs FY 2019 Enacted**
Research	**369,565**	**380,847**	**301,357**	**-79,490**
Facilities Operations				
Scientific User Facilities Operations	136,820	139,717	126,217	-13,500
Other Facilities	123,715	121,086	113,529	-7,557
Total, Facilities Operations	**260,535**	**260,803**	**239,746**	**-21,057**
Projects[a]				
Major Items of Equipment	112,300	141,350	96,935	-44,415
Other Projects	1,100	1,000	1,000	—
Construction	164,500	196,000	129,000	-67,000
Total, Projects	**277,900**	**338,350**	**226,935**	**-111,415**
Total, High Energy Physics	**908,000**	**980,000**	**768,038**	**-211,962**

[a] Includes Other Project Costs.

High Energy Physics
Scientific User Facility Operations

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.

(dollars in thousands)

	FY 2018 Enacted	FY 2018 Current	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
TYPE A FACILITIES					
Fermilab Accelerator Complex	**$132,000**	**$130,284**	**$132,650**	**$115,740**	**-$16,910**
Number of Users	2,393	2,489	2,489	2,100	-389
Achieved operating hours	N/A	5,026	N/A	N/A	N/A
Planned operating hours	4,800	4,800	5,740	4,200	-1,540
Optimal hours	4,800	4,800	5,740	4,800	-940
Percent optimal hours	100.0%	104.7%	100.0%	87.5%	-12.5%
Unscheduled downtime hours	N/A	482	N/A	N/A	N/A

	(dollars in thousands)				
	FY 2018 Enacted	**FY 2018 Current**	**FY 2019 Enacted**	**FY 2020 Request**	**FY 2020 Request vs FY 2019 Enacted**
Accelerator Test Facility (BNL)	**$4,820**	**$5,517**	**$6,067**	**$4,477**	**-$1,590**
Number of Users	97	91	118	87	-31
Achieved operating hours	N/A	2,529	N/A	N/A	N/A
Planned operating hours	2,360	2,360	2,500	1,845	-655
Optimal hours	2,050	2,500	2,500	2,500	—
Percent optimal hours	115.1%	101.2%	100.0%	73.8%	-26.2%
Unscheduled downtime hours	N/A	245	N/A	N/A	N/A
FACET-II (SLAC)	**N/A**	**N/A**	**$1,000**	**$6,000**	**+$5,000**
Number of Users	N/A	N/A	N/A	200	+200
Achieved operating hours	N/A	N/A	N/A	N/A	N/A
Planned operating hours	N/A	N/A	N/A	1,500	+1,500
Optimal hours	N/A	N/A	N/A	3,000	+3,000
Percent optimal hours	N/A	N/A	N/A	50.0%	N/A
Unscheduled downtime hours	N/A	N/A	N/A	N/A	N/A
Total Facilities	**$136,820**	**$135,801**	**$139,717**	**$126,217**	**-$13,500**
Number of Users	2,490	2,580	2,607	2,387	-220
Achieved operating hours	N/A	7,555	N/A	N/A	N/A
Planned operating hours	7,160	7,160	8,240	7,545	-695
Optimal hours	6,850	7,300	8,240	10,300	+2,060
Percent of optimal hours[a]	100.5%	104.6%	100.0%	85.2%	-14.8%
Unscheduled downtime hours	N/A	727	N/A	N/A	N/A

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

High Energy Physics
Scientific Employment

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Number of permanent Ph.D.'s (FTEs)	890	830	725	-105
Number of postdoctoral associates (FTEs)	350	340	255	-85
Number of graduate students (FTEs)	520	500	375	-125
Other[a]	1,815	1,745	1,475	-270

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

18-SC-42, Proton Improvement Plan II (PIP-II)
Fermi National Accelerator Laboratory
Project is for Design and Construction

1. Summary, Significant Changes, and Schedule and Cost History

Summary

The FY 2020 Request for Proton Improvement Plan II (PIP-II) is $20,000,000. Initial construction funding was provided in FY 2018 through the Consolidated Appropriations Act. The current preliminary Total Project Cost (TPC) range is $653,000,000 to $928,000,000 with a point estimate of $721,000,000.

The PIP-II project will enhance the Fermilab accelerator complex by providing the capability to deliver higher-power proton beams to the neutrino-generating target for groundbreaking discovery in neutrino physics, a major field of fundamental research in high energy particle physics.

The project will design and construct an 800 MeV superconducting radiofrequency (SRF) proton linac, beam transfer line, and infrastructure needed to support linac operation. It also will modify the existing Booster, Recycler, and Main Injector synchrotrons to accept the increased beam intensity. Some of the new linac components and the cryoplant will be international, in-kind contributions not funded by DOE.

Conceptual design work was completed and reviewed in FY 2018. DOE provided funds to the project in FY 2018 and FY 2019 for site-preparation activities, preliminary engineering design work, and R&D with the PIP-II Injector Test Facility, a prototype for the front-end injector, to reduce technical risks for the project.

The FY 2020 Request will continue site preparation activities, engineering design work for the conventional facilities and technical systems, procurement of prototype accelerator system components, and initiate construction of cryogenic plant support systems. Technical system R&D activities will continue.

Significant Changes

This Construction Project Data Sheet (CPDS) is new. This project was initiated in FY 2018 Appropriations. This is the first project data sheet identifying FY 2018 and FY 2019 funding.

The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-1 (Approve Alternative Selection and Cost Range), approved on July 23, 2018. The TPC cost range is $653,000,000 to $928,000,000. The funding profile supports the currently estimated TPC of $721,000,000. The CD-4 milestone is 1Q FY 2030. CD-0 established the mission need in FY 2015.

A Federal Project Director has been assigned to this project and has approved this CPDS. The FPD completed Level 3 certification in FY 2018, and Level 4 certification is in process.

Critical Milestone History

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2020	11/12/2015	7/23/2018	7/23/2018	3Q FY 2020	4Q FY 2021	4Q FY 2021	TBD	1Q FY 2030

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

Fiscal Year	Performance Baseline Validation	CD-3A
FY 2020	2Q FY 2020	3Q FY 2020

CD-3A – Approve long-lead procurement of niobium for SRF cavities, other long lead components for SRF cryomodules, completion of the remaining site preparation work, and construction of the building that will house the cryogenic plant.

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D	OPC, D&D	OPC, Total	TPC
FY 2020[a]	91,000	547,965	638,965	82,035	N/A	82,035	721,000

2. Project Scope and Justification

Scope

Specific scope elements of the PIP-II project include construction of (a) the SRF linac, (b) cryoplant to support SRF operation, (c) beam transfer line, (d) modifications to the Booster, Recycler and Main Injector synchrotrons, and (e) conventional facilities:

a) 800-MeV Superconducting H^- Linac consisting of a 2.1 MeV warm front-end injector and five types of SRF cryomodules that are CW-capable but operating initially in pulsed mode. The cryomodules include Half Wave Resonator cavities (HWR) at 162.5 MHz, two types of Single Spoke Resonator cavities (SSR1 and SSR2) at 325 MHz, Low-Beta and High-Beta elliptical cavities at 650 MHz (LB-650 and HB-650). The warm front-end injector consists of an H^- ion source, Low Energy Beam Transport (LEBT), Radiofrequency Quadrupole (RFQ) and Medium Energy Beam Transport (MEBT) that prepare the beam for injection into the SRF cryomodules. The scope includes the associated electronic power sources, instrumentation and controls to support linac operation.

   The PIP-II Injector Test Facility at Fermilab is an R&D prototype for the front-end injector consisting of H^- ion source, LEBT, RFQ, MEBT, HWR, and SSR1 cryomodule. It is being developed with participation and in-kind contributions from the India Department of Atomic Energy (DAE) Labs.

b) Cryoplant with storage and distribution system to support SRF linac operation. The cryoplant is an in-kind contribution by the India DAE Labs that is similar to the cryoplant being designed and constructed for a high-intensity superconducting proton accelerator project in India[b]
c) Beam Transfer Line from the Linac to the Booster Synchrotron, including accommodation of an 800-MeV beam dump and future delivery of beam to the Fermilab Muon Campus.
d) Modification of the Booster, Recycler and Main Injector synchrotrons to accommodate a 50% increase in beam intensity and construction of a new injection area in the Booster to accommodate 800-MeV injection.

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[a] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The preliminary TPC range at CD-1 is $653,000,000 to $928,000,000. The TPC point estimate is $721,000,000.
[b] See Section 8.

e) Civil construction of conventional facilities, including housings, service buildings, roads, access points and utilities with the special capabilities required for the linac and beam transport line. The linac housing will be constructed with adequate length to accommodate a future possible extension of the linac energy to 1.0 GeV.

Significant pieces of the linac and cryogenic scope (a and b, above) will be delivered as in-kind international contributions not funded by DOE. These include assembly and/or fabrication of linac SRF components and the cryoplant. The rationale or motivation behind these contributions are institutional and/or industrial technical capability, and interest in SRF technology. The construction phase scope of in-kind contributions is divided between U.S. DOE Labs, India Department of Atomic Energy (DAE) Labs, Italy National Institute for Nuclear Physics (INFN) Labs, French Atomic Energy Commission (CEA) and National Center for Scientific Research (CNRS)-National Institute of Nuclear and Particle Physics (IN2P3) Labs, and UK Science & Technology Facilities Council (STFC) Labs, tentatively as indicated in the following table of Scope Responsibilities for PIP-II.[a]

Construction-phase Scope Responsibilities for PIP-II Linac RF Components

Components	Quantity	Freq. (MHz)	SRF Cavities	Responsibility for Cavity Fabrication	Responsibility for Module Assembly	Responsibility for RF Amplifiers	Cryogenic Cooling Source
RFQ	1	162.5	—	—	U.S. DOE (LBNL)	U.S. DOE (FNAL)	N/A
HWR Cryomodule	1	162.5	8	U.S. DOE (ANL)	U.S. DOE (ANL)	U.S. DOE (FNAL)	India DAE Labs
SSR1 Cryomodule	2	325	16	U.S. DOE (FNAL), India DAE Labs	U.S. DOE (FNAL)	India DAE Labs	India DAE Labs
SSR2 Cryomodule	7	325	35	France CNRS (IN2P3 Lab)	U.S. DOE (FNAL)	India DAE Labs	India DAE Labs
LB-650 Cryomodule	11	650	33	Italy INFN (LASA)	France CEA (Saclay Lab)	India DAE Labs	India DAE Labs
HB-650 Cryomodule	4	650	24	UK STFC Labs	UK STFC Labs, U.S. DOE (FNAL)	India DAE Labs	India DAE Labs

Justification

Fermilab's high-energy neutrino beam, which is the world's most intense, is inadequate for further groundbreaking discovery in neutrino physics, a major field of fundamental research in high energy particle physics. Increasing the neutrino beam intensity requires increasing the proton beam power. The need for higher proton beam power comes at a time when critical components of the Fermilab accelerator complex (the linac and booster synchrotron) are approaching 50 years old and are in need of replacement.

PIP-II was identified as one of the highest priorities in the 10-year strategic plan for U.S. High Energy Physics developed by the High Energy Physics Program Prioritization Panel (P5) and unanimously approved by the High Energy Physics Advisory Panel (HEPAP), advising DOE and NSF, in 2014.[b]

The PIP-II project will enhance the Fermilab accelerator complex by enabling the capability to deliver higher-power proton beams to the neutrino-generating target that serves the LBNF/DUNE program.[c] The higher proton beam power will come from a 1.2 megawatt (MW) beam on target over an energy range of 60-120 GeV, a significant increase of beam power beyond the current proton beam capability.

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.

[a] See Section 8.

[b] "Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context," HEPAP, 2014.

[c] LBNF/DUNE is the DOE Long Baseline Neutrino Facility / Deep Underground Neutrino Experiment.

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. The KPPs shown below were approved at CD-1 and are preliminary. These KPPs will be updated and final versions will be approved at CD-2.

Performance Measure	Threshold	Objective
SRF Linac and Beam Transfer Line	700 MeV proton beam delivered to the Booster Injection Region	800 MeV proton beam delivered to the Booster Injection Region
Booster, Recycler and Main Injector Synchrotron Modifications	Booster injection region, Recycler and Main Injector RF Upgrades installed. Linac beam injected and circulated in the Booster	8 GeV proton beam transmitted through Recycler and Main Injector to the Main Injector beam dump
Cryogenic Infrastructure	Cryogenic plant and distribution lines ready to support pulsed RF operation, and operated to 2°K	Cryogenic plant and distribution lines ready to support CW RF operation, and operated to 2°K
Civil Construction	Tunnel enclosures and service buildings ready to support 700 MeV SRF Linac and Beam Transfer Line to the Booster	Tunnel enclosures ready to support 1 GeV SRF linac and transfer line to the Booster. Service Buildings ready to support 800 MeV SRF Linac and Beam Transfer Line to the Booster

3. Financial Schedule[a]

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs[b]
Total Estimated Cost (TEC)			
Design			
FY 2018	1,000	1,000	—
FY 2019	20,000	20,000	20,000[c]
FY 2020	15,000	15,000	15,000
Outyears	55,000	55,000	56,000
Total, Design	91,000	91,000	91,000
Construction			
FY 2020	5,000	5,000	5,000
Outyears	542,965	542,965	542,965
Total, Construction	547,965	547,965	547,965

[a] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The preliminary TPC range at CD-1 is $653,000,000 to $928,000,000. The TPC point estimate is $721,000,000.

[b] Costs through FY 2018 reflect actual costs; costs for FY 2019 and the outyears are estimates.

[c] Includes initiation of civil engineering design and site preparation for the cryoplant housing.

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs[b]
Total Estimated Costs (TEC)			
FY 2018	1,000	1,000	—
FY 2019	20,000	20,000	20,000
FY 2020	20,000	20,000	20,000[a]
Outyears	597,965	597,965	598,965
Total, TEC	**638,965**	**638,965**	**638,965**
Other Project Costs (OPC)			
FY 2016	18,715	18,715	12,724
FY 2017	15,220	14,155	17,494
FY 2018	23,100	24,165[b]	22,214
FY 2019	15,000	15,000	15,000
FY 2020	5,000	5,000	5,000
Outyears	5,000	5,000	9,603
Total, OPC	**82,035**	**82,035**	**82,035**
Total Project Costs (TPC)			
FY 2016	18,715	18,715	12,724
FY 2017	15,220	14,155	17,494
FY 2018	24,100	25,165	22,214
FY 2019	35,000	35,000	35,000
FY 2020	25,000	25,000	25,000
Outyears	602,965	602,965	608,568
Total, TPC	**721,000**	**721,000**	**721,000**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	76,000	N/A	N/A
Contingency	15,000	N/A	N/A
Total, Design	91,000	N/A	N/A

[a] Planned TEC activities are completion of site preparation and initiation of procurement for the cryoplant housing and the cryomodules.

[b] $1,065,000 of FY 2017 funding was attributed towards the Other Project Costs activities in FY 2018.

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Construction			
Site Work	20,000	N/A	N/A
Civil Construction	81,000	N/A	N/A
Technical Equipment	246,965	N/A	N/A
Contingency	200,000	N/A	N/A
Total, Construction	547,965	N/A	N/A
Total, TEC	**638,965**	**N/A**	**N/A**
Contingency, TEC	*215,000*	*N/A*	*N/A*
Other Project Cost (OPC)			
OPC except D&D			
R&D	50,935	N/A	N/A
Conceptual Planning	15,000	N/A	N/A
Conceptual Design	4,000	N/A	N/A
Contingency	12,100	N/A	N/A
Total, OPC	**82,035**	**N/A**	**N/A**
Contingency, OPC	*12,100*	*N/A*	*N/A*
Total Project Cost	**721,000**	**N/A**	**N/A**
Total, Contingency (TEC+OPC)	**227,100**	***N/A***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request	Type	Prior Years	FY 2018	FY 2019	FY 2020	Outyears	Total
FY 2020[a]	TEC	—	1,000	20,000	20,000	597,965	638,965
	OPC	33,935	23,100	15,000	5,000	5,000	82,035
	TPC	33,935	24,100	35,000	25,000	602,965	721,000

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	FY 2030
Expected Useful Life (number of years)	20
Expected Future Start of D&D of this capital asset	FY 2050

Fermilab will operate the PIP-II linac as an integral part of the entire Fermilab accelerator facility. Related funding estimates for operations, utilities, maintenance and repairs are incremental to the balance of the Fermilab accelerator complex for which the present cost of operation, utilities, maintenance and repairs is approximately $100 million annually.

[a] The project is Pre-CD-2 and has not been baselined. All estimates are preliminary. The preliminary TPC range at CD-1 is $653,000,000 to $928,000,000. The TPC point estimate is $721,000,000.

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Previous Total Estimate	**Current Total Estimate**	**Previous Total Estimate**	**Current Total Estimate**
Operations	N/A	4,000	N/A	80,000
Utilities	N/A	3,000	N/A	60,000
Maintenance & Repair	N/A	2,000	N/A	40,000
Total—Operations and Maintenance	N/A	9,000	N/A	180,000

7. 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 Fermilab	127,540
Area of D&D in this project at Fermilab	—
Area at Fermilab to be transferred, sold, and/or D&D outside the project, including area previously "banked"	—
Area of D&D in this project at other sites	—
Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked"	127,540
Total area eliminated	—

The one-for-one replacement will be met through banked space. A waiver from the one-for-one requirement to eliminate excess space at Fermilab to offset PIP-II and other projects 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 new facilities including Mu2e, LBNF, DUNE, and other facilities, as-yet unbuilt, from space that was banked at other DOE facilities. The PIP-II Project is following all current DOE procedures for tracking and reporting space utilization.

8. Acquisition Approach

DOE is acquiring the PIP-II project through Fermi Research Alliance (FRA), the Management and Operating (M&O) contractor responsible for Fermilab, 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 for PIP-II with an experienced team of project leaders managed by FRA, which will have primary responsibility for oversight of all subcontracts required to execute the project. The arrangement is expected to include subcontracts for the purchase of components from third party vendors as well as delivery of in-kind contributions from non-DOE partners.

Significant pieces of scope will be delivered as in-kind international contributions, not funded by U.S. DOE. The rationale or motivation behind these contributions are institutional and/or industrial technical capability, and interest in SRF technology. Scientific institutions from several countries, tabulated below, are engaged in discussion of potential PIP-II scope contributions within the framework of international, government-to-government science and technology agreements.

Scientific Agencies and Institutions Discussing Potential Contributions of Scope for PIP-II

Country	Funding Agency	Institutions
U.S.	Department of Energy (DOE)	Fermi National Accelerator Laboratory (FNAL); Lawrence Berkeley National Laboratory (LBNL); Argonne National Laboratory (ANL)
India	Department of Atomic Energy (DAE)	Bhabha Atomic Research Centre (BARC), Mumbai; Inter University Accelerator Centre (IUAC), New Delhi; Raja Ramanna Centre for Advanced Technology (RRCAT), Indore; Variable Energy Cyclotron Centre (VECC), Kolkata
Italy	National Institute for Nuclear Physics (INFN)	Laboratory for Accelerators and Applied Superconductivity (LASA), Milan
France	Atomic Energy Commission (CEA) National Center for Scientific Research (CNRS)	Saclay Nuclear Research Center; National Institute of Nuclear & Particle Physics (IN2P3), Paris
UK	Science & Technology Facilities Council (STFC)	Daresbury Laboratory

For example, joint participation by U.S. DOE and the India DAE in the development and construction of high intensity superconducting proton accelerator projects at Fermilab and in India is codified in Annex I to the “Implementing Agreement between DOE and Indian Department of Atomic Energy in the Area of Accelerator and Particle Detector Research and Development for Discovery Science for High Intensity Proton Accelerators,” signed in January 2015 by the U.S. Secretary of Energy and the India Chairman of DAE. A “Joint R&D Document” subsequently was developed between FNAL and the DAE Labs, outlining the specific roles and goals of the collaborators during the R&D phase of the PIP-II project. This R&D agreement is expected to lead to a similar agreement for the construction phase, describing roles and in-kind contributions. Similar agreements for PIP-II are being developed with Italy, France and the UK.

The Office of Science is putting mechanisms into place to facilitate joint consultation between the partnering funding agencies, such that coordinated oversight and actions will ensure the success of the overall program. Similar mechanisms for international partnering are being employed by the Office of Science successfully for the DOE LBNF/DUNE project and for DOE participation in LHC-related projects hosted by CERN.

Domestic engineering and construction subcontractors will perform the civil construction at Fermilab. An architectural-engineering contract was placed on a time-and-material basis for design of the site preparation scope. Fermilab is developing a procurement for an architectural-engineering contract on a firm fixed price basis for the overall Preliminary and Final Designs with an option for construction support. The general construction subcontract will be placed on a firm-fixed-price basis.

All subcontracts will be 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.

11-SC-40, Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment (LBNF/DUNE)
Fermi National Accelerator Laboratory
Project is for Design and Construction

1. Summary, Significant Changes, and Schedule and Cost History

<u>Summary</u>

The FY 2020 Request for Long Baseline Neutrino Facility (LBNF)/Deep Underground Neutrino Experiment (DUNE) is $100,000,000. The preliminary Total Project Cost (TPC) range is $1,260,000,000 to $1,860,000,000, as approved for CD-3A on September 1, 2016 with a preliminary CD-4 date of 4Q FY 2030. The range includes the full cost of the DOE contribution to the LBNF host facility and the DUNE experimental apparatus excluding foreign contributions.

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 and related realty actions 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. DOE continues to refine the development of the design and cost estimates as the U.S. DOE contributions to the multinational effort are now better understood. Fermilab continues to identify and incorporate additional design activities and prototypes into the project design. The cost estimate for the DOE contribution will be updated in FY 2019 as planning continues in preparation for CD-2.

Fermilab and DOE are negotiating contributions from the international partners to LBNF/DUNE. 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. In April 2018, DOE and India-Department of Atomic Energy (DAE) signed an agreement providing for neutrino physics collaboration between Fermilab and India, opening the way for advancing LBNF/DUNE project contributions. Fermilab is still finalizing the detailed distribution between the projects. For the DUNE detectors, the collaboration 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 review of the detector design with a complete set of funding responsibilities by the Long Baseline Neutrino Committee will take place in 2019. SC will manage all DOE contributions to the facility and the detectors according to DOE Order 413.3B, and Fermilab will provide unified project management reporting.

FY 2018 funding was used to continue project engineering design activities in preparation for CD-2, and to initiate pre-excavation site preparations for the equipment caverns at the Far Site as approved by CD-3A. FY 2019 funding supports an increase in the level of Far 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 2020 Request will support the Far Site civil construction activities for pre-excavation of the underground equipment caverns and connecting drifts (tunnels), as well as design and procurement activities for Far Site cryogenics systems. The Request will also support Near Site (Fermilab) beamline and conventional facilities design and a site-preparation construction subcontract at the Near Site for relocation of existing service roads and utilities including communications, power, and water systems. The Request supports the start of construction and fabrication for technical systems, which will be funded when design is final and authorized by CD-3, including contributions to the DUNE detectors.

Significant Changes

This Construction Project Data Sheet (CPDS) is an update of the FY 2019 CPDS and does not include a new start for FY 2020. This project was initiated with TEC funds in FY 2012.

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. 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. The refurbishment of the Ross Shaft, which will transport materials during the excavation of the caverns and the construction of the detectors, reached the 4,850 foot level, which is where the caverns will be excavated. The final design of the Far Site civil construction and the preliminary design of the beam line began.

Updated planning and analysis has increased the TPC point estimate for LBNF/DUNE to $1,850,000,000 and was reviewed by an Independent Project Review held January 8-10, 2019.

A Federal Project Director with a certification level 4 has been assigned to this project and has approved this CPDS.

Critical Milestone History

Fiscal Year	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
FY 2020	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 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

Fiscal Year	Performance Baseline Validation	CD-1R	CD-3A	CD-3B	CD-3(C)
FY 2017	1Q FY 2020	11/5/2015	2Q FY 2016	3Q FY 2018	1Q FY 2020
FY 2018	1Q FY 2021	11/5/2015	9/1/2016	1Q FY 2021	1Q FY 2022
FY 2019	1Q FY 2021	11/5/2015	9/1/2016	1Q FY 2021	1Q FY 2022
FY 2020	1Q FY 2021	11/5/2015	9/1/2016	1Q FY 2021	1Q FY 2022

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.)

Project Cost History

(dollars in thousands)

Fiscal Year	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[c]	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

[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.
[c] 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.

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC, Except D&D	OPC, D&D	OPC, Total	TPC
FY 2018	234,375	1,199,000	1,433,375	102,625	N/A	102,625	1,536,000
FY 2019	231,000	1,234,000	1,465,000	95,000	N/A	95,000	1,560,000
FY 2020[a b]	259,000	1,496,000	1,755,000	95,000	N/A	95,000	1,850,000

2. 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 capable of meeting the performance requirements if located underground, only liquid argon could work on the surface, and is less expensive. A low energy 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 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.

[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. An Independent Project Review was held January 8-10, 2019.

[b] 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.

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.

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 kiloton 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.

Performance Measure	Threshold	Objective
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.

3. Financial Schedule[a]

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Recovery Act Costs	Costs[b]
Total Estimated Cost (TEC)				
Design[c]				
FY 2012	4,000	4,000	—	—[d]
FY 2013	3,781	3,781	—	801
FY 2014	16,000	16,000	—	7,109
FY 2015	12,000	12,000	—	15,791
FY 2016	26,000	26,000	—	26,436[e]
FY 2017	48,585	48,585	—	37,257
FY 2018	25,000	25,000	—	39,829[f]
FY 2019	70,000	70,000	—	70,000
FY 2020	20,000	20,000	—	20,000
Outyears	33,634	33,634	—	41,777
Total, Design	259,000	259,000	—	259,000
Construction				
FY 2017	1,415	1,415	—	13,000
FY 2018	70,000	70,000	—	6,347[g]
FY 2019	60,000	60,000	—	60,000
FY 2020	80,000	80,000	—	80,000[h]
Outyears	1,284,585	1,284,585	—	1,336,653
Total, Construction	1,496,000	1,496,000	—	1,496,000
Total Estimated Costs (TEC)				
FY 2012	4,000	4,000	—	–
FY 2013	3,781	3,781	—	801
FY 2014	16,000	16,000	—	7,109

[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. Design and international collaboration plans are currently being developed; outyears are preliminary. An Independent Project Review was held January 8-10, 2019.

[b] Costs through FY 2018 reflect actual costs; costs for FY 2019 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 starting Far Site preparation including safety and reliability refurbishment of the underground infrastructure, which was 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.

[h] Estimated costs are for the Far Site civil construction excavation activities as well as design and procurement for Far Site cryogenics systems. Also will support beamline and conventional facilities design and a site-preparation construction subcontract at the Near Site (Fermilab).

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Recovery Act Costs	Costs[b]
FY 2015	12,000	12,000	—	15,791
FY 2016	26,000	26,000	—	26,436
FY 2017	50,000	50,000	—	50,257
FY 2018	95,000	95,000	—	46,176
FY 2019	130,000	130,000	—	130,000
FY 2020	100,000	100,000	—	100,000
Outyears	1,318,219	1,318,219	—	1,378,430
Total, TEC	**1,755,000**	**1,755,000**	**—**	**1,755,000**
Other Project Costs (OPC)				
FY 2009 Recovery Act	12,486[a]	12,486	—	—
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	—	13,232
FY 2014	10,000	10,000	—	11,505
FY 2015	10,000	10,000	—	10,079
FY 2016	86	86	—	2,284
FY 2017	—	—	—	120
FY 2018	1,000	1,000	—	86
FY 2019	1,000	1,000	—	1,000
FY 2020	4,000	4,000	—	4,000
Outyears	3,375	3,375	—	4,611
Total, OPC	**95,000**	**95,000**	**12,486**	**82,514**
Total Project Costs (TPC)				
FY 2009 Recovery Act	12,486	12,486	–	–
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	—	14,033
FY 2014	26,000	26,000	—	18,614

[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)

	Budget Authority (Appropriations)	Obligations	Recovery Act Costs	Costs[b]
FY 2015	22,000	22,000	—	25,870
FY 2016	26,086	26,086	—	28,720
FY 2017	50,000	50,000	—	50,377
FY 2018	96,000	96,000	—	46,262
FY 2019	131,000	131,000	—	131,000
FY 2020	104,000	104,000	—	104,000
Outyears	1,321,594	1,321,594	—	1,383,041
Total, TPC	**1,850,000**	**1,850,000**	**12,486**	**1,837,514**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	234,000	208,000	N/A
Contingency	25,000	23,000	N/A
Total, Design	259,000	231,000	N/A
Construction			
Far Site Civil Construction[a]	521,000	360,375	N/A
Fermilab Site Civil Construction[b]	370,000	317,375	N/A
Far Site Technical Infrastructure[c]	117,000	108,125	N/A
Fermilab Site Beamline[c]	107,000	125,125	N/A
DUNE Detectors	84,000	82,000	N/A
Contingency	297,000	241,000	N/A
Total, Construction	1,496,000	1,234,000	N/A
Total, TEC	**1,755,000**	**1,465,000**	**N/A**
Contingency, TEC	*322,000*	*264,000*	*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.

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
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
Other OPC Costs	9,375	9,375	N/A
Total, OPC	**95,000**	**95,000**	**N/A**
Total Project Cost	**1,850,000**	**1,560,000**	**N/A**
Total, Contingency (TEC+OPC)	***322,000***	***264,000***	***N/A***

5. Schedule of Appropriations Requests[a]

(dollars in thousands)

Request	Type	Prior Years	FY 2018	FY 2019	FY 2020	Outyears[b]	Total
FY 2011	TEC	102,000	—	—	—	—	102,000
	OPC	22,180	—	—	—	—	22,180
	TPC	124,180	—	—	—	—	124,180
FY 2012	TEC	133,000	—	—	—	—	133,000
	OPC	42,621	—	—	—	—	42,621
	TPC	175,621	—	—	—	—	175,621
FY 2016	TEC	51,781	—	—	—	731,612	783,393
	OPC	89,539	—	—	—	—	89,539
	TPC	141,320	—	—	—	731,612	872,932
FY 2017	TEC	106,802	—	—	—	1,307,659	1,414,461
	OPC	85,539	—	—	—	—	85,539
	TPC	192,341	—	—	—	1,307,659	1,500,000
FY 2018	TEC	111,781	54,900	—	—	1,266,694	1,433,375
	OPC	85,625	100	—	—	16,900	102,625
	TPC	197,406	55,000	—	—	1,283,594	1,536,000
FY 2019	TEC	111,781	54,900	113,000	—	1,185,319	1,465,000
	OPC	85,625	100	1,000	—	8,275	95,000
	TPC	197,406	55,000	114,000	—	1,193,594	1,560,000
FY 2020[c]	TEC	111,781	95,000	130,000	100,000	1,318,219	1,755,000
	OPC	85,625	1,000	1,000	4,000	3,375	95,000
	TPC	197,406	96,000	131,000	104,000	1,321,594	1,850,000

[a] Design and international collaboration plans are currently being developed; outyears are preliminary.

[b] Outyear requests are grouped as the project is pre-CD-2 and has not been baselined. All estimates are preliminary. For the first column of Request Year, the outyears represent the time period beyond that specific requested Budget Year.

[c] 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. An Independent Project Review was held January 8–10, 2019.

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy	FY 2030
Expected Useful Life (years)	20
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	
	Previous Total Estimate	**Current Total Estimate**	**Previous Total Estimate**	**Current 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—Operations and Maintenance	18,000	18,000	360,000	360,000

7. D&D Information

The new area being constructed in this project is replacing existing facilities.

	Square Feet
New area being constructed by this project at Fermi National Accelerator Laboratory	48,200
New area being constructed by this project at Sanford Underground Research Facility (SURF)	93,800
Area of D&D in this project at Fermi National Accelerator Laboratory	—
Area at Fermi National Accelerator Laboratory to be transferred, sold, and/or D&D outside the project, including area previously "banked"	48,200
Area of D&D in this project at other sites	—
Area at other sites to be transferred, sold, and/or D&D outside the project, including area previously "banked"	93,800
Total area eliminated	—

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.

8. 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 other DOE national laboratories (e.g. BNL, LBNL and SLAC), 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/DUNE-U.S. Project Office at Fermilab which will also manage and control DOE funding to the combination of university subcontracts and direct fixed-price vendor procurements that are anticipated for the design, fabrication and installation of LBNF and DUNE technical components. All actions will perform in accordance with 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, the laboratory will subcontract with an architect/engineer (A/E) firm for design, and with a CM/GC subcontractor to manage construction of LBNF Near Site facilities.

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 Barrick Gold Corporation for the sole purpose of facilitating scientific and technological research and development. Fermilab is contracting with an A/E firm for design of LBNF Far Site conventional facilities at SURF and with a CM/GC subcontractor 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 has 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 and related realty actions 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 was developed prior to lease signing.

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 resulting in an average of approximately 90 Ph.D. degrees awarded annually to students for research supported by the program. DOE NP is the steward of the nation's fundamental nuclear physics research portfolio; in FY 2018, DOE provided ~ 91% and NSF ~ 9 % of the total investment in the U.S. nuclear physics basic research portfolio. 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

[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).

to construct, support, and maintain the advanced instrumentation and world-class facilities used in experiments. The 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 2020, these facilities will provide particle beams for an international user community of almost 2,000 research scientists. In FY 2019, approximately 35 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 the 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 researchers to study quark structure. Construction of the Facility for Rare Isotope Beams (FRIB), a world-class nuclear physics scientific user facility with unique capabilities in nuclear structure and astrophysics, continues at Michigan State University (MSU), according to the baseline cost and schedule. This project is over 89% 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. The report[a], released in July 2018, strongly supports the scientific case for building a U.S.-based EIC, documenting that an EIC will advance the understanding of the origins of nucleon mass, the origin of the spin properties of nucleons, and the behavior of gluons. 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[b] (the Jones report), was invaluable in aligning R&D efforts to the highest priority efforts. The FY 2020 Request initiates Other Project Costs (OPC) support for conceptual design and R&D for the EIC.

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.

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[a] National Academies of Sciences, Engineering, and Medicine. 2018. *An Assessment of U.S.-Based Electron-Ion Collider Science.* Washington, DC: The National Academies Press. https://doi.org/10.17226/25171

[b]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

Highlights of the FY 2020 Request

The FY 2020 Request for $624,854,000 supports the highest priority efforts and capabilities in nuclear science to optimize scientific productivity. Research thrusts and instrumentation and construction initiatives are closely aligned to guidance from National Academy studies and the NSAC LRP. The supported initiatives, infrastructure, scientific user facilities, and R&D efforts maintain U.S. leadership in nuclear science. The Request will continue support for world-class discovery science research and R&D 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 increases support for 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 to support 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 includes an increase to develop new production capabilities for isotopes that are in short supply and of paramount importance for the Nation.

The Request for *Research* supports university and laboratory researchers to nurture critical core competencies and enable high priority theoretical and experimental activities to target compelling scientific opportunities at the frontier of nuclear science, and in concert with guidance from the NAS and the NSAC.
The FY 2020 Request supports world-class research in all 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;
- Targeted 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;
- The highest priority research in QIS to enable precision nuclear physics measurements, quantum simulations with trapped ions, and quantum computing solutions to otherwise intractable QCD challenges. NP participates in planned coordinated SC QIS research and facility activities;
- 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;
- 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;
- Funding for the initiation of the High Rigidity Spectrometer (HRS) instrumentation for FRIB. The HRS will enable the most sensitive experiments across the entire span of known nuclei, thereby enabling experiments with the most neutron-rich nuclei available at FRIB.
- Impactful studies into the nature of the neutron at the Fundamental Neutron Physics Beamline at the Spallation Neutron Source (SNS), and the development of the high-risk, high-discovery potential Neutron Electric Dipole Moment (nEDM) experiment; that could shed light on why there is more matter than anti-matter in the universe.
- The highest priority accelerator R&D of relevance to NP next-generation machines and to improve the performance of existing machines. Transformative accelerator science activities significantly advance the state-of-the-art in next-generation ion sources, SRF technology, beam physics and advanced materials for accelerators.
- Targeted investments to develop cutting-edge techniques based on Artificial Intelligence (AI) of relevance to nuclear science research, accelerator facility operations and automated machine operations in the DOE Isotope Program.
- Increased 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 1,500 hours in FY 2020. The Request allows for an initial run with the completed 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. Investments continue in the highest priority accelerator improvement projects and capital equipment for maintaining operations;
- Funding supports CEBAF to operate for 1,020 hours in FY 2020. This continues the highly anticipated science program of the 12 GeV machine with associated experimental instrumentation. Investments continue in the highest priority accelerator improvement projects and capital equipment for maintaining operations. A one-time increase to General Purpose Plant (GPP) funding is provided to fully fund a critical replacement End Station Refrigerator to mitigate end-of-life risk of current equipment and provide added capacity necessary for future experiments;
- ATLAS operates as the world's premiere stable ion beam facility for 2,090 hours to enable compelling experiments in nuclear structure and astrophysics. Investments continue in the highest priority accelerator improvement projects and capital equipment for maintaining operations;
- Operations funding will be provided to FRIB to partially support the operation of accelerator components as they complete fabrication and commissioning on the project, and the transition of some associated operational staff to the facility operations budget;
- Support is provided for the experimental physics University Centers of Excellence including the Center for Experimental Nuclear Physics and Applications (CENPA) at the University of Washington, the Research and Engineering Center at the Massachusetts Institute for Technology (MIT), the High Intensity Gamma Source (HIGS) at Duke University, and the Texas A&M Cyclotron Institute at the Texas A&M University (TAMU). These Centers provide niche capabilities and unique "hands-on" experiences in nuclear science.
- Funding fully supports mission readiness and nurtures critical core competencies at the 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 increased and networked into the DOE Isotope Program for the production of high priority short-lived isotopes. Operation of the Enriched Stable Isotope Prototype Plant (ESIPP) increases to replenish U.S. inventory, reduce dependence on foreign suppliers for research quantities of stable isotopes, and produce isotopes for quantum systems. The DOE Isotope Program participates in planned coordinated SC QIS research and facility activities.

The Request for *Construction and Major Items of Equipment (MIEs)* includes:

- Continued construction funding for the Facility for Rare Isotope Beams (FRIB), which will provide world-leading capabilities for nuclear structure and nuclear astrophysics; the project continues to make impressive progress and is over 89% complete. Construction funding continues according to the baselined profile.
- Initiation of engineering design of the U.S. Stable Isotope Production and Research Center (SIPRC) to significantly increase the domestic production capabilities of stable isotopes for scientific, industrial, national security and medical uses.
- Other Project Costs (OPC) funding to support high priority, critically needed accelerator R&D to retire high risk technical challenges for the proposed U.S.-based EIC. Subsequent to the FY 2018 National Academy of Science Report confirming the importance of a domestic EIC to sustain U.S. world leadership in nuclear science and accelerator R&D core competencies. Critical Decision-0, *Approve Mission Need*, is planned for FY 2019.
- Continued funding for the Gamma-Ray Energy Tracking Array (GRETA) MIE, which will enable provision of advanced, high resolution gamma ray detection capabilities for FRIB.
- Initiation of the Ton-scale Neutrinoless Double Beta Decay experiment to determine whether the neutrino is its own antiparticle. Critical Decision-0, *Approve Mission Need*, was approved in FY 2019.
- Support final year of funding for the Stable Isotope Production Facility (SIPF) MIE, which will provide increased domestic capability for production of critically needed enriched stable isotopes, and reduce the nation's dependence on foreign supply. While FY 2020 represents the final year of funding, this technically driven funding profile will support completion of the facility in FY 2024.

- Initiation of the Isotope Harvesting accelerator improvement project at FRIB. This modest project will add harvesting capabilities to the FRIB, which will provide access to a wide range of isotopes, including unusual isotopes for exploratory studies.
- Continued funding to support the super Pioneering High Energy Nuclear Interaction eXperiment (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. sPHENIX will be funded at a reduced level relative to the planned profile approved at CD-1/CD-3A.
- Initiation of the Measurement of a Lepton-Lepton Electroweak Reaction (MOLLER) MIE, which will measure the parity-violating asymmetry in electron-electron scattering with the 12 GeV CEBAF machine. This experiment will search for evidence of physics beyond our current understanding with unprecedented levels of precision, by comparing extremely small deviations in the outcomes of scattering experiments with the predictions of theory.

Nuclear Physics supports the following FY 2020 Administration Priorities.

FY 2020 Administration Priorities

(dollars in thousands)

	Quantum Information Science (QIS)
Nuclear Physics	7,000

Nuclear Physics
Funding

	(dollars in thousands)			
	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Medium Energy Nuclear Physics				
Research	40,050	43,286	35,500	-7,786
Operations	112,000	117,390	114,500	-2,890
Other Research	4,152	3,553	2,667	-886
SBIR/STTR	19,248	19,961	18,633	-1,328
Total, Medium Energy Nuclear Physics	**175,450**	**184,190**	**171,300**	**-12,890**
Heavy Ion Nuclear Physics				
Research	40,050	37,354	30,000	-7,354
Operations	187,500	193,125	186,000	-7,125
Total, Heavy Ion Nuclear Physics	**227,550**	**230,479**	**216,000**	**-14,479**
Low Energy Nuclear Physics				
Research	66,500	70,530	58,450	-12,080
Operations	29,250	30,215	36,838	+6,623
Total, Low Energy Nuclear Physics	**95,750**	**100,745**	**95,288**	**-5,457**
Nuclear Theory				
Theory Research	38,750	46,469	37,040	-9,429
Nuclear Data	8,600	8,858	7,726	-1,132
Other Project Costs	—	—	1,500	+1,500
Total, Nuclear Theory	**47,350**	**55,327**	**46,266**	**-9,061**
Isotope Development and Production for Research and Applications				
Research	11,000	9,808	12,000	+2,192
Operations	29,700	34,451	39,000	+4,549
Total, Isotopes[a]	**40,700**	**44,259**	**51,000**	**+6,741**
Subtotal, Nuclear Physics	**586,800**	**615,000**	**579,854**	**-35,146**

[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.

(dollars in thousands)

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Construction				
14-SC-50, Facility for Rare Isotope Beams	97,200	75,000	40,000	-35,000
20-SC-51, U.S. Stable Isotope Production and Research Center	—	—	5,000	+5,000
Total, Nuclear Physics	**684,000**	**690,000**	**624,854**	**-65,146**

SBIR/STTR Funding:

- FY 2018 Enacted: SBIR $16,875,000 and STTR $2,373,000
- FY 2019 Enacted: SBIR $17,500,000 and STTR $2,461,000
- FY 2020 Request: SBIR $16,336,000 and STTR $2,297,000

Nuclear Physics
Explanation of Major Changes

	(dollars in thousands) FY 2020 Request vs FY 2019 Enacted
Medium Energy Nuclear Physics	**-12,890**
The Request supports the highest priority research in medium energy nuclear physics at universities and national laboratories. 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, and operation of the recently upgraded CEBAF accelerator to support 1,020 operating hours. The Request provides support for experimental activities that will utilize some of the newly upgraded experimental halls to implement the 12 GeV CEBAF physics program; 12 GeV researchers from national laboratories and universities implement, commission, and operate the highest priority new experiments at CEBAF. The Request fully funds the End Station Refrigerator GPP to mitigate substantial risk to CEBAF operation. The Request supports high priority investments in capital equipment and accelerator improvement projects for CEBAF to maintain viability of the facility, and continues investments in maintenance activities and cryomodule refurbishment at CEBAF to improve the performance and reliability of the machine. The Request initiates support for the MOLLER MIE, which will measure the parity-violating asymmetry in electron-electron scattering at CEBAF. Funding continues for the highest priority accelerator R&D to support transformative accelerator science activities that significantly advance the state-of-the-art and activities to reduce risk in next-generations NP machines and improve performance of operating machines.	
Heavy Ion Nuclear Physics	**-14,479**
The Request supports the highest priority research in heavy ion nuclear physics at universities and national laboratories. 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 1,500 hour run, high priority core competencies, and experimental activities to prepare scientific instrumentation and infrastructure for the scientific program. The FY 2020 run will continue the 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. The Request supports the highest priority RHIC facility investments in capital equipment and accelerator improvement projects to maintain viability of the facility. Funding decreases for the ongoing sPHENIX MIE which will study high rate jets of particles at RHIC. Support for the U.S. participation in the complementary LHC program continues although annual U.S. commitments and fees for participation and computing are deferred until the following year, which may impact U.S. participation. Funding continues for the highest priority accelerator R&D to support transformative accelerator science activities that significantly advance the state-of-the-art and activities to reduce risk in next-generations NP machines and improve performance of operating machines.	

	(dollars in thousands)
	FY 2020 Request vs FY 2019 Enacted
Low Energy Nuclear Physics	**-5,457**

The Request supports the highest priority university and laboratory nuclear structure and nuclear astrophysics efforts at the ATLAS facility, which will operate for 2,090 hours. The Request supports targeted ATLAS facility investments in accelerator and scientific instrumentation capital equipment. Funding decreases for the ongoing GRETA MIE for FRIB according to the project plan; 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. The Request initiates the compelling High Rigidity Spectrometer to exploit the fast beam capabilities at FRIB. The Request maintains 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. Funding maintains operations of the three experimental University Centers of Excellence, the Texas A&M Cyclotron Facility, the HIGS at the Triangle Universities Nuclear Laboratory, and the CENPA at the University of Washington. Funding for Fundamental Symmetries research supports the highest priority activities in neutrinoless double beta decay domestically and abroad to determine whether the neutrino is its own antiparticle; funding is requested for the highest priority R&D towards next-generation experiments and the initiation of a world-leading ton-scale experiment MIE to reach unprecedented sensitivities. Funding in Fundamental Symmetries also includes targeted efforts such as the Fundamental Neutron Physics Beamline at the SNS and the continued development of its flagship experiment that, the nEDM experiment, to study neutron properties and study matter/anti-matter asymmetries in the universe.

Nuclear Theory	**-9,061**

The Request supports the highest priority theory research efforts at laboratories and universities, the U.S. Nuclear Data Program, and continues specialized Lattice Quantum Chromodynamics (LQCD) computing hardware at TJNAF and participation in SCIDAC. The Request supports targeted investments in QIS and quantum computing (QC), including the highest priority 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. The Request includes OPC funding for conceptual design and high risk R&D for the proposed Electron-Ion Collider, which recently received a strong endorsement from the National Academy of Sciences.

	(dollars in thousands) **FY 2020 Request vs FY 2019 Enacted**
Isotope Development and Production for Research and Applications The Request increases funding for university and laboratory research in new isotope production techniques and establishes core R&D groups at two new Isotope Program sites – ANL and MSU. The Request also initiates the FRIB Isotope Harvesting project, an accelerator improvement project at MSU, is supported to that will add isotope harvesting capabilities to the accelerator. Funding continues to support targeted efforts to produce Ac-225 and develop other promising cancer therapeutic isotopes for clinical trials and applications. Operations funding increases to effectively support mission readiness for production activities at national laboratory facilities. The Request provides a modest increase in university operations for a network of university accelerators and reactors to establish cost-effective, regional production of short-lived isotopes for research and medical applications; this includes the University of Washington cyclotron and University of Missouri Research Reactor. A modest increase provides for additional staff at the National Isotope Development Center to effectively address the significantly expanded Isotope Program product portfolio and the development of Drug Master Files for new medical isotopes. ESIPP is operated to produce research quantities of enriched stable isotopes. The Request includes increased funding to enhance activities related to the development of enriched isotopes for next generation quantum information systems and for the DOE Isotope Program participation in the coordinated SC QIS research and facility activities. The Request supports investments to increase isotope availability and production capabilities, including He-3 for cryogenics, Li-7 for reactor operations, infrastructure investments to increase processing capabilities of radioisotopes, and the development of new enriched stable isotope production capabilities for targeted isotopes.	**+6,741**
Construction Construction funding ramps down according to the baselined profile for the Facility for Rare Isotope Beams. Engineering effort and long-lead procurements begins on the new United States Stable Isotope Production and Research Center (U.S. SIPRC) to expand the nation's capabilities for expanded production capabilities.	**-30,000**
Total, Nuclear Physics	**-65,146**

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/or technical expertise through the SciDAC projects and Lattice QCD research 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 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 and the Federal Bureau of Investigations [FBI]). NP leads an Inter-Agency working group including NNSA, Department of Homeland Security (DHS), NE, the DOE Isotope Program and other Federal Agencies to coordinate targeted experimental efforts on opportunistic measurements to address serious gaps and uncertainties in existing nuclear data archives. 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]); and research in developing neutron, gamma, and particle beam sources with applications in cargo screening (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, Intelligence and Counterintelligence (IN), Environmental Management (EM), 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, Department of Transportation (DOT), NSF, the National Institute of Standards and Technology (NIST), Office of the Director of National Intelligence (ODNI), Department of State (DOS), and DOE) to ensure that isotopes are available for the federal complex to accomplish its missions.

Program Accomplishments

Science Under Pressure. New results from scattering electrons off quarks inside nuclei at the Continuous Electron Beam Accelerator Facility (CEBAF) indicate that the average peak pressure experienced by quarks near the center of protons is about 10^{35} pascals, or about 10 times greater than the pressure estimated inside the densest neutron stars. At the very center of a proton, the pressure experienced by quarks is strongly repulsive. At greater distances from the center, it is attractive. These results will allow exploration of the fundamental gravitational properties of protons, neutrons and nuclei. They will also help with the continuing quest by modern physics to gain a microscopic understanding of how quarks are confined within the protons and neutrons forming the nucleus of every atom and the visible mass of the universe. The recently commissioned 12 GeV CEBAF, which is now delivering beams to four experimental halls simultaneously, will enable a watershed of new scientific insights including a search for previously unobserved exotic mesons, a sensitive search for new physics, new understanding of the origin of the proton's spin, and pioneering tomographic imaging of the proton.

Nuclear and Atomic Worlds in Collision Impact the Synthesis of Heavy Elements. Within the atom's microsphere, the protons and neutrons in the nucleus and its much larger surrounding electron cloud, don't normally interact much. Held together at a distance by mutual Coulomb attraction they are almost always non-interacting. Rarely however, via a process called "internal conversion" these two subatomic worlds collide and an excited nucleus emits an energetic electron. This process is known and has been observed; since 1976 however, the question has been whether the inverse process is also possible. That question has now been answered by scientists working at Argonne National Lab. They made the first observation of a free electron captured into an atomic vacancy resulting in a nucleus being excited to a higher energy state, called nuclear excitation by electron capture (NEEC). This is particularly significant for models of how heavy elements are synthesized in violent events in the cosmos. Nuclear states called isomers produced in such cosmic furnaces can be particularly long-lived, dramatically impacting the time at which heavy nuclei are "forged". The discovery of NEEC means the density of long-lived states can be strongly depleted in favor of shorter lived nuclear states, dramatically accelerating processes by which stable heavy elements, such as gold and platinum, are produced.

A needle in a million-billion-trillion nuclear haystack. Three first-generation experiments have now confirmed that, if one has the patience to search for an entire year, less than one out of a million-billion-trillion atomic nuclei will decay via neutrino-less double beta decay. The Majorana Demonstrator (MJD), the Cryogenic Underground Observatory for Rare Events (CUORE), and the Enriched Xenon Observatory (EXO-200) all now know this is true because they searched diligently for more than a year and didn't see a signal. Neutrino-less double beta decay occurs if two neutrons in a nucleus each decay into a proton and an electron with no emission of neutrinos. The observation of neutrino-less double beta decay would be a paradigm-changing discovery indicating that the neutrino is its own anti-particle—a discovery with profound implications for the nature of the neutrino, and for resolving the mystery of why the neutrino mass is much, much smaller than the other leptons and the quarks. Ultimately a limit for detection or exclusion of neutrino-less double beta decay 10-100 times more stringent is the target of future research and next-generation proposed detectors.

An unanticipated new window into the workings of QCD. RHIC has the exceptional advantage of being a dedicated scientific facility for "chasing down" scientific clues about one of nature's most guarded mysteries—how QCD, the theory of the strong force, works. To advance understanding in this area, in 2018, RHIC accelerated beams of isobars –Ruthenium-96 (Ru-96) and Zirconium-96 (Zr-96) -- nuclei with the same total number of protons and neutrons but with different numbers of protons and neutrons individually. In this case, the four additional protons in Ru-96 compared to Zr-96 were critical. That's because Ru-96 nuclei colliding at nearly the speed of light should generate a significantly larger instantaneous magnetic field than collisions of Zr-96. If current theory conjecture is correct about the origin of parity violating charged particle correlations previously observed in such collisions at RHIC, the differing magnetic fields for the two isobars should result in a 15-20% difference in their magnitude. Confirmation of this hypothesis would provide groundbreaking new access to the microscopic workings of QCD. Enriched Ru-96 was not available anywhere in the world, so the RHIC team needed an assist from ORNL scientists in the DOE Isotope Program who also had to accomplish something extraordinary to help out: develop new capability for electromagnetic separation of isotopes. This challenging technical development required an intense effort, but knowing that RHIC had a small window in its experimental program to accomplish the isobar measurement, the ORNL isotope team commissioned the new enrichment capability and produced the rare Ru-96 on time. Results indicating whether the newly observed phenomena at RHIC constitute another important discovery should be available in about a year.

Enabling life-saving Research through Availability of Actinium-225. One of the most breathtaking developments in cancer treatment is recent success in trials which treat metastasized late-stage prostate cancer with the use of the alpha-emitting isotope Ac-225. Ac-225 is one of a number of alpha emitting isotopes, which if delivered to the site of a cancer cell, will irradiate a microscopic volume of tissue in its immediate vicinity, leaving healthy tissue farther away unharmed. Trial results have been stunningly successful[a]. Beyond the efficacy of this approach however, the key to making treatment options viable is sufficient quantities of Ac-225 to fully support clinical trials and therapy. The DOE Isotope Program formed a Tri-Laboratory Collaboration of scientists at Brookhaven, Los Alamos, and Oak Ridge National Laboratories with unique facilities and expertise to develop large-scale production capacity of Ac-225. The Tri-Laboratory Collaboration is now routinely producing up to 50 millicuries (mCi) batches of Ac-225 twice a month for clinical trials and will soon be capable of routine bi-weekly production runs of 100 mCi. Ultimately, the effort will be scaled up to bi-weekly production runs of at least 1,000 mCi --the equivalent of the current annual U.S. production of Ac-225 based on harvesting from the natural decay of legacy thorium-229.

Terra Incognita Near the Island of Stability for Super-heavy Nuclei. Oganesson (Og) is one of four new super-heavy elements confirmed by the International Union of Pure and Applied Physics and added to the periodic table of the elements and the chart of nuclides. Og has an atomic number of 118 (the heaviest element ever confirmed), and a half-life of less than a

[a] J. Nucl. Med., 2016; 57 (12); 1941 DOI: 10.2967/jnumed.116.178673 C. Kratochwil

millisecond. Discovered indirectly by nuclear physicists via observation of characteristic alpha particle decay chains, the chemical properties and electron structure of Og and its companions (Nihonium, Moscovium, Tennessine) are currently conjecture. To help unfold this mystery, using state-of-the art atomic and nuclear models and advanced computational tools, an international team of researchers, supported in part by the Office of Nuclear Physics, has calculated the electronic and nucleonic shell structure of Og. Formerly speculated to be a gas under normal conditions, Og is now predicted to be a metal at room temperature. Surprisingly, it may also be significantly reactive, unlike all the other elements of the group it identifies with (the noble gases) in the periodic table. These results are a significant contribution to the voyage of discovery to determine the properties of Og and its companion super-heavy nuclei.

A New Attack on the Problem of the Neutrino Mass. Even though neutrinos hold a special place in the workings of the universe, one of their most basic properties, their mass, is unknown. The international KATRIN experiment in Germany, in which U.S. nuclear physicists play leading scientific and technical roles, recently achieved a major milestone with the introduction of tritium to the experimental apparatus to begin first measurements of the electrons from tritium decay. If the energy of such electrons is measured precisely, the mass of neutrinos from tritium decay can be reconstructed via conservation of momentum and energy. The KATRIN experiment is the largest and most precise instrument of its type so far, with a goal of setting a limit on the neutrino mass significantly smaller than the currently available model dependent limits. With the start of operations of the experiment, the stage is set for the eagerly awaited data to achieve its experimental goals.

Thin Skinned Neutron Stars in the Cosmos. The first detection of a binary neutron star merger by the LIGO-Virgo collaboration is providing fundamentally new insights into the astrophysical site for the rapid-neutron capture process ("r-process") responsible for the creation of most heavy elements in the Universe. Theorists supported by the Office of Nuclear Physics confronted the predictions of realistic models of the equation of state (EOS) of matter against experimental data extracted from the LIGO gravitational-wave data. Given the sensitivity of the gravitational-wave signal to the underlying EOS, constraints can be placed on the neutron star radius. Based on these constraints, models that predict large stellar radii can be ruled out and an upper limit of about 0.25 femtometers is inferred for the neutron-skin thickness.

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 was 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. Next generation instrumentation to fully exploit the capabilities of the 12 GeV CEBAF are implemented, including the MOLLER MIE initiated in FY 2020, which will measure the parity-violating asymmetry in electron-electron scattering at CEBAF. 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 can be conducted at the HIGS at TUNL, Fermilab, Europe, and elsewhere. The Research and Engineering Center of the Massachusetts Institute of Technology (MIT) has specialized infrastructure used to develop and fabricate advanced instrumentation and accelerator equipment.

Since the 2002 LRP for Nuclear Science, a compelling, persistent, high scientific priority for the U.S. nuclear science community has been understanding how the fundamental properties of the proton such as its mass and spin are dynamically generated by the extraordinarily strong color fields resulting from dense systems of gluons in nucleons and nuclei. The answer to this question is key to addressing an outstanding grand challenge problem of modern physics: how Quantum Chromodynamics, the theory of the strong force, which explains all strongly interacting matter in terms of points-like quarks interacting via the exchange of gluons, acts in detail to generate the "macroscopic" properties of protons and neutrons. The 2015 LRP for Nuclear Science concluded, "…a high energy, polarized electron ion collider is the highest priority for new facility construction following the completion of FRIB." Most recently a National Academy of Science study charged to independently assess the impact, uniqueness, and merit of the science that would be enabled by U.S. construction of an electron-ion collider gave a strong endorsement to a U.S.-based EIC, and recognized its critical role in maintaining U.S. leadership in nuclear science and accelerator R&D. Scientists and accelerator physicists from both the Medium Energy and Heavy Ion sub-programs are actively engaged in the development of the scientific agenda, conceptual design of the facility, accelerator R&D and development of scientific instrumentation R&D related to a proposed EIC.

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.

Research

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 LBNL to carry out the highest priority research programs and experiments at CEBAF, RHIC, and elsewhere. Scientists participate in the development and implementation of targeted 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 focus on the 12 GeV experimental program, including implementation of select experiments, acquisition of data, and 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. Scientists at TJNAF and elsewhere participate in the initiation of the MOLLER MIE, which will measure the parity-violating asymmetry in electron-electron scattering.

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. The Request prioritizes support for transformative accelerator science activities that significantly advance the state-of-the-art. Researchers participate in the conceptual design of the EIC and development of scientific and experimental plans for the proposed machine.

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 team of accelerator physicists at TJNAF that operate CEBAF, as well as for power costs of operations and maintenance of the 12 GeV CEBAF. The Request provides investments in the highest priority accelerator improvements aimed at addressing CEBAF reliability and the highest priority capital equipment for research and facility instrumentation. Included in the Request is a one-time increase to GPP funding to fully fund a critically needed replacement of the End Station Refrigerator to mitigate end-of-life risk of current equipment and provide required additional capacity for future experiments. Support is provided for targeted 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 Linac Coherent Light Source (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. Accelerator scientists participate in the development of the EIC conceptual design. 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.

Activities and Explanation of Changes

FY 2019 Enacted		FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Medium Energy Nuclear Physics	**$184,190,000**	**$171,300,000**	**-$12,890,000**
Research	$43,286,000	$35,500,000	-$7,786,000
The FY 2019 Enacted budget supports scientific participation in the 12 GeV experimental program at CEBAF. 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.		The FY 2020 Request provides support for key scientists participating in the highest priority experiments taking data in select experimental halls at the CEBAF 12 GeV program. This includes support for critical 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. The Request continues targeted analysis of RHIC polarized proton beam data to learn more about the origin of the proton's spin and focused support for high priority accelerator R&D. The MOLLER MIE, which will measure the parity-violating asymmetry in electron-electron scattering, is initiated.	Decreased research funding supports high priority research activities and critical scientific workforce at universities and national laboratories conducting research at CEBAF, RHIC and other facilities. Decreased research funding supports high priority efforts in accelerator R&D activities that support transformational accelerator science and aimed at reducing risk and improving performance. The Request initiates the MOLLER MIE.
Operations	$117,390,000	$114,500,000	-$2,890,000
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 supports 4,080 operational hours of running for research, tuning, and beam studies. Experiments in multiple halls will be operated for data taking.		Operations of the newly upgraded CEBAF facility will support the continuation of the highest priority experiments in the 12 GeV science program. Funding will support 1,020 operational hours for research, tuning, and beam studies. The Request provides support to maintain critical core competencies that will increase the reliability of the CEBAF and conduct experiments in select halls. The Request supports targeted facility capital equipment, accelerator	The Request includes a one-time increase to GPP funding to fully fund a critical replacement End Station Refrigerator to mitigate end-of-life risk of current equipment and provide added capacity for future experiments.

FY 2019 Enacted	FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
	improvements, and the End Station Refrigerator GPP project. Accelerator scientists will participate in the highest priority accelerator R&D.	
Other Research $3,553,000	$2,667,000	-$886,000
Funding is provided for DOE and Office of Science requirements.	Funding is provided for DOE and Office of Science requirements.	Funding is provided for DOE and Office of Science central IT and working capital requirements.
SBIR/STTR $19,961,000	$18,633,000	-$1,328,000
Funding will be provided in accordance with the Small Business Innovation Development Act and subsequent related legislation.	Funding will be provided in accordance with the Small Business Innovation Development Act and subsequent related legislation.	The SBIR/STTR funding will be consistent with the NP total budget.

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 and whether a critical point exists in the phase diagram of nuclear matter. Within available resources, scientists participate in instrumentation upgrades, such as enhancements to the capabilities of the STAR detector, and an upgrade of the PHENIX detector to sPHENIX with funds previously used to operate the PHENIX detector. Accelerator physicists participate in 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 accelerators. The RHIC facility is typically used by about 1,200 DOE, NSF, and foreign agency-supported researchers annually.

Since the 2002 LRP for Nuclear Science, a compelling, persistent, high scientific priority for the U.S. nuclear science community has been understanding how the fundamental properties of the proton such as its mass and spin are dynamically generated by the extraordinarily strong color fields resulting from dense systems of gluons in nucleons and nuclei. The answer to this question is key to addressing an outstanding grand challenge problem of modern physics: how Quantum Chromodynamics, the theory of the strong force, which explains all strongly interacting matter in terms of points-like quarks interacting via the exchange of gluons, acts in detail to generate the "macroscopic" properties of protons and neutrons. The 2015 LRP for Nuclear Science concluded, "…a high energy, polarized electron ion collider is the highest priority for new facility construction following the completion of FRIB." Most recently a National Academy of Science study charged to independently assess the impact, uniqueness, and merit of the science that would be enabled by U.S. construction of an electron-ion collider gave a strong endorsement to a U.S.-based EIC, and recognized its critical role in maintaining U.S. leadership in nuclear science and accelerator R&D.[a] Scientists and accelerator physicists from both the Medium Energy and Heavy Ion sub-programs are actively engaged in the development of the scientific agenda, conceptual design of the facility, accelerator R&D and development of scientific instrumentation R&D related to a proposed EIC.

[a] Report: https://www.nap.edu/read/25171/chapter/1

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.

Research
The subprogram supports key heavy ion research groups at BNL, LBNL, LANL, and the Oak Ridge National Laboratory (ORNL) to participate in the highest priority efforts at RHIC and the LHC. U.S. commitments to the LHC “common funds”, fees to support individual U.S. scientist participation in the LHC program and the use of LHC computing capabilities, are deferred to the following year. In FY 2020, university workforce will also be focused on the highest priority efforts at RHIC and the LHC.

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.

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. Transformative accelerator science activities that significantly advance the state-of-the-art are a priority in the Request. Researchers participate in the conceptual design of the EIC and development of scientific and experimental plans for the proposed machine in FY 2020.

Operations
The Heavy Ion subprogram provides decreased support for the operations and power costs of the RHIC accelerator complex at BNL. In FY 2020, the Request supports the highest priority capital equipment and accelerator improvement projects at RHIC. 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 key experimental support to the facility, including the development, implementation, and commissioning of scientific equipment associated with the RHIC program. In FY 2020, the only detector operating at RHIC is STAR; PHENIX operations funding is redirected to continue to upgrade the PHENIX detector to the sPHENIX MIE. 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. Accelerator Improvement Projects in prior years have focused on the LEReC Project, installed in FY 2018, which cools low energy heavy ion beams with bunched electron beam and is projected to increase the luminosity by up to another factor of ten.

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. RHIC accelerator physicists are providing leadership and expertise to reduce technical risk of relevance to a possible next-generation collider, including beam cooling techniques and energy recovery linacs; they continue to participate in EIC-specific R&D and the development of a conceptual design for the EIC 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. Support for the mission readiness of BLIP is included in the Isotope Sub-program, while collected revenues from customers support the operations of the facility.

Activities and Explanation of Changes

FY 2019 Enacted		FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Heavy Ion Nuclear Physics	**$230,479,000**	**$216,000,000**	**-$14,479,000**
Research	$37,354,000	$30,000,000	-$7,354,000
Researchers 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 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 are supported.		Critical researchers will participate in the highest priority 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. The Request provides targeted support for scientific workforce resident at RHIC and outside universities and national laboratories to develop, fabricate, implement and maintain scientific instrumentation; participate in select experimental runs to acquire data; analyze data and publish experimental results; develop scientific plans and instrumentation for a proposed EIC; and train students in nuclear science. The Request also provides support to enable scientists to continue to implement the sPHENIX MIE for the study of high rate particle jets. U.S. scientists participate in the highest priority heavy ion efforts at the international ALICE, CMS, and ATLAS LHC experiments. In addition, the Request supports the highest priority accelerator R&D relevant to NP programmatic needs.	Decreased research funding supports critical workforce at universities and national laboratories associated with implementing the high priority RHIC science program. U.S. participation in the LHC continues, but commitments to the LHC “common funds”, fees to support individual U.S. scientist participation in the LHC program and the use of LHC computing capabilities, are deferred.

FY 2019 Enacted	FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Operations $193,125,000	$186,000,000	-$7,125,000
RHIC will operate for 3,290 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.	RHIC will operate for 1,500 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, 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, the highest priority facility and instrumentation capital equipment, the highest priority accelerator improvement projects, and the key computing capabilities for data taking and analysis. Support is provided to maintain critical core competencies and essential accelerator scientists, engineers, and technicians, and RHIC operations staff. Limited operations funding is redirected to the sPHENIX MIE which will study high rate particle jets; the impact to the sPHENIX cost and schedule will be assessed upon a FY 2020 Appropriation. Accelerator scientists participate in the highest priority accelerator R&D.	The Request provides limited support for facility and instrumentation capital equipment and Accelerator Improvement Projects to maintain the viability of the machine. Adjustment of support below project plans enables the continuation of the sPHENIX MIE while optimizing operations within available funds.

Nuclear Physics
Low Energy Nuclear Physics

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 that depend on U.S. leadership for their ultimate success (CUORE, KATRIN), and R&D of candidate technologies for next–generation experiments, including germanium (MJD and LEGEND), xenon (nEXO) and tellurium (CUPID). In partnership with the NSF, NP initiated support for the LEGEND-200 prototype in FY 2019. The NSAC 2015 LRP has as its second recommendation "the timely development and deployment of a U.S.-led ton-scale neutrinoless double beta decay experiment." Neutrino-less double beta decay can only occur if neutrinos are their own anti-particles and the observation of "lepton number violation" in such events would have profound, game changing consequences for the present understanding of the physical universe. The Request includes funding for the initiation of a Ton-Scale Neutrinoless Double Beta Decay (NLDBD) MIE, which is expected to provide unprecedented resolution for the detection of the rare process; the MIE received CD-0, Approve Mission Need, in November 2018.

Beams of cold and ultracold neutrons at the SNS are used to study fundamental properties of neutrons, and 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 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 over 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. ATLAS stewards a target development laboratory, the National Center for Accelerator Target Science, a national asset for the low energy community, including FRIB.

There are two university Centers of Excellence within the Low Energy subprogram with specific goals and unique physics programs: the Cyclotron Institute at TAMU and accelerator facilities at the TUNL at Duke University. A third university center, 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 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. Support for FRIB operations retains critical operations staff as accelerator components on the project are completed and efforts transition to operations. The Gamma-Ray Energy Tracking Array (GRETA) MIE 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 searches, and open new areas of study in nuclear astrophysics. The High Rigidity Spectrometer (HRS) at FRIB specifically exploits the fast beam capabilities of this powerful accelerator. The HRS will enable the most sensitive experiments across the entire chart of nuclei, thereby enabling experiments with the most neutron-rich nuclei available at FRIB.

<u>Research</u>

The subprogram will support the highest priority 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. The Request provides limited support of the GRETA MIE. Essential scientists are supported to participate in the initiation of the HRS MIE to exploit the fast beam capabilities of FRIB, and to conduct research in fundamental symmetries, including experiments at the Fundamental Neutron Physics Beamline (FNPB) at the SNS. Focused R&D continues towards an experiment to measure the electric dipole moment of the neutron, which could shed light on the asymmetry of matter versus antimatter in the universe. Currently operating double beta-decay experiments continue to acquire data, 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. The highest priority R&D aimed at a ton-scale neutrinoless double beta decay experiment continues with nEXO and the provision of scientific and technical leadership to LEGEND-200. U.S. researchers lead the initiation of an international ton-scale NLDBD MIE. Scientists participate in the operations of the Karlsruhe Tritium Neutrino (KATRIN) experiment at the Karlsruhe Institute of Technology in Karlsruhe, Germany to provide a measurement of the neutrino mass. The Request provides support to the university Centers of Excellence at TUNL, CENPA and TAMU for the conduct of experiments at these niche facilities. Funding to nurture an FRIB-specific research community is deferred in the short term.

Operations

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. In FY 2020, the Low Energy subprogram provides decreased support for the operations and power costs of the ATLAS. The subprogram provides decreased support for high priority accelerator and scientific instrumentation capital equipment, high priority accelerator improvement projects and experimental support of ATLAS. The facility complexity has been increasing, with the addition of 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 gas filled analyzer.

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. Critical efforts continue in developing technology that could reduce the backlog of experiments and increase available beam time, such as the multi-user upgrade Accelerator Improvement Project which will significantly increase the beam hours available for experiments to the scientific community.

The Request includes funding to support partial FRIB operations and retain the most critical operations staff as accelerator components are completed on the project and efforts begin to transition to operations. Staff commission accelerator components and perform system tests. The Request also provides support to maintain operations support of the 88-Inch Cyclotron for an in-house nuclear physics program.

Activities and Explanation of Changes

FY 2019 Enacted		FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Low Energy Nuclear Physics	**$100,745,000**	**$95,288,000**	**-$5,457,000**
Research	$70,530,000	$58,450,000	-$12,080,000
University and laboratory nuclear structure and nuclear astrophysics efforts are focused 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 continues with the Majorana Demonstrator and nEXO to consider performance of different technologies in neutrinoless double beta decay experiments; research is initiated, in partnership with the NSF, for the LEGEND-200 experiment. U.S. participation in the operations of the international KATRIN and CUORE experiments continues, 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 GRETA MIE is supported according to the planned profile.		The FY 2020 Request supports the highest priority university and laboratory nuclear structure and nuclear astrophysics efforts at ATLAS, the world's premiere stable beam facility, and development of the FRIB scientific program. Research support to ramp up funding for FRIB scientific personnel is deferred. Research continues at the unique university-based Centers of Excellence at TUNL, CENPA and TAMU. The Majorana Demonstrator, LEGEND-200 and nEXO continue their highest priority efforts. The Request initiates a ton-scale NLDBD MIE. U.S. participation in the operations of the international KATRIN and CUORE experiments continue. The Request will provide support for the GRETA MIE below its planned profile and initiates the HRS MIE for FRIB; the impact to the GRETA cost and schedule will be assessed upon a FY 2020 Appropriation.	The Request supports the highest priority efforts and essential workforce at universities and national laboratories associated with implementing experiments at ATLAS. Reduced funding will continue to enable progress on the GRETA MIE, and offsets initiation of the HRS for FRIB and the Ton-Scale NLDBD MIE.
Operations	$30,215,000	$36,838,000	+$6,623,000
The FY 2019 Enacted budget supports the operation of ATLAS to address the high demand for ATLAS beam time, which continues to exceed availability. ATLAS funding at this cost-effective facility will support 6,400 hours of beam time. Funding is also provided to ramp up the operations activities for FRIB according to plan.		The FY 2020 Request supports operation of ATLAS to partially address the high demand for ATLAS beam time, which continues to far exceed availability. ATLAS funding at this cost-effective facility will support 2,090 hours of beam time, maintenance, and the highest priority accelerator improvement projects and capital equipment for the facility and scientific instrumentation. Funding maintains operations of the 88" Cyclotron and to partially ramp up the operations activities for FRIB relative to planned levels.	Operations support for FRIB is increased but remains below the planned level. Funding supports reduced beam hours for experiments at ATLAS and reduced investments in capital equipment efforts and accelerator improvement projects.

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. Nuclear Theory addresses all three of NP's scientific thrusts. 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. It also supports topical collaborations within the university and national laboratory communities 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 provides evaluated cross-section and decay data relevant to a broad suite of Federal missions and topics. USNDP also supports targeted experimental efforts on opportunistic measurements to address serious gaps and uncertainties in existing nuclear data archives. The NP leads an Inter-Agency working group including NNSA, DHS, NE, the DOE Isotope Program and other Federal Agencies to coordinate targeted experimental 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. NP supports LQCD computing needs for dedicated computational resources with investments at JLab.

Nuclear physicists participate in activities related to QIS and quantum computing (QC), in coordination with other SC research program offices. NP-specific efforts 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.

Since the 2002 LRP for Nuclear Science, a compelling, persistent, high scientific priority for the U.S. nuclear science community has been understanding how the fundamental properties of the proton such as its mass and spin are dynamically generated by the extraordinarily strong color fields resulting from dense systems of gluons in nucleons and nuclei. The answer to this question is key to addressing an outstanding grand challenge problem of modern physics: how

Quantum Chromodynamics, the theory of the strong force, which explains all strongly interacting matter in terms of points-like quarks interacting via the exchange of gluons, acts in detail to generate the “macroscopic” properties of protons and neutrons. The 2015 LRP for Nuclear Science concluded, “…a high energy, polarized electron ion collider is the highest priority for new facility construction following the completion of FRIB.” Most recently a National Academy of Science study charged to independently assess the impact, uniqueness, and merit of the science that would be enabled by U.S. construction of an electron ion collider gave a strong endorsement to a U.S.-based EIC, and recognized its critical role in maintaining U.S. leadership in nuclear science and accelerator R&D. Scientists and accelerator physicists from both the Medium Energy and Heavy Ion subprograms are actively engaged in the development of the scientific agenda, design of the facility and development of scientific instrumentation related to a proposed EIC. Other Project Costs (OPC) efforts related to the development of a Conceptual Design and high risk design-specific R&D are supported out of the Theory Subprogram.

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 advances our fundamental understanding of nuclear physics, interpreting the results of experiments carried out under the auspices of the experimental nuclear physics program, and identifies and explores compelling new areas of research. The Request continues 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 some continued support in FY 2020: 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 supports high priority efforts on FRIB theory, 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 address the needs of the NP program and provide technological and computational advances relevant to other fields. Following exploratory QIS/QC workshops at the Institute for Nuclear Theory and at Argonne National Laboratory, as well as a QC “test-bed” simulation to demonstrate proof-of-principle use of quantum computing for scientific applications, an NSAC charge in FY 2019 will further articulate the priority areas in QIS/QC where unique opportunities exist for nuclear physics contributions. The output of that exercise will help to further elucidate priorities for targeted funding opportunities in FY 2020.

Five year SciDAC-4 awards selected in FY 2017 continue in FY 2020 with progress monitored via peer review. In addition to addressing specific problems relevant for nuclear physics research SciDAC-4 projects continue to serve as a water-shed for training scientists who can address national needs.

The Request includes funding to support the most essential activities of the USNDP to collect, evaluate, and disseminate nuclear physics data for basic nuclear research and for applied nuclear technologies and their development. In addition to improving the completeness and reliability of data already archived that is used for industry and for a variety of Federal missions, NP funding enables targeted experiments to address gaps in the data archives deemed of high priority and urgency. Examples of targeted measurements include gamma ray spectroscopy of relevance for medical isotope science; nuclear beta decay data and reactor decay heat data of relevance for optimizing the emergency cooling systems of nuclear reactors and for the control of fast breeder reactors, anti-neutrino data relevant for basic research, and ^{238}U(n,n'gamma) cross section data using neutron-gamma coincidences important for several Federal missions. Experimental measurements targeted by NP for funding are carried out in coordination with projects funded by other Federal offices in response to the joint Funding Opportunity Announcement for Nuclear Data issued by the NP-led Inter-Agency Nuclear Data Working Group.

Activities and Explanation of Changes

FY 2019 Enacted		FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Nuclear Theory	**$55,327,000**	**$46,266,000**	**-$9,061,000**
Theory Research	$46,469,000	$37,040,000	-$9,429,000
The FY 2019 Enacted budget supports QIS efforts, including support for QIS research and LQCD computing. Funding supports 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 supports the third year of support for SciDAC-4 grants and the fourth year for the theory topical collaborations initiated in FY 2016.		Funding will support the highest priority QIS efforts and LQCD computing hardware investments at JLab. Funding will support the most essential 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 planned research program at FRIB, and ongoing and planned RHIC experiments. Within available funding, support will be provided for the fourth year of SciDAC-4 grants and the final year of theory topical collaborations initiated in FY 2016.	The funding supports the highest priority efforts and critical workforce at universities and national laboratories associated with nuclear theory, SCIDAC and the FRIB Theory Alliance. Reduced funding supports activities in QIS/QC that are of high importance to NP and related to QIS/QC applications.
Other Project Costs	$—	$1,500,000	+$1,500,000
None.		The FY 2020 Request will provide for the first year of Other Project Costs for the Electron Ion Collider, aimed at research to reduce technical risk and the development of a conceptual design.	The Electron Ion Collider OPC support is initiated in FY 2020.

FY 2019 Enacted	FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Nuclear Data $8,858,000	$7,726,000	-$1,132,000
The FY 2019 Enacted budget supports the USNDP's efforts to collect, evaluate, and disseminate nuclear physics data for basic nuclear research and for applied nuclear technologies and their development. Funding supports a modest experimental component to address gaps in the existing nuclear data, in coordination with the interests and support of other federal agencies.	The FY 2020 Request will provide support for the highest priority USNDP efforts to collect, evaluate, and disseminate nuclear physics data for basic nuclear research and for applied nuclear technologies and their development. The FY 2020 Request would also provide funding for some critical experimental measurements to address gaps in existing nuclear data.	Funding supports the most essential Nuclear Data efforts and workforce, and allows for focused support of experimental nuclear data efforts.

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:

- actinium-225, actinium-227, tungsten-188, lutetium-177, strontium-90, and cobalt-60 for cancer therapy;
- californium-252 for well logging, homeland security, and energy security;
- germanium-68 for the development of gallium-68 radiopharmaceuticals for cancer imaging;
- berkelium-249, americium-243, plutonium-242, californium-251, and curium-248 for use as targets for discovery of new superheavy elements;
- selenium-75 for industrial radiography;
- 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; 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, NIST, 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,

[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.

to communicate advances in isotope production research and availability, 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 Subcommittee on Critical and Strategic Mineral Supply Chains, and the Interagency Group on Helium-3, which it leads, that reports to the White House National Security Staff. 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, jointly supported with the Office of Basic Energy Sciences program, 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 innovative 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 advanced 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 and universities 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 workforce 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 Isotope Program published in July 2015 under the title "Meeting Isotope Needs and Capturing Opportunities for the Future[a]." The Isotope Program also supports research to implement modern stable isotope enrichment devices to provide the Nation with 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. Since FY 2017, the program has been able to produce small-scale research quantities of enriched stable isotopes. The R&D program also develops domestic production capabilities for important radioisotopes for which the U.S. has demand and/or which the U.S. is dependent on foreign sources.

[a] Report: https://science.energy.gov/~/media/np/nsac/pdf/docs/2015/2015_NSACI_Report_to_NSAC_Final.pdf

A high priority is a dedicated research effort to develop large scale production capabilities of actinium-225, a high priority isotope that has shown stunning success in the treatment of diffuse cancers and infections; in the past, available quantities have limited clinical trials and applications. The Isotope Program commenced routine production of accelerator-produced Ac-225 in FY 2018 and is now ramping up production capabilities to enable sufficient supply of the isotope as a cancer therapeutic. Research efforts have demonstrated that the accelerator produced actinium-225 functions equivalently to the material derived from the decay of thorium-229 which used to be 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.

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.

<u>Operations</u>
The Isotope Program is the steward of the Isotope Production Facility (IPF) at LANL, the BLIP facility at BNL, and hot cell facilities for processing and handling irradiated materials and purified products at ORNL, BNL, and LANL. Funding provides mission readiness for isotope production at all of these facilities, as well as facilities at other sites, such as the Idaho National Laboratory reactor for the production of cobalt-60, the 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. Funding supports the essential personnel and infrastructure to ensure mission readiness for the production of isotopes; the isotope production costs are paid by the customer. Modest capital investments enable substantial and compelling enhancements to productivity, including new approaches to extract additional He-3 from new sources; the fabrication of a prototype production capability for Li-7, pertinent to next generation nuclear reactors; and upgrades to hot cell facilities at ORNL and LANL to increase radioisotope processing capabilities to keep up with new isotopes being produced for the community, including Ac-225.

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 University of Missouri Research Reactor 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. Also, in anticipation of the opportunity FRIB will provide as a unique source of many important isotopes for research and applications, scientists are implementing the capability to harvest some of the isotopes that will be produced during physics research experiments. The Request includes funding to initiate this accelerator improvement project, the FRIB Isotope Harvesting project.

The DOE Isotope Program supports operations of ESIPP to produce research quantities of enriched stable isotopes through the use of electromagnetic separation and centrifuge technology. The first campaign run at ESIPP produced ruthenium-96 in FY 2018 to provide the otherwise unavailable target material world-wide to RHIC for its planned physics program. Modest investments develop new and different enriched stable isotope and enriched radioisotope production capabilities. The Isotope Program participates in the Office of Science QIS initiative to develop production approaches for enriched stable isotopes of interest for future QIS-driven technologies.

The SIPF MIE was initiated in FY 2017 to establish kilogram production capability of select isotopes 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 SIPF MIE will reduce the nation's dependence for some critical isotopes on a foreign source and has a technically-driven profile for completion in FY 2024. SIPF adds additional gas centrifuge capability to the existing ESIPP. Examples of discovery research efforts that could benefit from the facility are neutrinoless double beta decay experiments and high energy physics dark matter experiments 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. SIPF will be able to partially meet the demands for these isotopes serially.

The capabilities of SIPF and ESIPF are not adequate to meet the quickly rising demands of the Nation for enriched stable isotopes. Additional capabilities in both electromagnetic ion separation and gas centrifuge capability are needed for the U.S. to play a strong role in this arena and operate multiple production lines simultaneously. Funding is requested in the FY 2020 Request to initiate construction of the U.S. Stable Isotope Production and Research Center (U.S. SIPRC) to consolidate stable isotope efforts throughout ORNL into a new building, and enhance electromagnetic ion separation and gas centrifuge production capabilities for enriched stable isotopes.

Activities and Explanation of Changes

FY 2019 Enacted	FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Isotope Development and Production for Research and Applications **$44,259,000**	**$51,000,000**	**+$6,741,000**
Research $9,808,000	$12,000,000	+$2,192,000
High priority competitive R&D activities continue at universities and national laboratories leading to new isotope production technologies. Core support will continue to be provided to national laboratories and universities for R&D that enhances isotope production capabilities.	Increased funding will support 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 and universities for R&D that enhances isotope production capabilities specifically relevant to the physical resources and expertise available at the institution. Funding supports the development of two new core R&D groups, one at MSU to support the new isotope harvesting capability being established at FRIB, and the other at ANL to support the new isotope production effort at the LEAF electron facility at ANL.	Increased funding supports additional compelling efforts at universities and national laboratories in isotope production and processing research. The Request strengthens support for core research groups at the national laboratories and universities and nurtures two new core R&D groups, one at MSU for isotope harvesting and the other at ANL related to isotope production at LEAF.
Operations $34,451,000	$39,000,000	+$4,549,000
The FY 2019 Enacted budget supports mission readiness of the isotope production facilities and the essential 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 supports mission readiness and operations of the ESIPP for the production of important enriched stable isotopes for the nation. The budget provides support to develop production approaches for stable	Increased funding fully supports mission readiness of the isotope production facilities and nurtures critical core competencies in isotope production and development, ensuring that isotope orders for cancer therapy and other commitments are reliably met. The Request provides a modest increase for NIDC activities to effectively interface with the growing stakeholder community and isotope portfolio. Increased funding permits a stronger and expanded University Isotope Production Network and increased ESIPP operations. Increased funding will provide	The funding for SIPF ramps down according to the planned profile. This decrease is offset with increases for robust mission readiness of isotope production and processing facilities, university isotope production, NIDC workforce to address the growing isotope portfolio, and development of isotope production approaches of importance for QIS, and modest and compelling investments in developing new production and processing capabilities including: new extraction techniques for He-3 from new

FY 2019 Enacted	FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
isotopes of interest for next generation QIS-driven technologies. The SIPF MIE is supported at its planned level. Funding supports the addition of new universities into the National University Isotope Production Network, which will emphasize production of astatine-211 for cancer therapy.	support to develop production approaches for isotopes of interest for next generation QIS-driven technologies. The FY 2020 Request includes final funding for the SIPF MIE, according to the planned profile. Investments will also provide support to develop new production and processing capabilities including: new extraction techniques for He-3 from new supplies, highly enriched Li-7 prototype production capabilities for next-generation nuclear reactors, electromagnetic separation production approaches optimized to heavy elements, enriched radioisotope separation, infrastructure investments to enhance processing capabilities, and the initiation of isotope harvesting capabilities at FRIB.	supplies, and the initiation of isotope harvesting capabilities at FRIB.

Nuclear Physics
Construction

Description

Consistent with the 2015 NSAC Long-Range Plan's highest priority, the FY 2020 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 one ongoing project, which receives construction line item funding in FY 2020; one new project, which receives initial Other Project Costs in this Request in the Nuclear Theory subprogram; and another new project which receives initial construction funding in the Isotope Program subprogram.

The FRIB at MSU will continue construction activities in FY 2020, 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 FY 2020 Request initiates a Total Project Cost start for the U.S. Stable Isotope Production and Research Center (U.S. SIPRC). The demand for enriched stable isotopes over the last decade has increased significantly. Demand drivers include enriched stables isotopes for medical, national security and fundamental research projects. DOE produced a legacy inventory of enriched stable isotopes using the former Y-12 plant Calutrons from the 1940s to 1990s, until they were decommissioned. DOE's supply of certain key enriched stable isotopes has been depleted or exhausted. Therefore the U.S. is becoming increasingly dependent on foreign imports for enriched stable isotopes. With support from the DOE Isotope Program, ORNL is advancing production capabilities for these stable isotopes, primarily electromagnetic isotope separation (EMIS) and gas centrifuge (GC) technologies. Electromagnetic isotope separators can separate isotopes for many elements to very high purity and at lower production rates while gas centrifuge production cascades can produce much larger quantities of isotopes but is limited to those isotopes that have compatible feedstock chemicals. The prototype capabilities of ESIPP, developed through DOE Isotope Program-supported research, demonstrated the feasibility of new EMIS and GC technology. The follow-on SIPF MIE, currently under construction, modestly increases GC production capability. SIPRC further expands GC production capability and significantly increases EMIS production capability to meet the Nation's growing demand for stable isotopes. To date, the current and modest production capabilities have been housed in several refurbished facilities; however, given the mission need for continued expansion of production capacity, the use of refurbished facilities is not optimal. Therefore, SIPRC will include a new facility at ORNL to integrate aspects of the stable isotope program such as EMIS and GC technologies; R&D units; and storage and dispensing operations. The new single facility will promote operational, cost and security effectiveness, with space for future growth, if needed. SIPRC will mitigate the Nation's dependence on foreign countries for stable isotope supply. Critical Decision-0 (CD-0), Approve Mission Need, was awarded in January of 2019 with a preliminary Total Project Cost Range of $150 – 200M at the time of CD-0.

Activities and Explanation of Changes

FY 2019 Enacted		FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Construction	**$75,000,000**	**$45,000,000**	**-$30,000,000**
14-SC-50, Facility for Rare Isotope Beams (FRIB)	$75,000,000	$40,000,000	-$35,000,000
The FY 2019 Enacted funding supports 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.		The FY 2020 Request will continue to support the fabrication, assembly, and testing of cryomodules, as well as their installation within the FRIB linear accelerator located in the tunnel area. As portions of the linear accelerator nears completion, commissioning efforts will also continue in order to validate accelerator's performance according to project requirements. In addition, fabrication, assembly, installation and testing of the experimental technical systems will continue; project completion is planned in FY 2022.	FRIB construction funding continues according to its baseline profile.
20-SC-51, U.S. Stable Isotope Production and Research Center (ORNL)	$—	$5,000,000	+$5,000,000
Funding in FY 2019 provides for the development of a conceptual design of the U.S. Stable Isotope Production and Research Center (U.S. SIPRC).		FY 2020 funding is requested for engineering design of the U.S. SIPRC and long lead procurements for known designs of technologies developed for prior efforts, ESIPP and SIPF.	Funding is requested to initiate the Total Estimated Cost ($150,000,000-$200,000,000) of the U.S. SIPRC.

Nuclear Physics
Capital Summary

(dollars in thousands)

	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Capital Operating Expenses Summary						
Capital equipment	N/A	N/A	22,402	38,025	17,418	-20,607
Minor Construction Activities						
General Plant Projects (GPP)	N/A	N/A	2,000	2,060	9,500	+7,440
Accelerator Improvement Projects (AIP)	N/A	N/A	4,929	5,077	6,929	+1,852
Total, Capital Operating Expenses	**N/A**	**N/A**	**29,331**	**45,162**	**33,847**	**-11,315**

Nuclear Physics
Capital Equipment

	(dollars in thousands)					
	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Capital Equipment						
Major Items of Equipment (MIE)						
Medium Energy Nuclear Physics						
MOLLER MIE	25,000-35,000	N/A	N/A	—	300	+300
Heavy Ion Nuclear Physics						
Super-PHENIX (sPHENIX) MIE[a]	24,200-34,500	N/A	N/A	5,310	3,000	-2,310
Low Energy Nuclear Physics						
Gamma-Ray Energy Tracking Array (GRETA) MIE	52,000–65,000[b]	N/A	5,200	6,600	2,500	-4,100
High Rigidity Spectrometer (HRS)[c]	80,000-90,000	N/A	N/A	—	1,000	+1,000
Neutrinoless Double Beta Decay MIE	215,000-250,000	N/A	N/A	—	1,440	+1,440
Isotope Development and Production for Research and Development						
Stable Isotope Production Facility (SIPF) MIE	25,500–28,000	N/A	10,000	11,500	1,500	-10,000
Total Non-MIE Capital Equipment	N/A	N/A	7,202	14,615	7,678	-6,937
Total, Capital Equipment	**N/A**	**N/A**	**22,402**	**38,025**	**17,418**	**-20,607**

[a] 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.

[b] Total Project Cost range

[c] HRS will be funded through a cooperative agreement with MSU and is not a capital asset.

Nuclear Physics
Minor Construction Activities

	(dollars in thousands)					
	Total	**Prior Years**	**FY 2018 Enacted**	**FY 2019 Enacted**	**FY 2020 Request**	**FY 2020 Request vs FY 2019 Enacted**
General Plant Projects						
Greater than or equal to $5M and less than $20M						
End Station Refrigerator at TJNAF	9,500	—	—	—	9,500	+9,500
Total GPPs, greater than or equal to $5M and less than $20M	9,500	—	—	—	9,500	+9,500
Total GPPs less than $5M[a]	N/A	N/A	2,000	2,060	—	-2,060
Total, General Plant Projects (GPP)	**N/A**	**N/A**	**2,000**	**2,060**	**9,500**	**+7,440**
Accelerator Improvement Projects (AIP)						
Greater than or Equal to $5M and less than $20M						
RHIC Low Energy Electron Cooling	8,300	7,000	1,300	—	—	—
FRIB Isotope Harvesting[b]	9,000-11,000	N/A	N/A	—	2,000	+2,000
Total AIPs (greater than or equal to $5M and less than $20M)	N/A	N/A	1,300	—	2,000	+2,000
Total AIPs less than $5M	N/A	3,652	3,629	5,077	4,929	-148
Total, Accelerator Improvement Projects	**N/A**	**10,652**	**4,929**	**5,077**	**6,929**	**+1,852**
Total, Minor Construction Activities	**N/A**	**N/A**	**6,929**	**7,137**	**16,429**	**+9,292**

[a] GPP activities less than $5M include design and construction for additions and/or improvements to land, buildings, replacements or additions to roads, and general area improvements.
[b] FRIB Isotope Harvesting will be funded through a cooperative agreement with MSU and is not a capital asset.

Nuclear Physics
Major Items of Equipment Description(s)

Medium Energy Nuclear Physics MIE:
The *Measurement of a Lepton-Lepton Electroweak Reaction (MOLLER)* experiment directly supports the Nuclear Physics mission by measuring the parity-violating asymmetry in electron-electron (Møller) scattering. CD-0 was approved December 2016 with an estimated Total Project Cost of $25,000,000 to $35,000,000. The proposed MOLLER experiment is an ultra-precise measurement of the weak mixing angle using Møller scattering which will improve on existing measurements by a factor of five, yielding the most precise measurement of the weak mixing angle at low or high energy anticipated over the next decade. This new result would be sensitive to the interference of the electromagnetic amplitude with new neutral current amplitudes as weak as $\sim 10^{-3}$ GF from as yet undiscovered dynamics beyond the Standard Model. The resulting discovery reach is unmatched by any proposed experiment measuring a flavor- and CP-conserving process over the next decade, and yields a unique window to new physics at MeV and multi-TeV scales, complementary to direct searches at high energy colliders such as the Large Hadron Collider (LHC). The FY 2020 Request for MOLLER of $300,000 is the first year of TEC funding.

Heavy Ion Nuclear Physics MIE:
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-1/3a was approved in August 2018 with a TPC range of $24,200,000 to $34,500,000. 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 2020 Request for sPHENIX of $3,000,000 is the second year of TEC funding and below the planned amount; project plans will be re-evaluated upon an FY 2020 appropriation to consider changes to the project cost and schedule.

Low Energy Nuclear Physics MIEs:
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 (TPC) of $52,000,000–$67,000,000. CD-1 was obtained in September FY 2017. CD-3a was obtained in September 2018 with an estimated TPC of $52,000,000 - $65,000,000. The FY 2020 Request for GRETA of $2,500,000 is the fourth year of Total Estimated Cost (TEC) funding and is below the planned amount; project plans will be re-evaluated upon an FY 2020 appropriation to consider changes to the project cost and schedule.

The *High Rigidity Spectrometer (HRS) MIE*: FRIB will be the world's premier rare-isotope beam facility producing a majority (~80%) of the isotopes predicted to exist. Eleven of the 17 NSAC Rare Isotope Beam Taskforce benchmarks, which were introduced to characterize the scientific research of a rare-isotope facility, require the use of fast beams at FRIB. The scientific impact of the FRIB fast beam science program will be substantially enhanced (by luminosity gain factors of between two and one hundred for neutron-rich isotopes, with the largest gains for the most neutron-rich species) by construction of the HRS. The HRS will allow experiments with beams of rare isotopes at the maximum production rates for fragmentation or in-flight fission. This enhancement in experimental sensitivity provides access to critical isotopes not available otherwise. The HRS will increase the scientific reach by an order of magnitude for other state-of-the-art and community-priority devices, such as the GRETA, in addition to other ancillary detectors. The 2015 NSAC LRP recognized that the "*HRS…will be essential to realize the scientific reach of FRIB"*. The FY 2020 Request for the HRS of $1,000,000 is the first year of funding. The HRS will be funded through a cooperative agreement with MSU and is not a capital asset. CD-0 was approved November 2018 with a TPC range of $80,000,000 - $90,000,000.

The *Ton-Scale Neutrino-less Double Beta Decay (NLDBD) Experiment* MIE, implemented by instrumenting a large volume of a specially selected isotope to detect neutrino-less nuclear beta decays (within a single nucleus, two neutrons decay into two protons and two electrons with no neutrinos emitted) directly supports DOE NP's mission to explore all forms of nuclear matter. Neutrino-less double beta decay can only occur if neutrinos are their own anti-particles and the observation of "lepton number violation" in such neutrino-less beta decay events would have profound, game changing consequences for present understanding of the physical universe. For example, one exciting prospect is that the observation of neutrino-less double beta decay would elucidate the mechanism, completely unknown at present, by which the mass of the neutrino is generated. The observation of lepton number violation would also have major implication for the present day matter/anti-matter asymmetry which has perplexed modern physics for decades. In the current experimental outlook, through FY 2018 a number of demonstrator efforts using smaller volumes of isotopes and various technologies (bolometry in TeO2 crystals, light collection in LXe, charge collection in enriched Ge-76) have been in progress for several years, and all are in the process of delivering new state-of-the-art lifetime limits for $0\nu\beta\beta$ which are of order a few times 10^{25} years. The goal of a next generation ton-scale experiment is to reach a lifetime limit of 10^{27} to 10^{28} years. For reference, the "lifetime limit" discussed is the time one might have to wait to observe neutrino-less double beta decay if observing a single nucleus only. Fortunately, in the ton of isotope planned for the ton-scale neutrino-less double beta decay experiment there are many trillions of nuclei. Thus, such decays, if they exist, should be observable on a much more reasonable timescale (5-10 years) similar to other large modern physics experiments. The FY 2020 Request for a Ton Scale Neutrino-less Double Beta Decay Experiment is $1,440,000 in the first year of TEC funding. CD-0 was approved November 2018 with a TPC range of $215,000,000 - $250,000,000.

<u>Isotope Development and Production for Research and Applications MIE:</u>
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 TPC of $9,500,000–$10,500,000. CD-1/3a was approved in May 2018 with an estimated TPC range of $25,500,000-$28,000,000. The FY 2020 Budget requests the final year of funding for SIPF.

Nuclear Physics
Construction Projects Summary

(dollars in thousands)

	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
14-SC-50, Facility for Rare Isotope Beams						
DOE TPC	635,500[a]	418,000[b]	97,200	75,000	40,000	-35,000
20-SC-51, U.S. Stable Isotope Production and Research Center						
TPC	150,000-200,000	—	—	—	5,000	+5,000
Total, Construction (TPC)	**N/A**	**N/A**	**97,200**	**75,000**	**45,000**	**-30,000**

Funding Summary

(dollars in thousands)

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Research	180,502	204,095	172,476	-31,619
Scientific User Facilities Operations	324,250	336,145	333,038	-3,107
Other Facility Operations	24,200	27,586	41,800	+14,214
Projects (includes Other Project Costs)				
Major Items of Equipment	15,200	23,410	9,740	-13,670
Facility for Rare Isotope Beams	97,200	75,000	40,000	-35,000
U.S. Stable Isotope Production and Research Center	—	—	5,000	+5,000
Electron Ion Collider (OPC)	—	—	1,500	+1,500
Total, Projects	112,400	98,410	56,240	-42,170
Other[c]	23,400	23,764	21,300	-2,464
Total, Nuclear Physics	**684,000**	**690,000**	**624,854**	**-65,146**

[a] 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.

[b] A portion of the PY funding was provided within the Low Energy subprogram. The FY 2014 appropriation established FRIB as a control point.

[c] Includes SBIR/STTR funding.

Nuclear Physics
Scientific User Facility Operations

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.

(dollars in thousands)

	FY 2018 Enacted	FY 2018 Current	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
TYPE A FACILITIES					
CEBAF (TJNAF)[a]	**$122,930**	**$123,810**	**$128,067**	**$124,964**	**-3,103**
Number of Users	1,600	1,615	1,615	800	-815
Achieved operating hours	N/A	2,415	N/A	N/A	N/A
Planned operating hours	2,660	2,660	4,080	1,020	-3,060
Optimal hours	2,660	2,660	4,250	4,320	+70
Percent optimal hours	100.0%	90.8%	96.0%	23.6%	-72.4%
Unscheduled downtime hours	—	—	N/A	N/A	N/A

[a] 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.

(dollars in thousands)

	FY 2018 Enacted	FY 2018 Current	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
RHIC (BNL)	**$194,022**	**$194,048**	**$199,705**	**$192,116**	**-7,589**
Number of Users	988	988	985	985	—
Achieved operating hours	N/A	4,055	N/A	N/A	N/A
Planned operating hours	3,170	4,054	3,290	1,500	-1,840
Optimal hours	3,170	3,170	3,700	3,700	—
Percent optimal hours[a]	100.0%	127.9%	88.9%	40.5%	-48.4%
Unscheduled downtime hours	—	—	N/A	N/A	N/A
ATLAS (ANL)	**$25,481**	**$25,241**	**$25,947**	**$22,756**	**-3,191**
Number of Users	360	208	410	145	-265
Achieved operating hours	N/A	5,747	N/A	N/A	N/A
Planned operating hours	5,800	5,800	6,400	2,090	-4,310
Optimal hours	6,600	6,600	6,800	6,800	—
Percent optimal hours	87.9%	87.1%	94.1%	30.7%	-63.4%
Unscheduled downtime hours	—	—	N/A	N/A	N/A
FRIB (MSU)	**$3,750**	**$3,750**	**$3,950**	**$13,538**	**+9,588**
Number of Users	N/A	N/A	N/A	N/A	N/A
Achieved operating hours	N/A	N/A	N/A	N/A	N/A
Planned operating hours	N/A	N/A	N/A	N/A	N/A
Optimal hours	N/A	N/A	N/A	N/A	N/A
Percent optimal hours	N/A	N/A	N/A	N/A	N/A
Unscheduled downtime hours	N/A	N/A	N/A	N/A	N/A

[a] RHIC was able to exceed planned optimal hours in FY 2018 due to unanticipated high reliabilities associated with the low energy beam scans.

(dollars in thousands)

	FY 2018 Enacted	FY 2018 Current	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Total Facilities	**$346,183**	**$346,849**	**$357,669**	**$353,374**	**-4,295**
Number of Users	2,948	2,811	3,010	1,930	-1,080
Achieved operating hours	N/A	12,217	N/A	N/A	N/A
Planned operating hours	8,970	12,514	13,770	4,610	-9,160
Optimal hours	12,430	12,430	14,750	14,820	+70
Percent of optimal hours[a]	100.0%	127.9%	91.9%	31.1%	-60.8%
Unscheduled downtime hours	—	—	N/A	N/A	N/A

Scientific Employment

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Number of permanent Ph.D.'s (FTEs)	825	830	814	-16
Number of postdoctoral associates (FTEs)	330	350	317	-33
Number of graduate students (FTEs)	530	550	461	-89
Other[b]	1,035	1,060	958	-102

[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] 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. Summary, Significant Changes, and Schedule and Cost History

Summary

The FY 2020 Request for the Facility for Rare Isotope Beams (FRIB) project is $40,000,000. The most recent Critical Decision (CD) for the FRIB project is CD-3B, Approve Start of Technical 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.

Significant Changes

This PDS is an update of the FY 2019 PDS and does not include a new start for FY 2020.

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, the most recent being in November 2018, have determined the project is proceeding on track and 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 and 4 of this Project Data Sheet (PDS) differ slightly from a traditional PDS for a federal capital asset construction project for how the baseline is presented in that they include the MSU cost share. The table in section 5, Schedule of Appropriations Requests, displays only DOE funding.

A Federal Project Director with certification level 4 has been assigned to this project and approves this PDS.

Critical Milestone History

Fiscal Year	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

[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.

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3A	CD-3B	D&D Complete	CD-4
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
FY 2020	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
CD-3A – Approve Start of Civil Construction
CD-3B – Approve Start of Technical Construction
D&D Complete – Completion Demolition & Decontamination
CD-4 – Approve Start of Operations or Project Closeout

Project Cost History[a]

(dollars in thousands)

Fiscal Year	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
FY 2020	655,700	24,600	49,700	730,000	-94,500	635,500

2. 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.

[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.

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.

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 (KPPs)

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

3. Financial Schedule[a]

(dollars in thousands)

	Budget Authority (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	97,200	97,200	84,124
FY 2019	75,000	75,000	70,000
FY 2020	40,000	40,000	30,000
FY 2021	5,300	5,300	15,300
FY 2022	—	—	18,076
Total, DOE TPC	**635,500**	**635,500**	**635,500**

4. Details of Project Cost Estimate[d]

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
DOE Total Project Costs (TPC)			
Design & Construction			
Management and Support	37,288	37,153	35,400
Conventional Facilities	208,100	208,100	165,300
Accelerator Systems	295,216	289,726	241,400
Experimental Systems	75,520	74,207	55,000
Contingency (DOE Held)	39,626	46,564	158,650
Total, Design & Construction	655,750	655,750	655,750

[a] The funding profile represents DOE's requested portion, which is less than the current baselined TPC which includes MSU's cost share.

[b] Costs through FY 2018 reflect actual costs; costs for FY 2019 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.

[d] This section shows a breakdown of the total project cost of $730,000,000 as of 6/30/2018, which includes MSU's cost share. The scope of work is not pre-assigned to DOE or MSU funds.

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Other Costs			
Conceptual Design/Tech R&D/NEPA	24,641	24,641	24,600
Pre-ops/Commissioning/Spares	34,659	34,659	35,500
Contingency (DOE Held)	14,950	14,950	14,150
Total, Other Costs	74,250	74,250	74,250
Total, TPC	**730,000**	**730,000**	**730,000**
MSU Cost Share	*94,500*	*94,500*	*94,500*
Total Project Costs (DOE Share)	**635,500**	**635,500**	**635,500**
Total, Contingency (DOE Held)	***54,576***	***61,514***	***172,800***

5. Schedule of Appropriations Requests[a]

(dollars in thousands)

Request Year	Type	Prior Years	FY 2018	FY 2019	FY 2020	FY 2021	Total
FY 2011	TPC	29,000	—	—	—	—	29,000
FY 2012	TPC	59,000	—	—	—	—	59,000
FY 2013	TPC	73,000	—	—	—	—	73,000
FY 2014	TPC	128,000	—	—	—	—	128,000
FY 2015	TPC	418,000	97,200	75,000	40,000	5,300	635,500
FY 2016	TPC	418,000	97,200	75,000	40,000	5,300	635,500
FY 2017	TPC	418,000	97,200	75,000	40,000	5,300	635,500
FY 2018	TPC	418,000	80,000	75,000	57,200	5,300	635,500
FY 2019	TPC	418,000	80,000	75,000	57,200	5,300	635,500
FY 2020	TPC	418,000	97,200	75,000	40,000	5,300	635,500

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy (fiscal quarter or date)	3Q FY 2022
Expected Useful Life (number of years)	20
Expected Future Start of D&D of this capital asset (fiscal quarter)	N/A[b]

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Previous Total Estimate	Current Total Estimate	Previous Total Estimate	Current Total Estimate
Operations[c]	90,000	90,000	1,800,000[d]	1,800,000

[a] The funding profile represents DOE's portion of the baselined TPC to be provided through federal appropriations.

[b] Per the financial assistance award agreement, MSU is responsible for D&D.

[c] Utilities, maintenance, and repair costs are included within the Operations amounts.

[d] The total operations and maintenance (O&M) is estimated at an average annual cost of approximately $90,000,000 (including escalation) over 20 years.

7. 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.

8. 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.

20-SC-51, United States Stable Isotope Production and Research Center (U.S. SIPRC)
Oak Ridge National Laboratory, Oak Ridge, Tennessee
Project Data Sheet is for Design

1. Summary, Significant Changes, and Schedule and Cost History

Summary

The FY 2020 request for the United States Stable Isotope Production and Research Center (U.S. SIPRC) is $5,000,000. The most recent DOE O 413.3B approved Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on January 4, 2020, with a preliminary Total Project Cost (TPC) range of $150,000,000 to $200,000,000.

Significant Changes

This project data sheet (PDS) is a new start for budget year FY 2020.

FY 2020 funding will support Project Engineering and Design activities. Other Project Cost (OPC) funded conceptual design work commenced in 2Q FY2019. Pre-conceptual design and research and development for this initiative are highly leveraged and advanced by prior efforts related to the technology that will be used by U.S. SIPRC. These prior efforts include the completed Electromagnetic Isotope Production Prototype and the ongoing Stable Isotope Production Facility (SIPF) Major Item of Equipment.

A Federal Project Director (FPD) has not been assigned to the U.S. SIPRC, but one will be assigned by CD-1.

Critical Milestone History

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2020[a]	1/04/2020	2Q FY 2020	2Q FY 2020	2Q FY 2021	TBD	2Q FY 2022	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 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

Project Cost History

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC Except D&D	OPC, D&D	OPC, Total	TPC
FY 2020	TBD	TBD	TBD	TBD	TBD	TBD	TBD

2. Project Scope and Justification

Scope

The scope of this project includes additional electromagnetic isotope separator systems and gas centrifuge cascades housed in a new single facility to promote operational, cost and security effectiveness, with space for future growth. The facility

[a] Dates presented are as approved at CD-0 and are notional, i.e., they will change as the conceptual design is developed.

includes adequate space for test stands and prototype development and is a purely technical facility (i.e., minimal office and staff amenities) and located on the ORNL main campus. Gas centrifuges and electromagnetic separators are based on existing designs developed from prior projects and R&D supported by DOE IP. As part of the alternatives analysis for Critical Decision-1 (CD-1), the optimal number of each type of technology is being considered.

Justification

U.S. SIPRC is critical to the DOE Isotope program within the Office of Science (SC), Office of Nuclear Physics (NP). The facility will expand the stable isotope production capability to address multiple production capabilities to meet the demand of the nation, while also mitigating our Nation's dependencies for critical isotopes on foreign suppliers. The current capacity within the United States is insufficient to meet the Nation's demands and spread out geographically at Oak Ridge National Laboratory (ORNL) which increases operating complexity, operating costs, and complicates security protection strategies. U.S. SIPRC will provide a consolidated approach to address our Nation's isotope needs in a more economical and operational efficient manner.

The proposed U.S. SIPRC at ORNL will integrate all aspects of the stable isotope program, including electromagnetic separation and centrifuge technologies; research and development laboratories; stable isotope storage and dispensing operations; and technical services for preparing special isotope forms through physical and chemical conversions. U.S. SIPRC will expand current production capabilities for enriched stable isotopes and provide a new building that will facilitate efficient operations and provide space, not only for all of the current needs, but will also accommodate the projected large-scale expansion of production systems.

Key Performance Parameters (KPPs)

Performance Measure	Threshold	Objective
TBD	TBD	TBD

This project is at CD-0. Preliminary Key Performance Parameters will be created in support of CD-1, Approve Alternative Selection and Cost Range.

The project is being conducted in accordance with the project management requirements in DOE O 413.3B, *Program and Project Management for the Acquisition of Capital Assets*, and all appropriate project management requirements will be met.

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
PED			
FY 2020	5,000	5,000	4,000
FY 2021	TBD	TBD	TBD
Total, PED	TBD	TBD	TBD
Construction			
FY 2020	—	—	—
FY 2021	TBD	TBD	TBD
Total, Construction	TBD	TBD	TBD

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Costs (TEC)			
FY 2020	5,000	5,000	4,000
FY 2021	TBD	TBD	TBD
Total, TEC	**TBD**	**TBD**	**TBD**
Other Project Costs (OPC)			
OPC except D&D			
FY 2019	500	500	400
FY 2020	—	—	100
Total, OPC	**TBD**	**TBD**	**TBD**
Total Project Costs (TPC)			
FY 2019	500	500	400
FY 2020	5,000	5,000	4,100
FY 2021	TBD	TBD	TBD
Total, TPC[a]	**TBD**	**TBD**	**TBD**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Estimate
Total Estimated Cost (TEC)			
Design			
Design	5,000	N/A	N/A
Contingency	—	N/A	N/A
Total, Design	TBD	N/A	N/A
Construction			
Construction	TBD	N/A	N/A
Contingency	TBD	N/A	N/A
Total, Construction	TBD	N/A	N/A
Total, TEC	**5,000**	**N/A**	**N/A**
Contingency, TEC	*TBD*	*N/A*	*N/A*
Other Project Cost (OPC)			
OPC except D&D			
Conceptual Design	500	N/A	N/A
R&D	TBD	N/A	N/A
Start-up	TBD	N/A	N/A
Contingency	TBD	N/A	N/A
Total, OPC	**500**	**N/A**	**N/A**
Contingency, OPC	*TBD*	*N/A*	*N/A*
Total Project Cost[a]	**TBD**	**N/A**	**N/A**
Total, Contingency (TEC+OPC)	***TBD***	***N/A***	***N/A***

[a] This request is for FY 2020 Design costs only. This project is at CD-0 and therefore is not baselined.

5. Schedule of Appropriation Requests

Request Year	Type	Prior Years	FY 2019	FY 2020	Outyears	Total
FY 2020 (Design only)	TEC	—	—	5,000	—	TBD
	OPC	—	500	—	—	TBD
	TPC	—	500	5,000	—	TBD

6. Related Operations and Maintenance Funding Requirements

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

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life cycle costs	
	Previous Total Estimate	**Current Total Estimate**	**Previous Total Estimate**	**Current Total Estimate**
Operations and Maintenance	TBD	TBD	TBD	TBD

7. D&D Information

	Square Feet
Area of new construction	TBD
Area of existing facility(ies) being replaced	TBD
Area of any additional D&D space to meet the "one-for-one" requirement	TBD

The "one-for-one" requirement will be met through an offset or waiver.

8. Acquisition Approach

The acquisition approach will be approved with CD-1 approval anticipated to be in FY 2020. The Oak Ridge National Laboratory will manage all acquisitions with appropriate Department of Energy oversight. DOE and ORNL will monitor cost, schedule, and technical performance using an earned-value process consistent with DOE O 413.3B, Program and Project Management for the Acquisition of Capital Assets.

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 worldwide. 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] More than 20 million Americans benefit each year from nuclear medicine procedures used to diagnose and treat a wide variety of diseases.[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.

Radioisotopes 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 the processing labs at Oak Ridge National Laboratory (ORNL); while enriched stable isotopes are produced at the Enriched Stable Isotope Prototype Plant (ESIPP) also at 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 near ORNL, the Low Energy Accelerator Facility (LEAF) at Argonne National Laboratory (ANL), and processing facilities at the Pacific Northwest National Laboratory (PNNL) and the Savannah River Site. IPF, BLIP, and LEAF 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

[a] http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/med-use-radioactive-materials.html

[b] http://www.snmmi.org/ClinicalPractice/content.aspx?ItemNumber=4825

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 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 2018, a total of $112.5 million was deposited into the revolving fund. This consists of the FY 2018 appropriation of $40.7 million paid into the revolving fund from the Nuclear Physics program, plus collections of $71.8 million to recover costs related to isotope production and isotope services. Collections in FY 2018 include, for example, sales of actinium-227 (Ac-227), californium-252, helium-3 (He-3), selenium-75, cobalt-60, nickel-63, germanium-68, actinium-225, strontium-82, and strontium-89. Actinium-227 provides radium-223 (Ra-223) for Xofigo®, which was the first alpha particle-emitting radioisotopic drug approved by the Federal Drug Administration; Xofigo® extends patient survival as well as 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; He-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; Ac-225 is used in pharmaceuticals under development to more effectively treat cancer and other diseases; strontium-82 has gained world-wide acceptance for use in heart imaging; and strontium-89 alleviates the pain associated with bone metastases. In FY 2018, the Isotope Program sold 161 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 isotopes with commercial applications; the remaining are low-volume, mostly research isotopes, which are more expensive to produce. Commercial isotopes are priced to recover full cost or the market price, whichever is higher and in consideration of the commercial value of the product.

Program Accomplishments

Development of Production of Alpha-Emitting Isotope for the Treatment of Metastatic Prostate Cancer. A multi-year research and development effort was completed to establish a large-scale production capability for Ac-227. A radioactive decay product of Ac-227, Ra-223, is the active ingredient in Bayer's drug Xofigo™ which is a treatment for metastatic prostate cancer that not only alleviates excruciating pain associated with bone metastases, but also extends patient survival. A collaboration between the Oak Ridge National Laboratory and Bayer developed radiopharmaceutical-grade production of Ac-227 and, upon completion, the DOE Isotope Program signed a multi-year contract with Bayer to supply their global demand for Ac-227.

Reestablishment of Domestic Production of Americium-241. Since 2003, the U.S. has been completely dependent upon a single foreign source of americium-241 (Am-241), an isotope with a variety of industrial applications such as neutron sources for oil and gas exploration and an ionization source for household smoke detectors. The DOE Isotope Program facilitated the formation of an industrial consortium that, in partnership with the Isotope Program, funded the reestablishment of a modest domestic Am-241 production capability at the Los Alamos National Laboratory. The production development effort was completed and routine production of Am-241 commenced in FY 2018. This domestic supply alleviates a significant concern of U.S. industry: the dependence on a single foreign supplier of Am-241.

Tri-Lab Effort Increases Availability of Ac-225 for Medical Applications Research. Scientists at Brookhaven, Los Alamos, and Oak Ridge National Laboratories are engaging in a collaboration that uses their unique facilities and expertise to develop large-scale production of Ac-225, an alpha-emitting radioisotope that shows great promise in treating a range of diseases—from metastatic cancer to fungal and even viral infections like HIV. Development of applications such as these has been inhibited by the lack of availability of sufficient quantities of Ac-225 to support laboratory research and clinical trials. In FY 2018, the Tri-Laboratory collaboration achieved routine production of up to 50 millicuries (mCi) of Ac-225 and will soon be capable of routine production runs of 100 mCi. Ultimately, the effort will be scaled up to two-week production runs of at least 1,000 mCi, which is the equivalent of the current U.S. annual production of Ac-225 from the decay of legacy thorium-229.

Highlights of the FY 2020 Request

For FY 2020, 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 rapidly as isotope availability is increased by the program. The FY 2020 Request provides $6,741,000 of additional funding to meet the needs of the expanding portfolio. Revolving fund resources will be used to support efforts to produce isotopes and develop production capabilities and availability to meet demand, increased He-3 extraction capabilities, enriched radioisotope capabilities, stable isotope electromagnetic separation enrichment capabilities, and development of enriched lithium-7 production capabilities. The Isotopes Program will make investments with revolving fund resources in aging isotope production infrastructure to maintain productivity and to provide enhanced facility infrastructure for increased production of Ac-225, a promising cancer therapeutic. The FY 2020 Request for the Isotope Program increases the development and production of specialized isotopes for Quantum Information Science.

The FY 2020 Request for Nuclear Physics includes a request for funding of the Stable Isotope Production Facility (SIPF) Major Item of Equipment, with planned completion of the facility in FY 2024 based on a technically-driven schedule. Initiated in 2017, SIPF ($25.5–28.0M Total Project Cost range) will provide increased domestic capability for cost-effective production of critically needed enriched stable isotopes and reduce the nation's dependence on foreign suppliers.

The Request for Nuclear Physics includes support to initiate the Facility for Rare Isotope Beams (FRIB) Isotope Harvesting accelerator improvement project ($9-11M Total Project Cost range). FRIB is a next generation scientific user facility being constructed at Michigan State University for nuclear structure and astrophysics measurements. This accelerator improvement project will add isotope harvesting capabilities to the FRIB, which will provide access to a wide range of isotopes, including unusual isotopes for exploratory studies.

The FY 2020 Request for the Nuclear Physics program requests $5.0 million to initiate the U.S. Stable Isotope Production and Research Center at ORNL, which will consolidate and significantly enhance stable isotope production capacity for the Nation. This Line item construction project has a preliminary Total Project Cost (TPC) range of $150-200M. This proposed new facility will build upon the expertise in centrifuge and electromagnetic isotope separation technology nurtured by SIPF.

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 for the 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® finals in Washington, D.C. These 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 DOE workforce development mission.

Highlights of the FY 2020 Request

The FY 2020 Request for $19,500,000 prioritizes funding for programs that place highly qualified applicants in authentic STEM learning and training experiences 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 draft 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 educating and training an American workforce for the 21st century economy.[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.

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

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[a] https://www.whitehouse.gov/wp-content/uploads/2018/12/STEM-Education-Strategic-Plan-2018.pdf

[b] https://www.whitehouse.gov/wp-content/uploads/2018/07/M-18-22.pdf

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 11 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. SC sponsors placement opportunities in WDTS and in Congressional offices., Other Federal agencies sponsor placement opportunities in their own offices. Participating agencies have included the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), the Library of Congress, and the National Oceanic and Atmospheric Administration (NOAA). The Fellows provide educational expertise, years of teaching experience, and personal insights to these offices to advance Federal science, mathematics, and technology education programs.

National Science Bowl®

The DOE National Science Bowl® (NSB) 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 290,000 students have participated in the NSB throughout its 28-year history, and it is one of the nation's largest science competitions. The U.S. Department of Energy Office of Science manages the NSB, 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.

In FY 2018, more than 5,000 middle school students (from 680 schools) and 9,000 high school students (from 1,211 schools) participated in the regional competitions, with 48 middle school teams (215 students) and 65 high school teams (310 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.

Technology Development and On-Line Application

This activity modernizes on-line systems used to manage application solicitations, review applications, facilitate data collection, perform outreach, and integrate evaluation for WDTS programs. A project to develop, build, and launch new online application and program support systems continues, with evolving new elements to advance 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 improved and new features. One of these features is 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 are being made available to DOE host laboratories to inform them of participant trends and program outcomes. WDTS is using 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 triennial 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 2019, as directed by the Federal STEM Education 5-Year Strategic Plan[a], WDTS will perform a systematic review of data-derived evidence from its current and past program participants, to be further augmented by the design of a longitudinal study of its cohorts of prior SULI participants, looking back more than 20 years.
An expected outcome of these activities is improved means to assess and inform programs, investments, and activities.

The Evaluation Studies activity is aligned with the Government Performance and Results Act (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. Additional online tools are being implemented to directly publicize opportunities for students via their institutional career offices, which is a rapidly expanding outreach modality amongst student populations seeking internship opportunities.

WDTS also annually solicits proposals from DOE host laboratories and facilities 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 host participants in the SULI, CCI, VFP, and/or SCGSR programs. Based upon reported outcomes of annually completed activities, a portfolio of model practices is evolving to help ensure that WDTS activities are fully open and accessible to all members of the population. The FY 2020 Request continues support for curation of this information.

The Laboratory Equipment Donation Program (LEDP) is operated under Outreach and provides excess laboratory equipment to STEM faculty at accredited 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.

[a] https://science.energy.gov/wdts

Workforce Development for Teachers and Scientists
Funding

(dollars in thousands)

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Activities at the DOE Laboratories				
Science Undergraduate Laboratory Internships	8,300	10,300	9,100	-1,200
Community College Internships	1,000	1,000	1,100	+100
Office of Science Graduate Student Research Program	2,500	3,500	2,600	-900
Visiting Faculty Program	1,700	1,700	1,700	—
Total, Activities at the DOE Laboratories	**13,500**	**16,500**	**14,500**	**-2,000**
Albert Einstein Distinguished Educator Fellowship	**1,200**	**1,200**	**800**	**-400**
National Science Bowl®	**2,900**	**2,900**	**2,900**	**—**
Technology Development and On-Line Application	**750**	**750**	**500**	**-250**
Evaluation Studies	**600**	**600**	**300**	**-300**
Outreach	**550**	**550**	**500**	**-50**
Total, Workforce Development for Teachers and Scientists	**19,500**	**22,500**	**19,500**	**-3,000**

Program Accomplishments

Science Undergraduate Laboratory Internships (SULI) — In FY 2018, and as in prior years, participants made notable contributions to research projects as evidenced by co-authorship in peer reviewed journals and/or presentations at scientific meetings. FY 2018 funding supported 790 placements, of which more than 50 were from Minority Serving Institutions (MSIs).

Community College Internships (CCI) — In FY 2018, approximately 20% of the participants were from MSIs.

Office of Science Graduate Student Research Program (SCGSR) — In FY 2018, the General Atomics/DIII-D National Fusion Facility in San Diego, California was added as a new host site (in addition to the 17 DOE national laboratories), and had its first SCGSR placement. To date, about 372 awardees from 120 graduate institutions across the U.S. have participated in SCGSR.

Visiting Faculty Program (VFP) —FY 2018 funding supported 51 faculty and 19 student placements. Approximately 40% of the faculty participants were from MSIs.

Albert Einstein Distinguished Educator Fellowship (AEF) — In FY 2018, two of the six WDTS sponsored AEF participants held WDTS office appointments. In addition to engaging in WDTS programmatic activities, as nationally recognized STEM educators, one of these Fellows collaborated with Brookhaven National Laboratory and the Pacific Northwest National Laboratory, while the other Fellow collaborated with Idaho National Laboratory, applying their expertise to portions of the laboratories' STEM education outreach activities. In efforts to expand federal agency participation, the incoming 2018-2019 cohort includes a placement at the Library of Congress, and WDTS is engaged in discussions with other agencies who have expressed interest in hosting a Fellow for the FY 2019 application cycle (2019-2020 cohort).

The National Science Bowl® (NSB) — The National Finals of the 28th DOE National Science Bowl® took place in the Washington, DC, area from April 27 – May 1, 2017. The Secretary of Energy addressed the high school finalists, while the Under Secretary for Science delivered congratulatory remarks to the 65 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 DOE laboratory workplace experience and careers to these students' STEM areas of study. 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 national laboratory complex. The 2018 NSB Science Day for high-school finalists had as its theme Cybersecurity, a DOE mission critical field with programmatic research activity in SC and in the National Nuclear Security Administration.

The Cyber-Challenge middle school activity continued in FY 2018. 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 provides an opportunity to develop and test these cybersecurity outreach and training activities at large concurrent participant scales. Based upon this success, as well as additional pilot activities sponsored under Outreach, the technical requirements for additional DOE national laboratories to host cyber-challenge events across the nation were defined.

Technology Development and On-Line Application — In FY 2018 the online system codebase was refreshed, including a review and update for compliance with current Section 508 of the Rehabilitation Act of 1973 accessibility requirements. Completed new development includes a budget management dashboard for enhanced transparency and tighter compliance, implementation of an ORCID iD (Open Researcher and Contributor ID - a nonproprietary alphanumeric code to uniquely identify scientific and other academic authors and contributors) as an unique online system applicant identifier to mitigate risks involving identity protection instead using the last four digits of social security numbers, and incorporation of

“Handshake”, a rapidly growing position posting system where students have access to search and apply for opportunities, which is especially gaining popularity when seeking internships.

Evaluation — WDTS completed additional phases of a project to develop and implement a data-dictionary/data-warehouse based analytics and visualization toolset supporting data-driven program evaluation. Completed activities in FY 2018 include the migration and normalization of participant data collected by legacy online systems. ORCID implementation enables seamless access to notable outcomes made by current and former participants and also providing means to unobtrusively follow STEM career outcomes without jeopardizing privacy.

Outreach — DOE host laboratories and facilities executed projects aimed at recruiting a more diverse applicant pool to WDTS laboratory-based programs, targeting recruitment of individuals traditionally underrepresented in STEM and addressing needs to increase the applicant pool diversity for one or more of the WDTS programs currently implemented at DOE host laboratories and facilities. As one outcome, a portfolio of model practices is evolving.

The LEDP online system has been migrated from the Office of Scientific and Technical Information (OSTI) to the Oak Ridge Institute for Science and Education (ORISE) and was integrated it into current online systems. By using established online resources, and their capabilities, this migration improves the client experience when accessing and applying for equipment, and also improves management and execution of equipment transfer processes.

Workforce Development for Teachers and Scientists

Activities and Explanation of Changes

FY 2019 Enacted		FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Workforce Development for Teachers and Scientists	**$22,500,000**	**$19,500,000**	**-$3,000,000**
Activities at the DOE Laboratories	$16,500,000	$14,500,000	-$2,000,000
Science Undergraduate Laboratory Internships	*$10,300,000*	*$9,100,000*	*-$1,200,000*
The FY 2019 Enacted budget for SULI supports approximately 1,000 students.		The Request for SULI will support approximately 870 students.	Funding will support 130 fewer students.
Community College Internships	*$1,000,000*	*$1,100,000*	*+$100,000*
The FY 2019 Enacted budget for CCI supports approximately 100 students.		The Request for CCI will support approximately 110 students.	Increased funding will support an additional 10 students.
Graduate Student Research Program	*$3,500,000*	*$2,600,000*	*-$900,000*
The FY 2019 Enacted budget for the SCGSR program supports approximately 210 graduate students. Targeted priority research areas are informed by SC's workforce training needs studies.		The Request for the SCGSR program will support approximately 115 graduate students. Targeted priority research areas will be informed by SC's workforce training needs studies.	Decreased funding will support 95 fewer students.
Visiting Faculty Program	*$1,700,000*	*$1,700,000*	*$—*
The FY 2019 Enacted budget for the VFP supports approximately 65 faculty and 40 students.		The Request for the VFP will support approximately 65 faculty and 40 students.	No change.
Albert Einstein Distinguished Educator Fellowship	$1,200,000	$800,000	-$400,000
The FY 2019 Enacted budget supports 6 Fellows.		The Request will support 4 Fellows.	Funding will support 2 fewer Fellows.

FY 2019 Enacted	FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
National Science Bowl $2,900,000	$2,900,000	$–
The FY 2019 Enacted budget for the NSB allows WDTS to sponsor the finals competition, and provides 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.	The Request will provide support to 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.
Technology Development and On-line Application Systems $750,000	$500,000	-$250,000
The FY 2019 Enacted budget continues support for the development and operation of the on-line systems.	The Request will continue development and operation of the on-line systems.	Funding will maintain operation of the on-line systems; development will be slowed.
Evaluation $600,000	$300,000	-$300,000
The FY 2019 Enacted budget continues support for evaluation activities, including data archiving, curation, and analyses.	The Request will continue support for evaluation activities, including data archiving, curation, and analyses. WDTS will perform a systematic review of data-derived evidence from its current and past program participants, to be further augmented by the design of a longitudinal study of its cohorts of prior SULI participants, looking back more than 20 years.	Funding will reduce evaluation activities.
Outreach $550,000	$500,000	-$50,000
The FY 2019 Enacted budget continues support for 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.	The Request 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. Support continues for the LEDP program.	Funding change will have no impact due to the launch of LEDP operations on WDTS online systems, improving its program management efficiency, and resulting in reduced costs.

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, efficient, reliable 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 manages an infrastructure portfolio worth nearly $22 billion, which is composed of 13 sites with nearly 23 million gross square feet (gsf) in 1,570 government owned buildings. SC assets at the 10 national laboratories include major research and user facilities, laboratory and office buildings, support facilities, and a vast network of utilities that form the backbone of each site. The average age of SC's buildings is over 42 years, and nearly half are rated substandard or inadequate to meet mission needs. In addition, utility systems across several laboratories are suffering from failures and frequent, often costly, repairs. While there has been significant federal stewardship of research, user and research support facilities, core infrastructure and utility systems maintenance has lagged behind, resulting in many of these critical assets falling into disrepair. Collectively, these issues impact scientific progress and impair mission accomplishment. The SLI program has taken the lead over the last several years in working with laboratories to ensure appropriate stewardship of general-purpose infrastructure and supporting utility systems.

In FY 2018, SC invested over $550 million 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 general plant projects (GPPs), as well as overhead-funded investments in institutional GPP (IGPP) 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.

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, 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 needs and priorities, which, combined with complex-wide infrastructure analyses, form the basis for SLI Budget Requests.

Highlights of the FY 2020 Request

The SLI program request for $163,600,000 continues to focus on improving infrastructure across the SC national laboratory complex. The FY 2020 Request includes funding for five new construction starts: the Critical Utilities Rehabilitation Project at Brookhaven National Laboratory (BNL), the Seismic and Safety Modernization project at Lawrence Berkeley National Laboratory (LBNL), the Continuous Electron Beam Accelerator Facility (CEBAF) Renovation and Expansion project at Thomas Jefferson National Accelerator Facility (TJNAF), the Craft Resources Support Facility at Oak Ridge National Laboratory (ORNL), and the Large Scale Collaboration Center at SLAC National Accelerator Laboratory (SLAC).

The Request supports six ongoing construction projects: the Integrated Engineering Research Center at Fermi National Accelerator Laboratory (FNAL), the Energy Sciences Capability project at Pacific Northwest National Laboratory (PNNL), the Science User Support Center at BNL, the Electrical Capacity and Distribution Capability at Argonne National Laboratory (ANL), the Translational Research Capability project at ORNL, and the Biological and Environmental Program Integration Center (BioEPIC) at LBNL. These ongoing projects, along with the newly proposed projects, will upgrade and improve aging utility systems and facilities and provide new laboratory space with the necessary performance capabilities to enhance SC mission potential.

The FY 2020 Request includes funding for general purpose infrastructure projects that will address inadequate core infrastructure and utility needs across SC laboratories and facilities. SLI maintains an active list of laboratory critical core infrastructure needs. Currently, the highest priority items include critical utility upgrades at ANL and safety and facility improvements at Ames Laboratory. Priorities are evaluated annually and will be reassessed upon entry into the FY 2020 execution year.

Funding is also requested in FY 2020 for the acquisition of previously leased real property on the PNNL campus. This funding addresses a long-standing complexity in consideration of laboratory recompetition while ensuring the continuity of PNNL activities.

Lastly, the Request continues funding a project to de-inventory, remove, and transfer nuclear material at Building 350, formerly the site of the New Brunswick Laboratory (NBL) on the ANL campus. In FY 2020, the NBL Special Nuclear Material (SNM) Certified Reference Material (CRM) program management mission is proposed for transfer from SC to the National Nuclear Security Administration (NNSA) as functions are better aligned with the Naval Reactors, Defense Nuclear Nonproliferation, and Defense program missions of NNSA than the core SC program missions.

Science Laboratories Infrastructure
Funding

(dollars in thousands)

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Infrastructure Support	**104,442**	**79,690**	**45,200**	**-34,490**
Construction				
20-SC-71, Critical Utilities Rehabilitation Project, BNL	—	—	12,000	+12,000
20-SC-72, Seismic and Safety Modernization, LBNL	—	—	5,000	+5,000
20-SC-73, CEBAF Renovation and Expansion, TJNAF	—	—	2,000	+2,000
20-SC-74, Craft Resources Support Facility, ORNL	—	—	20,000	+20,000
20-SC-75, Large Scale Collaboration Center, SLAC	—	—	3,000	+3,000
19-SC-71, Science User Support Center, BNL	—	7,000	6,400	-600
19-SC-72, Electrical Capacity and Distribution Capability, ANL	—	30,000	30,000	—
19-SC-73, Translational Research Capability, ORNL	—	25,000	15,000	-10,000
19-SC-74, BioEPIC, LBNL	—	5,000	6,000	+1,000
18-SC-71, Energy Sciences Capability, PNNL	20,000	24,000	9,000	-15,000
17-SC-71, Integrated Engineering Research Center, FNAL	20,000	20,000	10,000	-10,000
17-SC-73, Core Facility Revitalization, BNL	30,000	42,200	—	-42,200
15-SC-76, Materials Design Laboratory, ANL	44,500	—	—	—
15-SC-78, Integrative Genomics Building, LBNL	38,350	—	—	—
Total, Construction	**152,850**	**153,200**	**118,400**	**-34,800**
Total, Science Laboratories Infrastructure	**257,292**	**232,890**	**163,600**	**-69,290**

Science Laboratories Infrastructure
Explanation of Major Changes

	(dollars in thousands) FY 2020 Request vs FY 2019 Enacted
Infrastructure Support The Request continues funding to support Payment in Lieu of Taxes (PILT), nuclear facilities at ORNL, and landlord responsibilities at the Oak Ridge Reservation. Funding continues to support de-inventory, removal, and transfer of nuclear material at Building 350, formerly the site of NBL on the ANL campus. Funding for critical core infrastructure across the SC complex decreases in FY 2020. The FY 2020 Request proposes the transfer of Oak Ridge PILT requirements from the Oak Ridge Landlord activity to the PILT activity.	**-34,490**
Construction Funding supports six ongoing line-item projects at FNAL, PNNL, BNL, ANL, ORNL, and LBNL. Also, funding supports the initiation of five new line-item projects at BNL, LBNL, TJNAF, SLAC, and ORNL. Funding decreases in FY 2020 as the Core Facility Revitalization project at BNL received final funding in FY 2019.	**-34,800**
Total, Science Laboratories Infrastructure	**-69,290**

Program Accomplishments
Since FY 2006, the SLI program has invested over $1.2 billion in general purpose infrastructure across the SC-stewarded laboratory complex. These investments have provided state-of-the-art science user support facilities, renovated and repurposed aged facilities, upgraded inadequate core infrastructure and systems, and removed excess.

Line-Item Construction Projects. Since FY 2006, the SLI program has successfully completed 13 line-item projects while garnering nine 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 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.

Core General Plant Project upgrades across SC Laboratories. Since FY 2016, SLI has funded over $110 million in laboratory core infrastructure improvements including over $70 million in electrical and utility improvements and over $40 million in facility improvements. Examples of recent SLI investments in core infrastructure include renovating post-World War II era laboratory and support space at BNL, upgrading an outdated legacy fabrication facility at ORNL, and renovating mission critical buildings at Ames Laboratory. At LBNL, SLI funded the replacement of inadequate critical portions of the supply water and storm water drainage systems that serve all programs. Lastly, at SLAC, SLI funded the replacement of the low conductivity water cooling system serving the Stanford Synchrotron Radiation Light Source and the Linac Coherent Light Source.

Removal of Hazard Category 3 Materials from the former New Brunswick Laboratory (NBL). As of April 2017, the SLI program successfully removed nuclear material from the former NBL on the ANL site to bring the building to the state of a Radiological Facility – i.e., below Hazard Category 3. In FY 2018, the project team disposed of approximately 5,700 items, including about 1,170 higher-risk uranium metal items. The SLI program continues to remove the remaining nuclear materials so the building can eventually be renovated and repurposed.

The SLI funded *Utilities Improvement Project at FNAL* upgraded industrial cooling water and high voltage electrical systems that were well beyond useful life and experienced frequent malfunctions and unscheduled repairs. This project was completed in FY 2018 and has provided the laboratory with high capacity, efficient, and dependable systems directly supporting its mission of world leadership in particle physics.

The SLI funded *Utilities Infrastructure Modernization project at TJNAF* upgraded cryogenic, electrical distribution, cooling water, and communication systems that were experiencing frequent failures and were no longer adequate to support growth and SC mission requirements. This project was completed in FY 2018 and has provided the laboratory with the utilities necessary to pursue scientific excellence and preeminence in the study of nuclear building blocks, the underlying quark-gluon structure of the nucleus, and tests to verify predictions of the Standard Model.

The SLI funded *Infrastructure and Operational Improvements project at PPPL* addressed several inadequate facilities at PPPL that were impeding progress towards achieving research goals as well as hindering the attraction and retention of talented staff. The project included renovation of 70,000 gsf of space in existing buildings to provide space for offices and equipment, and demolition of trailers used for office space and storage of equipment. This project will be completed in FY 2019 and has provided the laboratory with upgraded infrastructure to support its mission of advancing the fields of fusion energy and plasma physics research necessary to realize fusion as an energy source.

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 core infrastructure 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.

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 proposed investments and maintains an active list of critical core infrastructure needs. Currently, the highest priority items include critical utility upgrades at ANL and safety and facility improvements at AMES. Priorities are evaluated annually and will be reassessed upon entry into the FY 2020 execution year.

This activity also supports operations and maintenance, de-inventory, removal, and transfer of nuclear material in the former NBL building on the site of ANL. In FY 2020, the NBL Program Office CRM functions, formerly operated out of ANL Building 350, is proposed for transfer to NNSA as those functions are better aligned with the Naval Reactors, Defense Nuclear Nonproliferation, and Defense program missions of NNSA than the core SC program missions.

In FY 2020, funding is requested for the acquisition of real property (land and facilities) from Battelle Memorial Institute (BMI) that is currently in use and already part of the Pacific Northwest National Laboratory (PNNL) campus. These parcels include facilities involved in research (e.g., the Atmospheric Radiation Measurement Research Facility) as well as basic operations (e.g., the site shipping and receiving facility and office space), as well as room for expansion and collaboration in proximity to existing federal facilities. This effort addresses a long standing complexity in the consideration of laboratory recompetition, while ensuring the continuity of PNNL activities. The construction of replacement facilities for those to be acquired from BMI land was considered but would be significantly more costly than the proposed acquisition.

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.

In FY 2020, SLI proposes the transfer of Oak Ridge PILT requirements from the Oak Ridge Landlord activity to the Payments in Lieu of Taxes activity.

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 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.

In FY 2020, SLI proposes to include funding for Oak Ridge PILT requirements within this activity. Funding for Oak Ridge PILT has previously been provided under the Oak Ridge Landlord activity. This action consolidates all PILT funding.

Science Laboratories Infrastructure
Infrastructure Support

Activities and Explanation of Changes

FY 2019 Enacted		FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Infrastructure Support	**$79,690,000**	**$45,200,000**	**-$34,490,000**
Facilities and Infrastructure	$45,543,000	$25,050,000	-$20,493,000
The FY 2019 Enacted budget continues 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.		The FY 2020 Request will continue to support de-inventory and removal of nuclear material at the former NBL Building at ANL, and the highest priority critical core infrastructure needs. In addition, funding is requested for the acquisition of real property at PNNL.	Funding decreases for de-inventory of nuclear materials activities at the NBL building as the project nears completion. Funding to address aging core infrastructure across the SC laboratory complex also decreases in FY 2020 to ensure ongoing infrastructure projects continue to make progress towards completion.
Nuclear Operations	$26,000,000	$10,000,000	-$16,000,000
The FY 2019 Enacted budget continues to support critical nuclear operations and provides funding to manage ORNL's nuclear facilities.		The FY 2020 Request will continue to support critical nuclear operations and will provide funding to manage ORNL's nuclear facilities.	Funding supports the most critical nuclear operations and facilities at ORNL.
Oak Ridge Landlord	$6,434,000	$5,610,000	-$824,000
The FY 2019 Enacted budget provides 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.		The FY 2020 Request will provide funding to support landlord responsibilities across the Oak Ridge Reservation. Activities include maintenance of roads, grounds, and other infrastructure; and support and improvement of environmental protection, safety, and health.	Funding decreases to reflect the transfer of OR PILT requirements to the Payments in Lieu of Taxes activity.
Payment in Lieu of Taxes	$1,713,000	$4,540,000	+2,827,000
The FY 2019 Enacted budget provides funding for PILT payments to communities around ANL and BNL.		The FY 2020 Request will provide funding for PILT payments to communities around ANL and BNL. In addition, the Request proposes the transfer of OR PILT payments to Oak Ridge communities from the Oak Ridge Landlord activity to the Payment in Lieu of Taxes activity.	Funding increases to support the transfer of OR PILT payments to this activity.

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 2020 Request includes funding for:

Five new line-item construction projects:

- Critical Utilities Rehabilitation Project at BNL;
- Seismic and Safety Modernization at LBNL;
- CEBAF Renovation and Expansion at TJNAF;
- Craft Resources Support Facility at ORNL; and,
- Large Scale Collaboration Center at SLAC.

Six ongoing line-item construction projects:

- Science User Support Center at BNL;
- Electrical Capacity and Distribution Capability project at ANL;
- Translational Research Capability at ORNL;
- Biological and Environmental Program Integration Center (BioEPIC) at LBNL;
- Energy Sciences Capability project at PNNL; and,
- Integrated Engineering Research Center at FNAL.

<u>Critical Utilities Rehabilitation Project, BNL</u>

The Critical Utilities Rehabilitation Project at BNL will revitalize and upgrade highest risk major utility systems to meet the needs of support SC facilities and Nuclear Physics (NP), Basic Energy Sciences (BES), High Energy Physics (HEP), Biological and Environmental Research (BER) and Advanced Scientific Computing Research (ASCR) program missions.

Specifically, this project will replace piping in areas prone to water main breaks and provide other water system improvements to improve system operations and reliability. Select sections of the sanitary utility systems with failing pumps, controllers and/or manholes will be replaced. This project will also provide several required modifications to the central chilled water system in order to support growth of process loads and assure reliability. Deteriorated and leaking steam systems along Cornell Avenue will be replaced to assure safe, reliable, and efficient steam service to mission critical facilities on the north side of the campus. In addition, older feeder cables and inadequate breakers will be replaced along Cornell Avenue increasing capacity, reliability and personnel safety.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, *Approve Mission Need,* approved on July 20, 2018. The preliminary estimate for CD-1*, Approve Alternative Selection and Cost Range*, is anticipated in the fourth quarter of FY 2019. This project is pre-CD-2, therefore schedule estimates are preliminary and subject to change. The preliminary TEC range for this project is $70,000,000 to $95,000,000. The preliminary TPC range for this project is $70,800,000 to $95,800,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The most likely TEC for this project is estimated at $85,000,000 and most likely TPC for this project is estimated at $85,800,000.

<u>Seismic and Safety Modernization, LBNL</u>

The Seismic and Safety Modernization project will address seismic safety issues and emergency response capabilities, specifically related to facilities with large congregation areas as well as improve facilities that are necessary for emergency response personnel and maintain continuity of operations. The facilities that are the primary focus of this project are the Cafeteria, Health Services, and Fire House sleeping quarters.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, *Approve Mission Need,* approved on September 6, 2018. The preliminary estimate for CD-1*, Approve Alternative Selection and Cost Range*, is anticipated in the fourth quarter of

FY 2019. This project is pre-CD-2; therefore schedule estimates are preliminary and subject to change. This project has a preliminary TEC range of $65,600,000 to $95,400,000 and the preliminary TPC range of $67,800,000 to $97,600,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The most likely TEC for this project is estimated at $95,400,000 and most likely TPC for this project is estimated at $97,600,000.

CEBAF Center Renovation and Expansion, TJNAF

The CEBAF Renovation and Expansion project will renovate existing space and provide new research, administrative, and support service space enabling TJNAF to better support SC missions. With a population of nearly 1,600 users, TJNAF supports one of the largest nuclear physics user communities in the world. The expanded scientific scope associated with the 12 GeV Upgrade (double the energy with simultaneous delivery to four experimental halls) is creating more and larger collaborations, resulting in more visiting scientists to the Lab and need for space to accommodate their work.

This project will renovate 67,000 to 80,000 gsf of existing space and provide 22,000 to 92,000 gsf of new high performing and sustainable space. Upon completion, staff from the Applied Research Center (ARC) and Service Support Center (SSC) will be relocated into the CEBAF Center, providing more efficient operations. In addition, the consolidation into the CEBAF Center will allow for costly leases to be discontinued and will reduce the cost to sustain existing buildings and infrastructure while more efficiently addressing the functional workspace needs for TJNAF staff and users. This project will also replace existing utility systems that are well past service life and experience frequent failures.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, *Approve Mission Need,* approved on July 20, 2018. The preliminary estimate for CD-1*, Approve Alternative Selection and Cost Range*, is anticipated in the fourth quarter of FY 2019. This project is pre-CD-2, therefore schedule estimates are preliminary and subject to change. This project has a preliminary TEC range of $47,000,000 to $75,000,000 and a preliminary TPC range of $48,900,000 to $76,900,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The most likely TEC for this project is estimated at $66,000,000 and the most likely TPC for this project is estimated at $67,900,000.

Craft Resources Support Facility, ORNL

The Craft Resources Support Facility project will relocate and consolidate craft resource services that are currently housed in multiple, inadequate facilities spread across the campus in the 7000 area. ORNL supports the mission work of all six of SC's research program offices and three scientific user facilities. The complex infrastructure required to support the SC mission and associated one-of-a-kind large scale facilities places a substantial demand on craft resource support functions, which is comprised of 28 different trades ranging from automotive mechanics to instrument technicians. Craft resource support services are currently housed in multiple facilities spread across the 7000 campus area which are outdated and poorly configured resulting in inefficient operations, congested vehicle and pedestrian traffic patterns, and increased safety risks. These conditions are creating inefficient, and unreliable operations, which are directly impacting many high-priority SC programs at ORNL.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, *Approve Mission Need,* approved on July 20, 2018. The preliminary estimate for CD-1*, Approve Alternative Selection and Cost Range*, is anticipated in the fourth quarter of FY 2019. This project is pre-CD-2, therefore schedule estimates are preliminary and subject to change. This project has a preliminary TEC range of $24,500,000 to $40,000,000 and a preliminary TPC range of $25,000,000 to $40,500,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The most likely TEC for this project is estimated at $40,000,000 and the most likely TPC for this project is estimated at $40,500,000.

Large Scale Collaboration Center, SLAC

The Large Scale Collaboration Center project will construct a multi-office building of approximately 38,000 to 45,000 gsf to consolidate and provide space for 100-150 occupants in a common building, provide synergies among all major SC-sponsored programs at SLAC, and provide a centralized office and collaboration space for cross-functional teams with the necessary performance capabilities to grow the science research programs. With the growth in SC mission activities at SLAC – from the Linac Coherent Light Source (LCLS), LCLS-II, LCLS-II-HE projects to Facility for Advanced Accelerator Experimental Tests (FACET)-II and the Matter in Extreme Conditions project – the lab currently lacks office spaces for scientists and staff as current spaces is fully occupied or oversubscribed and do not support needs for joint collaborations for exploring challenges and developing solutions using large-scale data sets. Adjacent office spaces that enable researchers to benefit from collaboration with subject matter experts in computational science, machine learning, artificial intelligence, exascale computing, data management, data acquisition, simulation, imaging, visualization, and modeling are also not currently available.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, *Approve Mission Need,* approved on July 20, 2018. The preliminary estimate for CD-1*, Approve Alternative Selection and Cost Range*, is anticipated in the fourth quarter of FY 2019. This project is pre-CD-2; therefore schedule estimates are preliminary and subject to change. This project has a preliminary TEC range of $32,000,000 to $60,000,000 and a preliminary TPC range of $33,000,000 to $61,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The most likely TEC for this project is estimated at $60,000,000 and the most likely TPC for this project is estimated at $61,000,000.

<u>Science User Support Center, BNL</u>
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 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. 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, deteriorated condition, and dispersed nature of BNL's current facilities.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-1, *Approve Alternative Selection and Cost Range,* approved on December 18, 2018. The preliminary estimate for CD-2*, Approve Performance Baseline*, is anticipated in the fourth quarter of FY 2020. This project is pre-CD-2, therefore schedule estimates are preliminary and subject to change. This project has a preliminary TEC range of $71,000,000 to $95,000,000. The preliminary total TPC range for this project is $72,000,000 to $96,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The most likely TEC for this project is estimated at $85,000,000 and the most likely TPC for this project is estimated at $86,000,000.

<u>Electrical Capacity and Distribution Capability, ANL</u>
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. 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 most recent DOE Order 413.3B Critical Decision (CD) is CD-0, *Approve Mission Need,* approved on September 11, 2017. The preliminary estimate for CD-1*, Approve Alternative Selection and Cost Range*, is anticipated in the second quarter of FY 2019. This project is pre-CD-2, therefore schedule estimates are preliminary and subject to change. This project has a preliminary TEC range of $52,000,000 to $96,000,000 and a preliminary TPC range of $53,000,000 to $97,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The most likely TEC for this project is estimated at $60,000,000 and the most likely TPC for this project is estimated at $61,000,000.

<u>Translational Research Capability, ORNL</u>
The Translational Research Capability project is proposed to provide a new building with laboratory space to support mission-critical research sponsored by ASCR, BES, FES and HEP. Currently, ORNL has a shortage of modern, flexible, and adaptable space, wet and dry laboratories, and high bay space needed to support research directed by these SC programs. Aging infrastructure and utilities have caused severe temperature, humidity and power quality problems, particularly in the advanced materials development and research. Finally, dispersed research space across the ORNL campus remains a challenge in supporting the increasingly interdisciplinary and collaborative research required to advance SC program mission areas.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-1, *Approve Alternative Selection and Cost Range,* approved on November 2, 2018. The preliminary estimate for CD-2*, Approve Performance Baseline*, is anticipated in the first quarter of FY 2020. This project is pre-CD-2, therefore schedule estimates are preliminary and subject to change. This project has a preliminary TEC range of $80,000,000 to $97,000,000 and a preliminary TPC range of $81,500,000 to $98,500,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The most likely TEC for this project is estimated at $93,500,000 and most likely TPC for this project is estimated at $95,000,000.

Biological and Environmental Program Integration Center (BioEPIC), LBNL

The BioEPIC project will construct a new, state-of-the-art facility with laboratory space to support high performance research by the BER, ASCR and BES programs. 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 DOE mission. Much of the biological sciences program at LBNL is located off-site, away from the main laboratory, while others are dispersed across several locations on the LBNL campus. This arrangement has posed a challenge to research and operational capabilities limiting scientific progress and the kind of collaborative science that is required for understanding, predicting and harnessing the Earth's microbiome for energy and environmental benefits.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, *Approve Mission Need,* approved on March 13, 2018. The preliminary estimate for CD-1*, Approve Alternative Selection and Cost Range*, is anticipated in the second quarter of FY 2019. This project is pre-CD-2, therefore schedule estimates are preliminary and subject to change. This project has a preliminary TEC range of $90,000,000 to $140,000,000 and a preliminary TPC range of $92,200,000 to $142,200,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The most likely TEC for this project is estimated at $140,000,000 and the most likely TPC for this project is estimated at $142,200,000.

Energy Sciences Capability, PNNL

The Energy Sciences Capability project will enhance PNNL's core fundamental science programs by addressing 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.

The most recent DOE Order 413.3B Critical Decision (CD) is CD-2/3, *Approve Project Performance Baseline and Approve Start of Construction,* approved on December 7, 2018. The preliminary estimate for CD-4, *Approve Start of Operations or Project Completion,* is anticipated in the fourth quarter of FY 2025. The Total Estimated Cost (TEC) for this project is $90,000,000. The Total Project Cost (TPC) for this project is $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. Currently, FNAL staff and their associated manufacturing, assembly, engineering, and technical facilities are scattered among three parts of the campus. 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, will reduce the overall footprint of outdated facilities and collocate engineering and associated research staff near the central campus, and will improve operational efficiency and collaboration because groups working on key projects would be in close proximity.

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 estimate for CD-2/3, *Approve Project Baseline and Approve Start of Construction Activities,* is anticipated in the third quarter of FY 2019. This project is pre-CD-2, therefore schedule estimates are preliminary and subject to change. This project has a preliminary TEC range of $73,000,000 to $98,000,000. The TPC range for this project is $74,000,000 to $99,000,000. The most likely TEC for this project is estimated at $85,000,000 and most likely TPC for this project is estimated at $86,000,000.

Activities and Explanation of Changes

FY 2019 Enacted		FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Construction	**$153,200,000**	**$118,400,000**	**-$34,800,000**
20-SC-71, Critical Utilities Rehabilitation Project, BNL	$—	$12,000,000	+$12,000,000
No funding was requested in FY 2019.		Funding will support Project Engineering and Design (PED) and construction activities.	Funding supports PED and construction activities.
20-SC-72, Seismic and Safety Modernization, LBNL	$—	$5,000,000	+$5,000,000
No funding was requested in FY 2019.		Funding will support PED activities.	Funding supports PED activities.
20-SC-73, CEBAF Renovation and Expansion, TJNAF	$—	$2,000,000	+$2,000,000
No funding was requested in FY 2019.		Funding will support PED activities.	Funding supports PED activities.
20-SC-74, Craft Resources Support Facility, ORNL	$—	$20,000,000	+$20,000,000
No funding was requested in FY 2019.		Funding will support PED and construction activities.	Funding supports PED and construction activities.
20-SC-75, Large Scale Collaboration Center, SLAC	$—	$3,000,000	+$3,000,000
No funding was requested in FY 2019.		Funding will support PED activities.	Funding supports PED activities.
19-SC-71, Science User Support Center, BNL	$7,000,000	$6,400,000	-$600,000
Funding supports PED activities.		Funding will support the completion of PED activities and start of construction activities.	Funding supports PED and construction activities.
19-SC-72, Electrical Capacity and Distribution Capability, ANL	$30,000,000	$30,000,000	$—
Funding supports PED and construction activities.		Funding will support the completion of construction activities.	FY 2020 Request reflects final year of funding.

FY 2019 Enacted		FY 2020 Request		Explanation of Changes FY 2020 Request vs FY 2019 Enacted	
19-SC-73, Translational Research Capability, ORNL	$25,000,000		$15,000,000		-$10,000,000
Funding supports PED and construction activities.		Funding will support construction activities.		Funding supports construction activities.	
19-SC-74, BioEPIC, LBNL	$5,000,000		$6,000,000		+$1,000,000
Funding supports PED activities.		Funding will support PED activities.		Funding supports PED activities.	
18-SC-71, Energy Sciences Capability, PNNL	$24,000,000		$9,000,000		-$15,000,000
Funding supports construction activities.		Funding will support construction activities.		Funding supports construction activities.	
17-SC-71, Integrated Engineering Research Center, FNAL	$20,000,000		$10,000,000		-$10,000,000
Funding supports construction activities.		Funding will support construction activities.		Funding supports construction activities.	
17-SC-73, Core Facility Revitalization, BNL	$42,200,000		$—		-$42,200,000
Funding supports construction activities.		No funding is requested in FY 2020.		Project received final funding in FY 2019.	

Science Laboratories Infrastructure
Capital Summary

(dollars in thousands)

	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Capital Operating Expenses Summary						
Minor Construction Activities						
General Plant Projects (GPP)	N/A	N/A	59,492	13,188	5,050	-8,138
Total, Capital Operating Expenses	**N/A**	**N/A**	**59,492**	**13,188**	**5,050**	**-8,138**

Minor Construction Activities

(dollars in thousands)

	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
General Plant Projects (GPP)						
Greater than or equal to $5M and less than $20M						
Upgrade Hot Cells and Labs B801 at BNL	N/A	N/A	8,500	—	—	—
Revitalize Biology Labs at BNL	N/A	N/A	5,000	—	—	—
Supply Water CMLC Piping Replacement at LBNL	N/A	N/A	9,500	—	—	—
Upgrade Cryogenics Infrastructure Phase 2 at TJNAF	N/A	N/A	9,900	—	—	—
Storm Drain Repairs at LBNL	N/A	N/A	7,000	—	—	—
Low Conductivity Water Cooling System at SLAC	N/A	N/A	8,800	—	—	—
Cooling Water Tower System at SLAC	N/A	N/A	—	9,400	—	-9,400
Total, GPPs (greater than or equal to $5M and less than $20M)	N/A	N/A	48,700	9,400	—	-9,400
Total, GPPs less than $5M[a]	N/A	N/A	10,792	3,788	5,050	+1,262
Total, GPP	**N/A**	**N/A**	**59,492**	**13,188**	**5,050**	**-8,138**
Total, Minor Construction Activities	**N/A**	**N/A**	**59,492**	**13,188**	**5,050**	**-8,138**

[a] GPP activities less than $5M include design and construction for additions and/or improvements to land, buildings, replacements or additions to roads, and general area improvements.

Science Laboratories Infrastructure
Construction Projects Summary

(dollars in thousands)

	Total	Prior Years	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
20-SC-71, Critical Utilities Rehabilitation Project, BNL						
TEC	85,000[a]	—	—	—	12,000	+12,000
OPC[b]	800	—	—	800	—	-800
TPC	**85,800[a]**	**—**	**—**	**800**	**12,000**	**+11,200**
20-SC-72, Seismic and Safety Modernization, LBNL						
TEC	95,400[a]	—	—	—	5,000	+5,000
OPC[b]	2,200	—	—	1,500	—	-1,500
TPC	**97,600[a]**	**—**	**—**	**1,500**	**5,000**	**+3,500**
20-SC-73, CEBAF Renovation and Expansion, TJNAF						
TEC	66,000[a]	—	—	—	2,000	+2,000
OPC[b]	1,900	—	20	1,465	—	-1,465
TPC	**67,900[a]**	**—**	**20**	**1,465**	**2,000**	**+535**
20-SC-74, Craft Resources Support Facility, ORNL						
TEC	40,000[a]	—	—	—	20,000	+20,000
OPC[b]	500	—	—	400	—	-400
TPC	**40,500[a]**	**—**	**—**	**400**	**20,000**	**+19,600**
20-SC-75, Large Scale Collaboration Center, SLAC						
TEC	60,000[a]	—	—	—	3,000	+3,000
OPC[b]	1,000	—	—	700	—	-700
TPC	**61,000[a]**	**—**	**—**	**700**	**3,000**	**+2,300**
19-SC-71, Science User Support Center, BNL						
TEC	85,000[a]	—	—	7,000	6,400	-600
OPC[b]	1,200	700	300	200	—	-200
TPC	**86,200[a]**	**700**	**300**	**7,200**	**6,400**	**-800**

[a] This project has not received CD-2 approval; therefore, preliminary cost estimates are shown for TEC and TPC.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

	(dollars in thousands)					
	Total	**Prior Years**	**FY 2018 Enacted**	**FY 2019 Enacted**	**FY 2020 Request**	**FY 2020 Request vs FY 2019 Enacted**
19-SC-72, Electrical Capacity and Distribution Capability, ANL						
TEC	60,000[a]	—	—	30,000	30,000	—
OPC[b]	1,000	—	1,000	—	—	—
TPC	**61,000[a]**	**—**	**1,000**	**30,000**	**30,000**	**—**
19-SC-73, Translational Research Capability, ORNL						
TEC	93,500[a]	—	—	25,000	15,000	-10,000
OPC[b]	1,500	190	1,000	—	—	—
TPC	**95,000[a]**	**190**	**1,000**	**25,000**	**15,000**	**-10,000**
19-SC-74, BioEPIC, LBNL						
TEC	140,000[a]	—	—	5,000	6,000	+1,000
OPC[b]	2,200	—	—	1,500	—	-1,500
TPC	**142,200[a]**	**—**	**—**	**6,500**	**6,000**	**-500**
18-SC-71, Energy Sciences Capability, PNNL						
TEC	90,000	—	20,000	24,000	9,000	-15,000
OPC[b]	3,000	839	400	—	—	—
TPC	**93,000[a]**	**839**	**20,400**	**24,000**	**9,000**	**-15,000**
17-SC-71, Integrated Engineering Research Center, FNAL						
TEC	85,000[a]	2,500	20,000	20,000	10,000	-10,000
OPC[b]	1,000	930	—	—	—	—
TPC	**86,000[a]**	**3,430**	**20,000**	**20,000**	**10,000**	**-10,000**
17-SC-73, Core Facility Revitalization, BNL						
TEC	74,000[a]	1,800	30,000	42,200	—	-42,200
OPC[b]	850	850	—	—	—	—
TPC	**74,850[a]**	**2,650**	**30,000**	**42,200**	**—**	**-42,200**

[a] This project has not received CD-2 approval; therefore, preliminary cost estimates are shown for TEC and TPC.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

	(dollars in thousands)					
	Total	**Prior Years**	**FY 2018 Enacted**	**FY 2019 Enacted**	**FY 2020 Request**	**FY 2020 Request vs FY 2019 Enacted**
15-SC-76, Materials Design Laboratory, ANL						
TEC	95,000	30,910	44,500	—	—	—
OPC[a]	1,000	1,000	—	—	—	—
TPC	**96,000**	**31,910**	**44,500**	**—**	**—**	**—**
15-SC-78, Integrative Genomics Building, LBNL						
TEC	90,000	32,090	38,350	—	—	—
OPC[a]	1,500	1,500	—	—	—	—
TPC	**91,500**	**33,590**	**38,350**	**—**	**—**	**—**
Total, Construction						
TEC	N/A	N/A	152,850	153,200	118,400	-34,800
OPC[a]	N/A	N/A	2,720	6,565	—	-6,565
TPC	**N/A**	**N/A**	**155,570**	**159,765**	**118,400**	**-41,365**

[a] Other Project Costs (OPC) are funded through laboratory overhead.

20-SC-71, Critical Utilities Rehabilitation Project
Brookhaven National Laboratory (BNL)
Project is for Design and Construction

1. Summary, Significant Changes, and Schedule and Cost History

Summary

The FY 2020 Request for the Critical Utilities Rehabilitation Project is $12,000,000. The current preliminary Total Estimated Cost (TEC) range for this project is $70,000,000 to $95,000,000. The preliminary Total Project Cost (TPC) range for this project is $70,800,000 to $95,800,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TEC for this project is estimated at $85,000,000 and preliminary TPC for this project is estimated at $85,800,000.

This project will upgrade failing utility infrastructure that is still in use from BNL's origins as World War II Army Camp Upton. Utility systems including steam, water, sanitary sewer, chilled water and electrical systems will be revitalized and upgraded to meet the needs of supporting SC facilities and the Nuclear Physics (NP), Basic Energy Sciences (BES), High Energy Physics (HEP), Biological and Environmental Research (BER), and Advanced Scientific Computing Research (ASCR) programs.

Significant Changes

This project is a new start in FY 2020. The most recent DOE Order 413.3B approved Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on July 20, 2018. FY 2020 funds will support Project Engineering and Design (PED) activities and initiate long-lead procurement activities.

A Federal Project Director with the appropriate certification level will be assigned prior to CD-1 approval.

Critical Milestone History

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2020	7/20/2018	4Q FY 2019	4Q FY 2019[a]	4Q FY 2020[a]	4Q FY 2021	4Q FY 2021[a]	N/A	4Q FY 2026[a]

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

Fiscal Year	Performance Baseline Validation	CD-3A	CD-3B
FY 2020	4Q FY 2020[a]	N/A	N/A

CD-3A – Approve Long-Lead Procurements and Start of Early Construction
CD-3B – Approve Remaining Construction Activities

[a] This project is pre-CD-2; therefore, funding and schedule estimates are preliminary.

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC[a], Except D&D	OPC, D&D	OPC, Total	TPC
FY 2020	8,500	76,500	85,000[b]	800	N/A	800	85,800[b]

2. Project Scope and Justification

Scope

The Critical Utilities Rehabilitation Project at BNL will revitalize and upgrade highest risk major utility systems across the BNL campus. This project will replace piping in areas prone to water main breaks and provide other water system improvements to improve system operations and reliability. Select sections of the sanitary utility systems with failing pumps, controllers, and/or manholes will be replaced. This project will also provide several required modifications to the central chilled water system in order to support growth of process loads and assure reliability. Deteriorated and leaking steam systems along Cornell Avenue will be replaced to assure safe, reliable, and efficient steam service to mission critical facilities on the north side of the campus. In addition, older feeder cables and inadequate breakers will be replaced along Cornell Avenue increasing capacity, reliability, and personnel safety.

Justification

BNL is a multi-program DOE national laboratory with recognized impact on national science needs. BNL provides scientific leadership in NP, photon sciences, energy science for BES, and data-driven discovery for ASCR, with leading programs in selected areas of HEP, BER, accelerator science and technology, and national security and non-proliferation. BNL utilizes world-class facilities and core expertise to: advance energy and environment-related basic research and apply them to 21st Century problems of critical importance to the Nation; and advance fundamental research in nuclear and particle physics to gain a deeper understanding of matter, energy, space, and time.

Although there has been substantial investment in recent years to modernize and construct new research facilities at BNL, much of BNL's utility infrastructure serving these facilities is over 50 years old and some is over 70 years old, dating to BNL's origin as a U. S. Army base during World Wars I and II. Efficient, maintainable, and reliable utilities are critical to the success and mission capability of BNL's research facilities. Currently, a significant portion of BNL's utility infrastructure is beyond useful life and suffering from failures, decreased reliability, lack of redundancy and limitations in capacity. As such, there is an urgent need to revitalize and selectively upgrade BNL's existing major utility systems to assure reliable service, meet capacity requirements, and enable readiness of facilities critical to the research mission.

Key Performance Parameters (KPPs) (Preliminary)

This project has not yet received CD-1 approval; therefore the Key Performance Parameters (KPPs) are yet to be determined. The table below outlines preliminary KPPs.

Performance Measure	Threshold	Objective
Chilled Water Supply	Replacement/installation of components	TBD
Sanitary Sewer System	Replacement/installation of components	TBD
Electrical Distribution System	Replacement/installation of components	TBD

[a] Other Project Costs (OPC) are funded through laboratory overhead.

[b] This project has not received CD-2 approval, therefore, funding estimates are preliminary.

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design			
FY 2020	8,500	8,500	8,500
Total, Design	8,500	8,500	8,500
Construction			
FY 2020	3,500	3,500	2,000
Outyears	73,000	73,000	74,500
Total, Construction	76,500	76,500	76,500
Total Estimated Costs (TEC)			
FY 2020	12,000	12,000	10,500
Outyears	73,000	73,000	74,500
Total, TEC[a]	**85,000**	**85,000**	**85,000**
Other Project Costs (OPC)[b]			
FY 2019	800	800	800
Total, OPC	800	800	800
Total Project Costs (TPC)			
FY 2019	800	800	800
FY 2020	12,000	12,000	10,500
Outyears	73,000	73,000	74,500
Total, TPC[a]	**85,800**	**85,800**	**85,800**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	6,800	N/A	N/A
Contingency	*1,700*	*N/A*	*N/A*
Total, Design	8,500	N/A	N/A
Construction			
Construction	61,200	N/A	N/A
Contingency	*15,300*	*N/A*	*N/A*
Total, Construction	76,500	N/A	N/A
Total, TEC[a]	**85,000**	**N/A**	**N/A**
Contingency, TEC	*17,000*	*N/A*	*N/A*
Other Project Cost (OPC)			
OPC except D&D			
OPC Costs	800	N/A	N/A
Contingency	—	*N/A*	*N/A*

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total, OPC[a]	**800**	**N/A**	**N/A**
Contingency, OPC	—	*N/A*	*N/A*
Total Project Cost[b]	**85,800**	**N/A**	**N/A**
Total Contingency (TEC+OPC)	***17,000***	***N/A***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2020	Outyears	Total
FY 2020	TEC	—	12,000	73,000	85,000[b]
	OPC[a]	800	—	—	800
	TPC	800	12,000	16,000	85,800[b]

6. Related Operations and Maintenance Funding Requirements

N/A

7. D&D Information

This project replaces critical infrastructure components and minimal, if any, support buildings will be constructed. 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*	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
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] Other Project Costs (OPC) are funded through laboratory overhead.

[b] This project has not received CD-2 approval, therefore, funding estimates are preliminary.

[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.

8. Acquisition Approach

The BNL Management and Operating (M&O) contractor, Brookhaven Science Associates will perform the acquisition for this project. The M&O contractor is responsible for awarding and managing all subcontracts related to this project. The M&O contractor will evaluate various acquisition alternatives and project delivery methods prior to achieving CD-1. Potential acquisition and project delivery methods include, but are not limited to, firm fixed price contracts for design-bid-build and design-build. The M&O contractor will also evaluate potential benefits of using a single or multiple contracts to procure materials, equipment, construction, commissioning and other project scope elements. Project performance metrics for BNL will be included in the M&O contractor's annual performance and evaluation measurement plan.

20-SC-72, Seismic and Safety Modernization
Lawrence Berkeley National Laboratory (LBNL)
Project is for Design and Construction

1. Summary, Significant Changes, and Schedule and Cost History

Summary

The FY 2020 Request for the Seismic and Safety Modernization project is $5,000,000. The preliminary Total Estimated Cost (TEC) range is $65,600,000 to 95,400,000 and the preliminary the Total Project Cost (TPC) range is $67,800,000 to $97,600,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TEC for this project is estimated at $95,400,000 and the preliminary TPC for this project is estimated at $97,600,000.

Significant Changes

This project is a new start in FY 2020. The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on September 6, 2018. FY 2020 funds will support the Project Engineering and Design (PED) activities.

A Federal Project Director with the appropriate certification level will be assigned to this project prior to CD-1 approval.

Critical Milestone History

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2020	09/06/2018	4Q FY 2019	4Q FY 2019[a]	4Q FY 2021[a]	4Q FY 2022	4Q FY 2022[a]	N/A	4Q FY 2027[a]

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

Fiscal Year	Performance Baseline Validation	CD-3A	CD-3B
FY 2020	4Q FY 2021	N/A	N/A

CD-3A – Approve Long-Lead Procurements and Start of Early Construction
CD-3B – Approve Start of Remaining Construction Activities

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC[b], Except D&D	OPC, D&D	OPC, Total	TPC
FY 2020	10,000	85,400	95,400[a]	2,200	N/A	2,200	97,600[a]

[a] This project is pre-CD-2; therefore, funding and schedule estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

2. Project Scope and Justification

Scope

The Seismic and Safety Modernization project will address seismic safety issues and emergency response capabilities, specifically related to facilities with large congregation areas as well as improve facilities and transportation capabilities that are necessary for emergency response personnel and maintain continuity of operations. The facilities that are the primary focus of this project are the Cafeteria, Health Services, and Fire House sleep quarters. The project will also address the limited space to congregate during an emergency situation.

Justification

The Office of Science (SC) utilizes the capabilities of LBNL to execute 22 of the 24 core capabilities and the mission of multiple SC program offices, specifically strong presences by the Advanced Scientific Computing Research (ASCR), Biological and Environment Research (BER), Basic Energy Sciences (BES), and High Energy Physics (HEP) programs. LBNL is located on a 202 acre site in the hills above the University of California, Berkeley campus employs approximately 3,400 full time employees; and is home to five SC national user facilities: the Advanced Light Source, the Energy Sciences Network, the Joint Genome Institute, the Molecular Foundry, and the National Energy Research Scientific Computing Center. In FY 2016, over 11,000 researchers used these facilities, representing roughly one third of the total for all SC user facilities. In pursuing the SC mission, LBNL leverages collaborative science to bring together teams of individuals with different fields of expertise to work together on common solutions to the SC mission. However, these research activities must be executed with a unique caution since LBNL is located less than one mile from the Hayward Fault and less than 25 miles from the San Andreas Fault, which would both pose a life safety risk to employees, visitors, and guests during a significant seismic event.

The U.S. Geological Survey's newest earthquake forecast, the third Uniform California Earthquake Rupture Forecast (UCERF3), states a 98% probability of a 6.0 magnitude or higher earthquake in the San Francisco Bay Area before 2043. Recent engineering evaluations from a San Francisco Bay Area structural engineering firm have identified significant and extensive seismic safety hazards in critical LBNL support buildings, including the Cafeteria, Health Services, and Fire House. Structural deficiencies identified in these buildings will likely cause significant structural damage with life safety hazards during a magnitude 6.0+ earthquake on the Hayward Fault or a magnitude 8.3 earthquake on the San Andreas Fault and will impede LBNL's ability to resume operations.

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) (Preliminary)

This project is pre-CD-1, therefore preliminary KKPs are not yet established. At CD-2 approval, the KPPs will be baselined. 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.

Performance Measure	Threshold	Objective
TBD	TBD	TBD

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design			
FY 2020	5,000	5,000	5,000
Outyears	5,000	5,000	5,000

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total, Design	10,000	10,000	10,000
Construction			
Outyears	85,400	85,400	85,400
Total, Construction	85,400	85,400	85,400
Total Estimated Costs (TEC)			
FY 2020	5,000	5,000	5,000
Outyears	90,400	90,400	90,400
Total, TEC[a]	**95,400**	**95,400**	**95,400**
Other Project Costs (OPC)			
FY 2019	1,500	1,500	1,500
Outyears	700	700	700
Total, OPC[b]	**2,200**	**2,200**	**2,200**
Total Project Costs (TPC)			
FY 2019	1,500	1,500	1,500
FY 2020	5,000	5,000	5,000
Outyears	94,100	94,100	94,100
Total, TPC[a]	**97,600**	**97,600**	**97,600**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	8,500	N/A	N/A
Contingency	*1,500*	*N/A*	*N/A*
Total, Design	10,000	N/A	N/A
Construction			
Construction	68,400	N/A	N/A
Contingency	*17,000*	*N/A*	*N/A*
Total, Construction	85,400	N/A	N/A
Total, TEC[a]	**95,400**	**N/A**	**N/A**
Contingency, TEC	*18,500*	*N/A*	*N/A*

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.

[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)			
OPC except D&D	2,000	N/A	N/A
Contingency	*200*	*N/A*	*N/A*
Total, OPC[b]	**2,200**	**N/A**	**N/A**
Contingency, OPC	*200*	*N/A*	*N/A*
Total Project Cost[a]	**97,600**	**N/A**	**N/A**
Total Contingency (TEC+OPC)	***18,700***	***N/A***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	FY 2019	FY 2020	Outyears	Total
FY 2020	TEC	—	5,000	90,400	95,400[a]
	OPC[b]	1,500	—	—	2,200
	TPC	1,500	5,000	90,400	97,600[a]

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy (fiscal quarter or date)	4Q FY 2027
Expected Useful Life (number of years)	50
Expected Future Start of D&D of this capital asset (fiscal quarter)	4Q FY 2077

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Previous Total Estimate	**Current Total Estimate**	**Previous Total Estimate**	**Current Total Estimate**
Operations	N/A	TBD	N/A	TBD
Utilities	N/A	TBD	N/A	TBD
Maintenance and Repair	N/A	TBD	N/A	TBD
Total—Operations and Maintenance	N/A	TBD	N/A	TBD

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

7. D&D Information

The new area being constructed in this project is replacing existing facilities.

	Square Feet
New area being constructed by this project at *Lawrence Berkeley National Laboratory*	TBD
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
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	TBD

8. Acquisition Approach

The LBNL Management and Operating (M&O) Contractor, University of California will perform the acquisition for this project. The M&O Contractor will be responsible for awarding and managing all subcontracts related to the project. The LBNL 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 LBNL 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.

20-SC-73, CEBAF Renovation and Expansion
Thomas Jefferson National Accelerator Facility (TJNAF)
Project is for Design and Construction

1. Summary, Significant Changes, and Schedule and Cost History

Summary

The FY 2020 Request for the CEBAF Renovation and Expansion project is $2,000,000. The preliminary Total Estimated Cost (TEC) range for this project is $47,000,000 to $75,000,000. The preliminary Total Project Cost (TPC) range for this project is $48,900,000 to $76,900,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TEC point estimate for this project is $66,000,000 and the preliminary TPC point estimate for this project is $67,900,000.

The CEBAF center at TJNAF is currently overcrowded and has inadequate utility systems that are experiencing frequent failures. This project will renovate 67,000 to 80,000 gross square feet (gsf) of existing space in the CEBAF center, upgrade high risk utility systems, and provide 22,000 to 95,000 gsf of new space for visitors, users, research, education, and support.

Significant Changes

This project is a new start in FY 2020.The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on July 20, 2018. FY 2020 funds will support Project Engineering and Design (PED) activities.

A Federal Project Director has been assigned to this project and has approved this CPDS.

Critical Milestone History

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2020	07/20/2018	4Q FY 2019	4Q FY 2019	4Q FY 2020[a]	3Q FY 2021	4Q FY 2021[a]	N/A	4Q FY 2026[a]

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
CD-1 – Approve Alternative Selection and Cost Range
CD-2 – Approve Performance Baseline
Final Design Complete – Estimated/Actual date the project design will be complete
CD-3 – Approve Start of Construction
D&D Complete – Completion of D&D work
CD-4 – Approve Start of Operations or Project Closeout

Fiscal Year	Performance Baseline Validation	CD-3A	CD-3B
FY 2020	4Q FY 2020[a]	N/A	N/A

CD-3A – Approve Long-Lead Procurements and Start of Early Construction Activities
CD-3B – Approve Start of Remaining Construction Activities

[a] This project is pre-CD-2; therefore, funding and schedule estimates are preliminary.

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC[a], Except D&D	OPC, D&D	OPC, Total	TPC
FY 2020	4,200	61,800	66,000[b]	1,900	N/A	1,900	67,900[a]

2. Project Scope and Justification

Scope

The CEBAF Renovation and Expansion project will renovate existing and provide new research, administrative, and support service space enabling TJNAF to better support current SC missions and planned mission growth. This project will renovate 67,000 to 80,000 gsf of existing space and provide 22,000 to 92,000 gsf of new office space for 120 to 200 research, education, and support staff. The renovation will include reconfiguration to provide more functional spaces that meet current code standards. Research and office spaces will be designed to meet evolving staff needs and provide a more efficient work environment, providing more functional meeting spaces. Ceilings will be removed and replaced to match the designed spaces.

The mechanical systems in the existing CEBAF Center, which have exceeded their service life and experienced multiple failures, will be replaced. The renovated building will be energy sustainable and will meet high performance building standards, including energy conservation, green building principles and sustainable design, and will be designed to meet Federal legislative objectives.

Upon completion, staff from the Applied Research Center (ARC) and Service Support Center (SSC) will be relocated into the CEBAF Center to more efficiently address functional workspace needs for TJNAF staff and users.

Justification

With a population of nearly 1600 users, TJNAF supports one of the largest nuclear physics user communities in the world. The expanded scientific scope associated with the 12 GeV upgrade (e.g., double the energy with simultaneous delivery to four experimental halls) is creating more and larger collaborations, requiring more technical workshops, and resulting in more visitors to the Lab. Staff and user population is expected to increase 2% per year for the next 10 years and will soon exceed available space, which is already near capacity. Further, TJNAF is actively pursuing a number of large inter-entity transfer projects such as the cryomodules and cryogenics plants for LCLS-I, LCLS-II-HE, and FRIB that are projected to require additional staffing. TJNAF will play a key role, potentially as lead, for the design and development of a major SC initiative.

Currently TNAF is lacking technically equipped and functional space to accommodate advanced scientific research and major missions on the immediate horizon. The existing CEBAF Center is well beyond full capacity. The current occupant density of this building is 110 gsf per occupant which is significantly below the DOE standard of 180 gsf per occupant. In addition, utility systems at the CEBAF center are inadequate, failing, and inefficient for the existing usage, let alone the potential anticipated usage in the near future.

TJNAF also continues to advance a strategic campus plan designed to deliver more attractive, mission-focused, and functional workspaces by consolidating the Lab workforce scattered over several leased buildings in a single center that provides more effective and efficient operations. This includes consolidating workers currently housed in the ARC and SSC into a single facility. This would allow for costly leases to be discontinued and reduce the cost to sustain existing buildings and infrastructure and more efficiently address functional workspace needs for TJNAF staff and users.

TJNAF must be prepared to accommodate planned staff and user growth which means additional office space must be programmed soon. The Laboratory is pursuing Major Items of Equipment, several large inter-agency transfer projects for other National Labs, and a pivotal technical role in a proposed Electron Ion Collider.

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[a] Other Project Costs (OPC) are funded through laboratory overhead.

The project will be conducted in accordance with the project management requirements in DOE Order 413.3B, and all appropriate project management requirements will be met.

Key Performance Parameters (KPPs) (Preliminary)
The project has not yet received CD-1 approval; therefore Key Performance Parameters are yet to be determined. The table below outlines preliminary KPPs.

Performance Measure	Threshold	Objective
CEBAF Center Renovation	67,000 GSF	80,000 GSF
CEBAF Center Expansion	22,000 GSF	92,000 GSF

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs[a]
Total Estimated Cost (TEC)			
Design			
FY 2020	2,000	2,000	2,000
Outyears	2,200	2,200	2,200
Total, Design	4,200	4,200	4,200
Construction			
Outyears	61,800	61,800	61,800
Total, Construction	61,800	61,800	61,800
Total Estimated Costs (TEC)			
FY 2020	2,000	2,000	2,000
Outyears	64,000	64,000	64,000
Total, TEC[b]	**66,000**	**66,000**	**66,000**
Other Project Costs (OPC)			
FY 2018	20	20	20
FY 2019	1,465	1,465	1,465
Outyears	415	415	415
Total, OPC[c]	1,900	1,900	1,900
Total Project Costs (TPC)			
FY 2018	20	20	20
FY 2019	1,465	1,465	1,465
FY 2020	2,000	2,000	2,000
Outyears	64,415	64,415	64,415
Total, TPC[b]	**67,900**	**67,900**	**67,900**

[a] Costs for FY 2019 and the outyears are estimates.

[b] This project has not received CD-2 approval, therefore, funding estimates are preliminary.

[c] Other Project Costs (OPC) are funded through laboratory overhead.

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	3,400	N/A	N/A
Contingency	*800*	*N/A*	*N/A*
Total, Design	4,200	N/A	N/A
Construction			
Construction	49,800	N/A	N/A
Contingency	*12,000*	*N/A*	*N/A*
Total, Construction	61,800	N/A	N/A
Total, TEC[a]	66,000	N/A	N/A
Contingency, TEC	*12,800*	*N/A*	*N/A*
Other Project Cost (OPC)			
OPC except D&D	1,900	N/A	N/A
Contingency	—	*N/A*	*N/A*
Total, OPC[b]	1,900	N/A	N/A
Total Project Cost[a]	67,900	N/A	N/A
Total Contingency (TEC+OPC)	***12,800***	***N/A***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	FY 2018	FY 2019	FY 2020	Outyears	Total
FY 2020	TEC	—	—	2,000	64,000	66,000[a]
	OPC[b]	20	1,465	—	415	1,900
	TPC	20	1,465	2,000	64,415	67,900[a]

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy (fiscal quarter or date)	4Q FY 2026
Expected Useful Life (number of years)	50
Expected Future Start of D&D of this capital asset (fiscal quarter)	4Q FY 2076

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.

[b] Other Project Costs (OPC) are funded through laboratory overhead.

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Previous Total Estimate	**Current Total Estimate**	**Previous Total Estimate**	**Current Total Estimate**
Operations	288	N/A	14,400	N/A
Utilities	432	N/A	21,600	N/A
Maintenance and Repair	1,008	N/A	50,400	N/A
Total—Operations and Maintenance	1,728	N/A	86,400	N/A

7. D&D Information

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

	Square Feet
New area being constructed or procured by this project at *Thomas Jefferson National Accelerator Facility*	22,000–144,000
Area of D&D in this project at *Thomas Jefferson National Accelerator Facility*	None
Area at *Thomas Jefferson National Accelerator Facility* 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[a]
Total area eliminated	None

8. Acquisition Approach

The TJNAF Management and Operating (M&O) contractor, Jefferson Science Associates, will perform the acquisition for this project, overseen by the Thomas Jefferson 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.

[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.

20-SC-74, Craft Resources Support Facility
Oak Ridge National Laboratory, Oak Ridge, TN
Project is for Design and Construction

1. Summary, Significant Changes, and Schedule and Cost History

Summary

The FY 2020 Request for the Craft Resources Support Facility is $20,000,000. The preliminary Total Estimated Cost (TEC) range for this project is $24,500,000 to $40,000,000 and the preliminary Total Project Cost (TPC) range for this project is $25,000,000 to $40,500,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The most likely TEC for this project is estimated at $40,000,000 and the most likely TPC for this project is estimated at $40,500,000.

This project will provide a new facility that will allow craft resource services currently located in inadequate facilities to be consolidated into one modern, efficient facility.

Significant Changes

This project is a new start in FY 2020. The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on July 20, 2018. FY 2020 funds will be used to support Project Engineering and Design (PED) activities and initiate construction activities.

A Federal Project Director with the appropriate certification level will be assigned to this project prior to CD-1 approval.

Critical Milestone History

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2020	07/20/2018	4Q FY 2019	4Q FY 2019[a]	3Q FY 2020[a]	3Q FY 2019	3Q FY 2020[a]	N/A	4Q FY 2023[a]

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

Fiscal Year	Performance Baseline Validation	CD-2/3	CD-3A	CD-3B
FY 2020	3Q FY 2020[a]	3Q FY 2020[a]	N/A	N/A

CD-2/3 – Approve Performance Baseline and Start of Construction
CD-3A – Approve Long-Lead Procurements and Start of Early Construction
CD-3B – Approve Start of Remaining Construction Activities

[a] This project is pre-CD-2; therefore, funding and schedule estimates are preliminary.

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC[a], Except D&D	OPC, D&D	OPC, Total	TPC
FY 2020	4,000	36,000	40,000[b]	500	N/A	500	40,500[b]

2. Project Scope and Justification

Scope

The Craft Resources Support Facility project will provide modern space with an appropriate design, configuration, and environmental conditions to maintain Oak Ridge National Laboratory (ORNL) infrastructure and support activities conducted at user, experimental, and developmental research facilities for multiple SC research programs. Craft resource services that are currently housed in multiple inadequate facilities spread across the 7000 area of ORNL will be consolidated into this new facility.

Justification

SC utilizes over 20 core capabilities supported by ORNL and core mission facilities at ORNL, such as the Spallation Neutron Source (SNS), the High Flux Isotope Reactor (HFIR), and the Oak Ridge Leadership Computing Facility (OLCF). These core capabilities and facilities support the mission of Basic Energy Sciences, Fusion Energy Sciences, Nuclear Physics, Biological & Environmental Research, and Advanced Scientific Computing Research.

The complex infrastructure required to support the SC mission and associated facilities places a substantial demand on craft resource support functions, which is comprised of 28 different trades ranging from automotive mechanics to instrument technicians. Craft resources within ORNL's Facilities and Operations maintains and/or supports the Laboratory's 5.7 million square feet of space, maintains a fleet of over 400 vehicles, and supplies utilities to this footprint including nearly 50 miles of water distribution piping, 670 million pounds of high-pressure steam distributed over 10 miles of steam lines, three major electrical substations, 60 miles of overhead transmission lines, and 14,000 tons of chilled water production.

Continued research at ORNL that supports over 3,200 users utilizing the many user facilities, as well as experimental and developmental research facilities, are dependent on support services provided by craft resources. Due to the distinctive nature and complexity of many of ORNL infrastructure systems, in house craft services are often required to respond to unique circumstances. Similarly, operational inefficiencies in these areas result in a ripple effect that increases risk to SC research productivity and the ORNL science mission. Inefficient operation of craft resource support services directly impacts many high-priority science programs at ORNL.

ORNL mission support personnel provide multiple services supporting the ORNL science mission including but not limited to hoist and rigging, welding and inspection, maintenance and repair garage, and others. These support services are currently housed in multiple inadequate facilities spread across the 7000 area, which are outdated and poorly configured resulting in inefficient operations, congested vehicle and pedestrian traffic patterns, and increased safety risks. These conditions are creating inefficient, unreliable operations that are directly impacting many high-priority SC programs at ORNL. Current facilities also lack conditioned space and covered storage that reduces life for high value equipment and materials as well provide poor working conditions for staff.

This project provides modern space with appropriate design, configuration, and environmental conditions to support activities conducted at user, experimental, and developmental research facilities for multiple SC research programs including SNS, HFIR, and OLCF.

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.

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[a] Other Project Costs (OPC) are funded through laboratory overhead.

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.

Key Performance Parameters (KPPs) (Preliminary)
The project has not yet received CD-1 approval; therefore Key Performance Parameters are yet to be determined. The table below outlines preliminary KPPs.

Performance Measure	Threshold	Objective
Craft services support building	40,000 gsf	60,000 gsf

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design			
FY 2020	4,000	4,000	4,000
Total, Design	4,000	4,000	4,000
Construction			
FY 2020	16,000	16,000	10,000
Outyears	20,000	20,000	26,000
Total, Construction	36,000	36,000	36,000
Total Estimated Cost (TEC)			
FY 2020	20,000	20,000	14,000
Outyears	20,000	20,000	26,000
Total, TEC[a]	**40,000**	**40,000**	**40,000**
Other Project Cost (OPC)			
FY 2019	400	400	400
Outyears	100	100	100
Total, OPC[b]	500	500	500
Total Project Costs (TPC)			
FY 2019	400	400	400
FY 2020	20,000	20,000	14,000
Outyears	20,100	20,100	26,100
Total, TPC[a]	**40,500**	**40,500**	**40,500**

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	3,500	N/A	N/A
Contingency	*500*	*N/A*	*N/A*
Total, Design	4,000	N/A	N/A
Construction			
Construction	30,000	N/A	N/A
Contingency	*6,000*	*N/A*	*N/A*
Total, Construction	36,000	N/A	N/A
Total, TEC[a]	**40,000**	**N/A**	**N/A**
Contingency, TEC	*6,500*	*N/A*	*N/A*
Other Project Cost (OPC)			
OPC except D&D			
Conceptual Design	420	N/A	N/A
Contingency	*80*	*N/A*	*N/A*
Total, OPC[b]	**500**	**N/A**	**N/A**
Contingency, OPC	*80*	*N/A*	*N/A*
Total Project Cost[b]	**40,500**	**N/A**	**N/A**
Total Contingency (TEC+OPC)	***6,580***	***N/A***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2019	FY 2020	Outyears	Total
FY 2020	TEC	—	—	20,000	20,000	40,000[a]
	OPC[b]	—	400	—	100	500
	TPC	—	400	20,000	20,100	40,500[a]

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy (fiscal quarter or date)	4Q FY 2022
Expected Useful Life (number of years)	50
Expected Future Start of D&D of this capital asset (fiscal quarter)	4Q FY 2072

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Previous Total Estimate	**Current Total Estimate**	**Previous Total Estimate**	**Current Total Estimate**
Operations	N/A	101	N/A	4,249
Utilities	N/A	146	N/A	6,141
Maintenance and Repair	N/A	194	N/A	8,161
Total—Operations and Maintenance	N/A	441	N/A	18,551

7. 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 *Oak Ridge National Laboratory*	40,000–60,000
Area of D&D in this project at *Oak Ridge National Laboratory*	None
Area at *Oak Ridge 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[a]
Total area eliminated	40,000–60,000

8. Acquisition Approach

The ORNL Management and Operating (M&O) Contractor, UT-Battelle will perform the acquisition for this project. The M&O Contractor will be responsible for awarding and managing all subcontracts related to the project. The ORNL 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 ORNL 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.

20-SC-75, Large Scale Collaboration Center
SLAC National Accelerator Laboratory (SLAC)
Project is for Design and Construction

1. Summary, Significant Changes, and Schedule and Cost History

Summary

The FY 2020 Request for the Large Scale Collaboration Center is $3,000,000. The current preliminary Total Estimated Cost (TEC) range for this project is $32,000,000 to $60,000,000. The current preliminary Total Project Cost (TPC) range for this project is $33,000,000 to $61,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The most likely TEC for this project is estimated at $60,000,000 and the most likely TPC for this project is estimated at $61,000,000.

This project will construct a new facility that will allow for collocation of cross-functional teams in a common building, providing synergies between all major SC-sponsored programs

Significant Changes

This project is a new start in FY 2020. The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on July 20, 2018. FY 2020 funds will be used to support Project Engineering and Design (PED) activities.

A Federal Project Director with the appropriate certification level will be assigned to this project prior to CD-1 approval.

Critical Milestone History

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2020	7/20/2018	4Q FY 2019	4Q FY 2019[a]	4Q FY 2020[a]	4Q FY 2020	4Q FY 2020[a]	N/A	4Q FY 2026[a]

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

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC[b], Except D&D	OPC, D&D	OPC, Total	TPC
FY 2020	6,000	54,000[a]	60,000[a]	1,000	N/A	1,000	61,000[a]

[a] This project is pre-CD-2 and schedule and funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

2. Project Scope and Justification

Scope

The Large Scale Collaboration Center project will construct an office building of approximately 38,000 to 45,000 gross square feet (gsf) to consolidate and provide space for 100-150 occupants in a common building with the necessary performance capabilities to grow the science research programs.

Justification

Advances in scientific exploration require the coordinated development of an extensive range of sophisticated imaging tools and extremely large amounts of data sets and images for current and future user facilities and research programs, including the Linac Coherent Light Source (LCLS), the LCLS-II, the LCLS-II-HE, the Stanford Synchrotron Radiation Laboratory (SSRL), Cryo-Electron Microscopy (EM), the ATLAS at the Large Hadron Collider (LHC), the Large Synoptic Survey Telescope (LSST), the Deep Underground Neutrino Experiment (DUNE), and the Facility for Advanced Accelerator Experimental Tests (FACET)-II.

Existing buildings provide sufficient laboratory and experimental space. However, current office spaces near experimental areas are fully occupied or oversubscribed, and staff and users are projected to increase and exceed the availability of adequate space. Office spaces in current buildings are not properly configured and do not address the pressing need to accommodate teams that are developing critical algorithms and data analysis techniques alongside staff scientists or visiting researchers and users.

With growing numbers of scientific staff and users dealing with increased rates of data generation on the order of terabytes per second streaming from detectors, it is essential to reduce data volumes while preserving the science content of the data. This can be accomplished by collaboration among teams with expertise in data science and massive-scale data analytics. The real-time computing for data reduction and, most importantly, for feedback, defines the scale of the computing infrastructure required onsite and offsite. This real-time feedback, received during experiment operation and between shifts, is instrumental for the user to optimize the experiment and receive datasets as complete as possible before leaving the facility. Cross-functional teams that understand accelerator and instrument operations also need to collaborate to address the common and expanding need for substantial computation support.

Furthermore, the High Energy Density program is also working closely with SLAC's LCLS directorate and the U.S. scientific community to advance the Matter in Extreme Conditions (MEC), which will result in much improved optical and x-ray laser capabilities that will enable novel experiments to push the scientific frontier. Scientists at the MEC project will perform these activities in collaboration with LCLS and academic partners and users ahead of full scale experiments at LCLS.

SLAC currently lacks sufficient office space for scientists and staff to jointly explore challenges and develop solutions using large-scale data sets. Adjacent office spaces that enable researchers to benefit from collaboration with subject matter experts in computational science, machine learning, artificial intelligence, exascale computing, data management, data acquisition, simulation, imaging, visualization, and modeling are also not currently available.

To address these capability gaps, SLAC proposes to construct a new Large Scale Collaboration Center that will enable SLAC to collocate cross-functional teams of SLAC and outside scientists in one building. This centralization will provide SLAC with the necessary performance capabilities to support and grow the science research 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.

Key Performance Parameters (KPPs) (Preliminary)
The project has not yet received CD-1 approval; therefore Key Performance Parameters are yet to be determined. The table below outlines preliminary KPPs.

Performance Measure	Threshold	Objective
Construction of a Multi-story Building	38,000 gsf	45,000 gsf

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design			
FY 2020	3,000	3,000	3,000
Outyears	3,000	3,000	3,000
Total, Design	6,000	6,000	6,000
Construction			
Outyears	54,000	54,000	54,000
Total, Construction	54,000	54,000	54,000
Total Estimated Costs (TEC)			
FY 2020	3,000	3,000	3,000
Outyears	57,000	57,000	57,000
Total, TEC[a]	**60,000**	**60,000**	**60,000**
Other Project Costs (OPC)			
FY 2019	700	700	700
Outyears	300	300	300
Total, OPC[b]	1,000	1,000	1,000
Total Project Costs (TPC)			
FY 2019	700	700	700
FY 2020	3,000	3,000	3,000
Outyears	57,300	57,300	57,300
Total, TPC[a]	**61,000**	**61,000**	**61,000**

[a] This project has not received CD-2 approval; therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	4,800	N/A	N/A
Contingency	*1,200*	*N/A*	*N/A*
Total, Design	6,000	N/A	N/A
Construction			
Construction	43,000	N/A	N/A
Contingency	*11,000*	*N/A*	*N/A*
Total, Construction	54,000	N/A	N/A
Total, TEC[a]	**60,000**	**N/A**	**N/A**
Contingency, TEC	*12,200*	*N/A*	*N/A*
Other Project Cost (OPC)[b]			
OPC except D&D			
OPC Costs	1,000	N/A	N/A
Contingency	—	*N/A*	*N/A*
Total, OPC	**1,000**	**N/A**	**N/A**
Contingency, OPC	—	*N/A*	*N/A*
Total Project Cost[a]	**61,000**	**N/A**	**N/A**
Total Contingency (TEC+OPC)	***12,200***	***N/A***	***N/A***

5. Schedule of Appropriations Requests

(dollars in thousands)

Request Year	Type	FY 2019	FY 2020	Outyears	Total
FY 2020	TEC	—	3,000	57,000	60,000[a]
	OPC[b]	700	—	300	1,000
	TPC	700	3,000	57,300	61,000[a]

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy (fiscal quarter or date)	4Q FY 2026
Expected Useful Life (number of years)	50
Expected Future Start of D&D of this capital asset (fiscal quarter)	4Q FY 2076

[a] This project has not received CD-2 approval; therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

Related Funding Requirements
(dollars in thousands)

	Annual Costs		**Life-Cycle Costs**	
	Previous Total Estimate	**Current Total Estimate**	**Previous Total Estimate**	**Current Total Estimate**
Operations	N/A	81	N/A	4,050
Utilities	N/A	154	N/A	7,700
Maintenance and Repair	N/A	170	N/A	8,500
Total – Operations and Maintenance	N/A	405	N/A	20,250

7. 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 National Accelerator Laboratory*................	38,000-45,000
Area of D&D in this project at *SLAC National Accelerator Laboratory*	None
Area at *SLAC National Accelerator 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	38,000-46,000

8. Acquisition Approach

The SLAC Management and Operating (M&O) contractor, Stanford University will perform the acquisition for this project. The M&O contractor is responsible for awarding and managing all subcontracts related to this project. The M&O contractor will evaluate various acquisition alternatives and project delivery methods prior to achieving CD-1. Potential acquisition and project delivery methods include, but are not limited to, firm fixed price contracts for design-bid-build and design-build. The M&O contractor will also evaluate potential benefits of using a single or multiple contracts to procure materials, equipment, construction, commissioning and other project scope elements. Project performance metrics for SLAC 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-71, Science and User Support Center
Brookhaven National Laboratory (BNL)
Project is for Design and Construction

1. Summary, Significant Changes, and Schedule and Cost History

Summary

The FY 2020 Request for the Science and User Support Center is $6,400,000. 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. The most likely TEC for this project is estimated at $85,000,000 and the most likely TPC for this project is estimated at $86,200,000.

This project will provide a facility to serve the research community and improve scientific and operational productivity by consolidating visitor and support services.

Significant Changes

This project was initiated in FY 2019. The most recent DOE Order 413.3B Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, which was approved on December 18, 2018. FY 2020 funds will continue Project Engineering and Design (PED) activities and begin long lead procurement activities.

A Federal Project Director with the appropriate certification level has been assigned to this project.

Critical Milestone History

Fiscal Year	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]
FY 2020	12/12/2016	9/7/2018	12/18/2018	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

Fiscal Year	Performance Baseline Validation	CD-3A
FY 2019	4Q FY 2020	N/A
FY 2020	4Q FY 2020	4Q FY 2019

CD-3A – Approve Site Preparation

[a] This project is pre-CD-2; schedule and funding estimates are preliminary.

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC[a], Except D&D	OPC, D&D	OPC, Total	TPC
FY 2019	9,400	75,600[b]	85,000[b]	1,000	N/A	1,000	86,000[b]
FY 2020	9,400	75,600	85,000[b]	1,200	N/A	1,200	86,200[b]

2. Project Scope and Justification

Scope

The Science and User Support Center (SUSC) project received CD-1, Approve Alternative Selection and Cost Range, which identified a single new facility at BNL perimeter as the preferred alternative. It is currently conceived as a project to construct a multi-story office building of approximately 70,000 to 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.

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.*

Key Performance Parameters (KPPs)

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.

Performance Measure	Threshold	Objective
Multi-story Building	70,000 gsf	120,000 gsf

[a] Other project costs (OPC) are funded through laboratory overhead.

[b] This project has not received CD-2 approval, therefore, funding estimates are preliminary.

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs[a]
Total Estimated Cost (TEC)			
Design			
FY 2019	7,000	7,000	7,000
FY 2020	2,400	2,400	2,400
Total, Design	9,400	9,400	9,400
Construction			
FY 2020	4,000	4,000	2,000
Outyears	71,600	71,600	73,600
Total, Construction	75,600	75,600	75,600
Total Estimated Costs (TEC)			
FY 2019	7,000	7,000	7,000
FY 2020	6,400	6,400	4,400
Outyears	71,600	71,600	73,600
Total, TEC[b]	85,000	85,000	85,000
Other Project Costs (OPC)[c]			
FY 2017	700	700	700
FY 2018	300	300	300
FY 2019	200	200	200
Total, OPC	**1,200**	**1,200**	**1,200**
Total Project Costs (TPC)			
FY 2017	700	700	700
FY 2018	300	300	300
FY 2019	7,200	7,200	7,200
FY 2020	6,400	6,400	4,400
Outyears	71,600	71,600	73,600
Total, TPC[b]	**86,200**	**86,200**	**86,200**

[a] Costs for FY 2019 and the outyears are estimates.
[b] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[c] Other Project Costs (OPC) are funded through laboratory overhead.

4. 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[a]	**85,000**	**N/A**	**N/A**
Contingency, TEC	*14,200*	*N/A*	*N/A*
Other Project Cost (OPC)			
OPC except D&D			
Conceptual Planning	500	N/A	N/A
Conceptual Design	500	N/A	N/A
Contingency	*200*	*N/A*	*N/A*
Total, OPC[b]	**1,200**	**N/A**	**N/A**
Contingency, OPC	*200*	*N/A*	*N/A*
Total Project Cost[a]	**86,200**	**N/A**	**N/A**
Total Contingency (TEC+OPC)	***14,400***	***N/A***	***N/A***

5. Schedule of Appropriation Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2018	FY 2019	FY 2020	Outyears	Total
FY 2019	TEC	—	—	2,000	7,400	75,600	85,000[a]
	OPC[b]	—	1,000	—	—	—	1,000
	TPC	—	1,000	2,000	7,400	75,600	86,000[a]
FY 2020	TEC	—	—	7,000	6,400	71,600	85,000[a]
	OPC[b]	700	300	200	—	—	1,200
	TPC	700	300	7,200	6,400	71,600	86,200[a]

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy (fiscal quarter or date)	4Q FY 2025
Expected Useful Life (number of years)	50
Expected Future Start of D&D of this capital asset (fiscal quarter)	N/A

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Previous Total Estimate	**Current Total Estimate**	**Previous Total Estimate**	**Current Total Estimate**
Operations	N/A	166	N/A	8,307
Utilities	N/A	78	N/A	3,879
Maintenance and Repair	N/A	384	N/A	19,200
Total – Operations and Maintenance	N/A	628	N/A	31,386

7. 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

8. Acquisition Approach

The BNL Management and Operating (M&O) Contractor, Brookhaven Science Associates will perform the acquisition for this project. 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)
Project is for Design and Construction

1. Summary, Significant Changes, and Schedule and Cost History

Summary

The FY 2020 Request for the Electrical Capacity and Distribution Capability project is $30,000,000. This project has a preliminary Total Estimated Cost (TEC) range of $52,000,000 to $96,000,000 and a preliminary Total Project Cost (TPC) range of $53,000,000 to $97,000,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The preliminary TEC for this project is estimated at $60,000,000 and the preliminary TPC for this project is estimated at $61,000,000.

This project will 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).

Significant Changes

This project was initiated in FY 2019. The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on September 22, 2017. CD-1, Approve Alternative Selection and Cost Range, CD-3A, Approve Long-lead Procurement and Start of Early Construction Activities, and CD-3B, Approve Start of Remaining Construction Activities approvals are anticipated in FY 2019. FY 2020 funds will continue construction activities.

A Federal Project Director with the appropriate certification level will be assigned to this project prior to CD-1 approval.

Critical Milestone History

Fiscal Year	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
FY 2020	09/22/2017	N/A	2Q FY 2019[a]	4Q FY 2019[a]	2Q FY 2019	4Q FY 2019[a]	N/A	1Q FY 2023[a]

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

Fiscal Year	Performance Baseline Validation	CD-3A	CD-3B
FY 2019	N/A	N/A	N/A
FY 2020	N/A	2Q FY 2019	4Q FY 2019

CD-3A – Approve Long-Lead Procurements and Start of Early Construction Activities
CD-3B – Approve Start of Remaining Construction Activities

[a] This project is pre-CD-2 approval and schedule estimates are preliminary.

Project Cost History

(dollars in thousands)

Fiscal Year	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
FY 2020	6,000	54,000	60,000[b]	1,000	N/A	1,000	61,000[b]

2. 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.

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.

[a] Other Project Costs (OPC) are funded through laboratory overhead.

[b] This project has not received CD-2 approval, therefore, funding estimates are preliminary.

Key Performance Parameters (KPPs)

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.

Performance Measure	Threshold	Objective
Upgrade High Voltage Electrical System & Supporting Infrastructure	CD-3: Construct new redundant high voltage supply transmission system to meet projected site loads (> 150 MVA)	Threshold Value plus: Potential line upgrades, new equipment, equipment replacements, various other electrical system reliability projects) to increase reliability of laboratory internal electrical distribution

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design			
FY 2019	6,000	6,000	6,000
Total, Design	6,000	6,000	6,000
Construction			
FY 2019	24,000	24,000	10,000
FY 2020	30,000	30,000	15,000
Outyears	—	—	29,000
Total, Construction	54,000	54,000	54,000
Total Estimated Costs (TEC)			
FY 2019	30,000	30,000	16,000
FY 2020	30,000	30,000	15,000
Outyears	—	—	29,000
Total, TEC[a]	**60,000**	**60,000**	**60,000**
Other Project Costs (OPC)			
OPC except D&D			
FY 2018	1,000	1,000	1,000
Total, OPC[b]	**1,000**	**1,000**	**1,000**
Total Project Cost (TPC)			
FY 2018	1,000	1,000	1,000
FY 2019	30,000	30,000	16,000
FY 2020	30,000	30,000	15,000
Outyears	—	—	29,000
Total, TPC[a]	**61,000**	**61,000**	**61,000**

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.

[b] Other Project Costs (OPC) are funded through laboratory overhead.

4. 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	5,100	N/A
Contingency	*900*	*900*	*N/A*
Total, Design	6,000	6,000	N/A
Construction			
Construction	45,000	45,000	N/A
Contingency	*9,000*	*9,000*	*N/A*
Total, Construction	54,000	54,000	N/A
Total, TEC[a]	**60,000**	**60,000**	**N/A**
Contingency, TEC	*9,900*	*9,900*	*N/A*
Other Project Cost (OPC)[a]			
OPC except D&D			
Conceptual Planning	750	750	N/A
Conceptual Design	250	250	N/A
Contingency	—	—	*N/A*
Total, OPC	**1,000**	**1,000**	**N/A**
Contingency, OPC	—	—	*N/A*
Total Project Cost[b]	**61,000**	**61,000**	**N/A**
Total Contingency (TEC+OPC)	***9,900***	***9,900***	***N/A***

5. Schedule of Appropriation Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2018	FY 2019	FY 2020	Total
FY 2019	TEC	—	—	20,000	40,000	60,000[b]
	OPC[a]	—	1,000	—	—	1,000
	TPC	—	1,000	20,000	40,000	61,000[b]
FY 2020	TEC	—	—	30,000	30,000	60,000[b]
	OPC[a]	—	1,000	—	—	1,000
	TPC	—	1,000	30,000	30,000	61,000[b]

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy (fiscal quarter or date)	1Q FY 2023
Expected Useful Life (number of years)	50
Expected Future Start of D&D of this capital asset (fiscal quarter)	4Q FY 2073

[a] Other Project Costs (OPC) are funded through laboratory overhead.

[b] This project has not received CD-2 approval, therefore, funding estimates are preliminary.

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life-Cycle Costs	
	Previous Total Estimate	Current Total Estimate	Previous Total Estimate	Current Total Estimate
Operations	1,117	1,117	107,628	107,628
Utilities	162	162	21,571	21,571
Maintenance and Repair	536	536	51,646	51,646
Total – Operations and Maintenance	1,815	1,815	180,845	180,845

7. 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

8. Acquisition Approach

The Management and Operating (M&O) Contractor, UChicago Argonne, LLC will perform the acquisition for this project, 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.

19-SC-73, Translational Research Capability
Oak Ridge National Laboratory (ORNL)
Project is for Design and Construction

1. Summary, Significant Changes, and Schedule and Cost History

Summary

The FY 2020 Request for the Translational Research Capability project is $15,000,000. The preliminary Total Estimated Cost (TEC) range for this project is of $80,000,000 to $97,000,000. The preliminary Total Project Cost (TPC) range for this project is $81,500,000 to $98,500,000. These cost ranges encompass the most feasible preliminary alternatives at this time. The TEC point-estimate for this project is $93,500,000 and the TPC point-estimate is $95,000,000.

This project will provide laboratory, high bay, office, and collaboration space to support advancement in computing and materials science in support of multidisciplinary research.

Significant Changes

This project was initiated in FY 2019. This project was not included in the FY 2019 Congressional Request but was included in the FY 2019 Enacted Appropriation; therefore, this is the first PDS for this project. The most recent DOE Order 413.3B Critical Decision (CD) is CD-1, Approve Alternative Selection and Cost Range, which was approved on November 02, 2018. FY 2020 funds will support construction activities pending CD-3 approval in FY 2020.

A Federal Project Director with the appropriate certification level will be assigned to this project prior to CD-1 approval.

Critical Milestone History

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2020	10/26/2017	7/20/2018	11/02/2018[a]	1Q FY 2020[a]	4Q FY 2019	1Q FY 2020[a]	N/A	4Q FY 2025[a]

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-3A – Approve Long-Lead Procurements and Start of Early Construction Activities
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

Fiscal Year	Performance Baseline Validation	CD-3A	CD-2/3	CD-3B
FY 2020	N/A	2Q FY 2019	1Q FY 2020[a]	N/A

CD-2/3 – Approve Performance Baseline and Start of Construction Activities
CD-3A –Approve Long-Lead Procurements and Start of Early Construction Activities
CD-3B – Approve Start of Remaining Construction Activities

[a] This project is pre-CD-2 and schedule estimates are preliminary.

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC[a], Except D&D	OPC, D&D	OPC, Total	TPC
FY 2020	9,700	83,800	93,500[b]	1,500	N/A	1,500	95,000[b]

2. Project Scope and Justification

Scope

The Translational Research Capability (TRC) project received CD-1, Approve Alternative Selection and Cost Range, which identified a single new facility as the preferred alternative. It is currently conceived as a project to provide 80,000 to 150,000 gross square feet (gsf) of laboratory, high bay, office, and collaboration space to support advancement in computing and materials science in support of multidisciplinary research. Additional supporting functions such as utilities or site modifications may be included in the project, if they are deemed necessary.

Justification

The Office of Science (SC) has 24 core capabilities distributed across ten of the world-class national laboratories with the following four core capabilities that are relevant to this project in support of the SC mission at Oak Ridge National Laboratory (ORNL): advanced computer science, visualization, and data; materials science and engineering; decision science and analysis; and plasma and fusion energy science. Several SC Advisory Committee reports support the continuing need for these core capabilities encouraging development and integration of several multidisciplinary efforts, such as developing computational tools and the increasing necessity for interdisciplinary collaboration. This project will provide modern, flexible, and adaptable space that is capable of responding to the pressing demand to support advancement in computing and materials science in support of multidisciplinary research. The project is conceived to provide laboratory spaces that provide noise isolation, electromagnetic shielding, and low vibration to support research in the advancement of computing as well as wet laboratories, dry laboratories, and high bay space for materials science and advancement in computing.

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 table below outlines preliminary KPPs for this project.

Performance Measure	Threshold	Objective
Multifunction Laboratory and Office Building	79,900 gsf	115,000 gsf

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design			
FY 2019	9,700	9,700	9,700
Total, Design	9,700	9,700	9,700

[a] Other Project Costs (OPC) are funded through laboratory overhead.

[b] This project has not received CD-2 approval, therefore, funding estimates are preliminary.

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Construction			
FY 2019	15,300	15,300	3,500
FY 2020	15,000	15,000	16,500
Outyears	53,500	53,500	63,800
Total, Construction	83,800	83,800	83,800
Total Estimated Costs (TEC)			
FY 2019	25,000	25,000	13,200
FY 2020	15,000	15,000	16,500
Outyears	53,500	53,500	63,800
Total, TEC[a]	**93,500**	**93,500**	**93,500**
Other Project Costs (OPCs)[b]			
OPC except D&D			
FY 2017	190	190	190
FY 2018	1,000	1,000	1,000
Outyears	310	310	310
Total, OPC	**1,500**	**1,500**	**1,500**
Total Project Cost (TPC)			
FY 2017	190	190	190
FY 2018	1,000	1,000	1,000
FY 2019	25,000	25,000	13,200
FY 2020	15,000	15,000	16,500
Outyears	53,810	53,810	64,110
Total, TPC[a]	**95,000**	**95,000**	**95,000**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)[a]			
Design			
Design	8,200	N/A	N/A
Contingency	*1,500*	*N/A*	*N/A*
Total, Design	9,700	N/A	N/A
Construction			
Construction	70,500	N/A	N/A
Contingency	*13,300*	*N/A*	*N/A*
Total, Construction	83,800	N/A	N/A
Total, TEC	**93,500**	**N/A**	**N/A**
Contingency, TEC	*14,800*	*N/A*	*N/A*

[a] This project has not received CD-2 approval, therefore, funding estimates are preliminary.

[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	500	N/A	N/A
Conceptual Design	800	N/A	N/A
Contingency	*200*	*N/A*	*N/A*
Total, OPC	**1,500**	**N/A**	**N/A**
Contingency, OPC	*200*	*N/A*	*N/A*
Total Project Cost[b]	**95,000**	**N/A**	**N/A**
Total Contingency (TEC+OPC)	***15,000***	***N/A***	***N/A***

5. Schedule of Appropriation Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2018	FY 2019	FY 2020	Outyears	Total
FY 2020	TEC	—	—	25,000	15,000	53,500	93,500[b]
	OPC[a]	190	1,000	—	—	310	1,500
	TPC	190	1,000	25,000	15,000	53,810	95,000[b]

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy Expected (fiscal quarter or date)	4Q FY 2025
Useful Life (number of years)	50
Expected Future Start of D&D of this capital asset (fiscal quarter)	4Q FY 2075

7. D&D Information

	Square Feet
New area being constructed by this project at *Oak Ridge National Laboratory*...	80,000–115,000
Area of D&D in this project at *Oak Ridge National Laboratory*............................	None
Area at *Oak Ridge 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..	80,000–115,000

8. Acquisition Approach

The ORNL Management and Operating (M&O) Contractor, UT-Battelle will perform the acquisition for this project. The M&O Contractor will be responsible for awarding and managing all subcontracts related to the project. The ORNL Site Office will

[a] Other Project Costs (OPC) are funded through laboratory overhead.

[b] This project has not received CD-2 approval, therefore, funding estimates are preliminary.

[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.

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 ORNL 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.

19-SC-74, Biological and Environmental Program Integration Center (BioEPIC)
Lawrence Berkeley National Laboratory (LBNL)
Project is for Design and Construction

1. Summary, Significant Changes, and Schedule and Cost History

Summary

The FY 2020 Request for the Biological and Environmental Program Integration Center (BioEPIC) project is $6,000,000. The preliminary Total Estimated Cost (TEC) range for this project is $90,000,000 to $140,000,000. The preliminary Total Project Cost (TPC) range for this project is $92,200,000 to $142,200,000. These cost ranges encompass the most feasible preliminary alternatives at this time.

This project will construct a new building with high performance laboratory space in close proximity to key LBNL facilities and programs. Research operations currently located in commercially leased space and dispersed across the campus will be collocated into this building allowing for better facilitation of Biological and Environmental Research (BER), Advanced Scientific Computing Research (ASCR), and Basic Energy Sciences (BES) program research activities.

Significant Changes

This project was initiated in FY 2019. This project was not included in the FY 2019 Congressional Request but was included in the FY 2019 Enacted Appropriation; therefore, this the first PDS for this project. The most recent DOE Order 413.3B Critical Decision (CD) is CD-0, Approve Mission Need, which was approved on March 13, 2018. FY 2020 funds will be used to continue Project Engineering and Design (PED) activities.

A Federal Project Director with the appropriate certification level will be assigned to this project prior to CD-1 approval.

Critical Milestone History

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	Final Design Complete	CD-3	D&D Complete	CD-4
FY 2020	03/13/2018	2Q FY 2019	3Q FY 2019[a]	4Q FY 2020[a]	2Q FY 2022[a]	4Q FY 2021[a]	N/A	4Q FY 2027[a]

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

Fiscal Year	Performance Baseline Validation	CD-3A	CD-3B
FY 2020	4Q FY 2020[a]	N/A	N/A

CD-3A – Approve Long-Lead Procurements and Start of Early Construction Activities
CD-3B – Approve Start of Remaining Construction Activities

[a] This project is pre-CD-2 and schedule and funding estimates are preliminary.

Project Cost History

(dollars in thousands)

Fiscal Year	TEC, Design	TEC, Construction	TEC, Total	OPC[a], Except D&D	OPC, D&D	OPC, Total	TPC
FY 2020	13,000[b]	127,000[b]	140,000[b]	2,200	N/A	2,200	142,200[b]

2. Project Scope and Justification

Scope

The BioEPIC project will construct a new, state-of-the-art facility with laboratory space to support high performance research by BER, ASCR, and BES programs. This facility will be constructed in close proximity to key LBNL facilities and programs. Research operations currently located in commercially leased space and dispersed across the campus will be collocated to the BioEPIC building. Co-location of researchers in this unique experimental facility, near other important Office of Science (SC) assets, will increase synergy and efficiency which will better facilitate collaborative research in support of the SC mission.

Justification

The mission need of this project is to increase the synergy and efficiency of biosciences and other SC 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. Much of the biological sciences program at LBNL is located off-site, away from the main laboratory, while others are dispersed across several locations on the LBNL campus. This arrangement has produced research and operational capability gaps that limit scientific progress and is a significant roadblock to the kind of collaborative science that is required for understanding, predicting, and harnessing the Earth's microbiome for energy and environmental benefits. This project will close the present capability gap by providing a state-of-the-art facility that will collocate biosciences research and other programs.

The project will be conducted in accordance with the project management requirements in DOE Order 413.3B, and all appropriate project management requirements will be met.

Key Performance Parameters (KPPs)

The project has not yet received CD-1 approval; therefore Key Performance Parameters are yet to be determined. The table below outlines preliminary KPPs.

Performance Measure	Threshold	Objective
Biosciences and other research space	60,000 gross square feet	100,000 gross square feet

[a] Other Project Costs (OPC) are paid for through laboratory overhead.

[b] This project is pre-CD-2 and schedule and funding estimates are preliminary.

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design			
FY 2019	5,000	5,000	5,000
FY 2020	6,000	6,000	6,000
Outyears	2,000	2,000	2,000
Total, Design	13,000	13,000	13,000
Construction			
Outyears	127,000	127,000	127,000
Total, Construction	127,000	127,000	127,000
Total Estimated Costs (TEC)			
FY 2019	5,000	5,000	5,000
FY 2020	6,000	6,000	6,000
Outyears	129,000	129,000	129,000
Total, TEC[a]	**140,000**	**140,000**	**140,000**
Other Project Costs (OPC)[b]			
FY 2019	1,500	1,500	1,500
Outyears	700	700	700
Total, OPC	**2,200**	**2,200**	**2,200**
Total Project Cost (TPC)[a]			
FY 2019	6,500	6,500	6,500
FY 2020	6,000	6,000	6,000
Outyears	129,700	129,700	129,700
Total, TPC[a]	**142,200**	**142,200**	**142,200**

4. Details of Project Cost Estimate

(dollars in thousands)

	Current Total Estimate	Previous Total Estimate	Original Validated Baseline
Total Estimated Cost (TEC)			
Design			
Design	10,400	12,800	N/A
Contingency	*2,600*	*3,200*	*N/A*
Total, Design	13,000	16,000	N/A
Construction			
Construction	105,000	103,000	N/A
Contingency	*22,000*	*21,000*	*N/A*
Total, Construction	127,000	124,000	N/A
Total, TEC[a]	**140,000**	**140,000**	**N/A**
Contingency, TEC	*24,600*	*24,200*	*N/A*

[a] This project has not received CD-2 approval; therefore, funding estimates are preliminary.
[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)[b]			
OPC except D&D			
Conceptual Design	1,300	1,300	N/A
Start-up	600	600	N/A
Contingency	*300*	*300*	*N/A*
Total, OPC	**2,200**	**2,200**	**N/A**
Contingency, OPC	***300***	***300***	***N/A***
Total Project Cost[a]	**142,200**	**142,200**	**N/A**
Total Contingency (TEC+OPC)	***24,900***	***24,500***	***N/A***

5. Schedule of Appropriation Requests

(dollars in thousands)

Request Year	Type	FY 2019	FY 2020	Outyears	Total
FY 2020	TEC	5,000	6,000	129,000	140,000[b]
	OPC[c]	1,500	—	700	2,200
	TPC	6,500	6,000	129,700	142,200[a]

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy (fiscal quarter or date)	4Q FY 2027
Expected Useful Life (number of years)	50
Expected Future Start of D&D of this capital asset (fiscal quarter)	1Q FY 2077

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life Cycle Costs	
	Previous Total Estimate	**Current Total Estimate**	**Previous Total Estimate**	**Current Total Estimate**
Operations	150	150	5,700	5,700
Utilities	270	270	11,900	11,900
Maintenance and Repair	530	530	20,600	20,600
Total—Operations and Maintenance	950	950	38,200	38,200

[b] This project has not received CD-2 approval; therefore, funding estimates are preliminary.

[c] Other Project Costs (OPC) are funded through laboratory overhead.

7. 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*	60,000–100,000
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[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

8. Acquisition Approach

The LBNL Management and Operating (M&O) Contractor, University of California will perform the acquisition for this project, overseen by the Berkeley Site Office. Various acquisition approaches and project delivery methods will be evaluated prior to achieving CD-1 including, but not limited to, a tailored Design-Bid-Build approach with a Construction Manager as General Contractor and design build. The M&O contractor is responsible for awarding and administering all subcontracts related to this project. Project performance metrics will be 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)
Project is for Design and Construction

1. Summary, Significant Changes, and Schedule and Cost History

Summary
The FY 2020 Request for the Energy Sciences Capability project is $9,000,000. The TEC for this project is $90,000,000 and the TPC for this project is $93,000,000.

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 PNNL Richland campus.

Significant Changes
This project was initiated in FY 2018. The most recent DOE Order 413.3B Critical Decision (CD) is CD-2/3, Approve Performance Baseline and Approve Start of Construction, which was approved on December 7, 2018. FY 2020 funds will support construction and associated activities.

A Federal Project Director with the appropriate certification level was assigned to this project.

Critical Milestone History

Fiscal Year	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	N/A	4Q FY 2020	N/A	4Q FY 2025
FY 2019	12/12/2016	3Q FY 2018	2Q FY 2018	4Q FY 2019	4Q FY 2019	4Q FY 2019	N/A	4Q FY 2025
FY 2020	12/12/2016	3Q FY 2018	2/13/2018	12/7/2018	12/7/2018	12/7/2018	N/A	12/31/2023

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. Note the project has a Design-Build delivery method, so the design proceeds during construction activities.
CD-3– Approve Start of Construction
D&D Complete – Completion of D&D work (see Section 9)
CD-4 – Approve Project Completion

Fiscal Year	Performance Baseline Validation
FY 2018	4Q FY 2019
FY 2019	4Q FY 2019
FY 2020	12/7/2018

Project Cost History

(dollars in thousands)

Fiscal Year	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	3,000	N/A	3,000	93,000
FY 2019	9,000	81,000	90,000	3,000	N/A	3,000	93,000
FY 2020	9,000	81,000	90,000	3,000	N/A	3,000	93,000

2. 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.

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."

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.

[a] Other Project Costs (OPC) are funded through laboratory overhead.

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 (Preliminary)
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.

Performance Measure	Threshold	Objective
Multi-story Laboratory Building	110,000 gross square feet (GSF)	145,000 GSF

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
Total Estimated Cost (TEC)			
Design			
FY 2018	9,000	9,000	200
FY 2019	—	—	8,800
Total, Design	9,000	9,000	9,000
Construction			
FY 2018	11,000	11,000	—
FY 2019	24,000	24,000	20,000
FY 2020	9,000	9,000	20,000
FY 2021	20,000	20,000	20,000
FY 2022	17,000	17,000	15,000
FY 2023	—	—	6,000
Total, Construction	81,000	81,000	81,000
TEC			
FY 2018	20,000	20,000	200
FY 2019	24,000	24,000	28,800
FY 2020	9,000	9,000	20,000
FY 2021	20,000	20,000	20,000
FY 2022	17,000	17,000	15,000
FY 2023	—	—	6,000
Total, TEC	**90,000**	**90,000**	**90,000**
Other Project Cost (OPC)[a]			
OPC except D&D			
FY 2017	839	839	839
FY 2018	400	400	400
FY 2023	1,761	1,761	1,761
Total, OPC except D&D	3,000	3,000	3,000
Total Project Cost (TPC)			
FY 2017	839	839	839
FY 2018	20,400	20,400	600
FY 2019	24,000	24,000	28,800

[a] Other Project Costs (OPC) are funded through laboratory overhead.

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs
FY 2020	9,000	9,000	20,000
FY 2021	20,000	20,000	20,000
FY 2022	17,000	17,000	15,000
FY 2023	1,761	1,761	7,761
Total, TPC	**93,000**	**93,000**	**93,000**

4. 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	**90,000**	**90,000**	**N/A**
Contingency, TEC	*12,500*	*12,500*	*N/A*
Other Project Cost (OPC)[a]			
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 Project Cost	**93,000**	**93,000**	**N/A**
Total, Contingency	***12,750***	***12,750***	***N/A***

5. Schedule of Appropriation Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2018	TEC	—	20,000	TBD	TBD	TBD	TBD	TBD	TBD	90,000
	OPC[a]	—	—	—	—	—	—	—	—	3,000
	TPC	—	20,000	TBD	TBD	TBD	TBD	TBD	TBD	93,000
FY 2019	TEC	—	1,000	4,000	8,194	22,209	30,500	24,097	—	90,000
	OPC[a]	1,100	1,500	—	—	—	—	400	—	3,000
	TPC	1,100	2,500	4,000	8,194	22,209	30,500	24,497	—	93,000

[a] Other Project Costs (OPC) are funded through laboratory overhead.

(dollars in thousands)

Request Year	Type	Prior Years	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023	Outyears	Total
FY 2020	TEC	—	20,000	24,000	9,000	20,000	17,000	—	—	90,000
	OPC[a]	839	400	—	—	—	—	1,761	—	3,000
	TPC	839	20,400	24,000	9,000	20,000	17,000	1,761	—	93,000

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy (fiscal quarter or date)	1Q FY 2024
Expected Useful Life (number of years)	50
Expected Future Start of D&D of this capital asset (fiscal quarter)	1Q FY 2074

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life-Cycle Costs	
	Previous Total Estimate	Current Total Estimate	Previous Total Estimate	Current Total Estimate
Operations	480	480	23,989	23,989
Utilities	547	547	27,370	27,370
Maintenance and Repair	1,222	1,222	61,121	61,121
Total – Operations and Maintenance	2,249	2,249	112,480	112,480

7. 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*	110,000–145,000
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[a]
Total area eliminated	None

8. Preliminary Acquisition Approach

The Management and Operating (M&O) contractor, Battelle Memorial Institute will perform the acquisition for this project, 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.

[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-71, Integrated Engineering Research Center
Fermi National Accelerator Laboratory (FNAL), Batavia, IL
Project is for Design and Construction

1. Summary, Significant Changes, and Schedule and Cost History

Summary

The FY 2020 Request for the Integrated Engineering Research Center project is $10,000,000. 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. The preliminary TEC for this project is estimated at $85,000,000 and the preliminary TPC for this project is estimated at $86,000,000.

This project will 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).

Significant Changes

This project was initiated in FY 2017. 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. FY 2020 funds will support the continuation of construction and associated activities.

A Federal Project Director with the appropriate certification level has been assigned to this project.

Critical Milestone History

Fiscal Year	CD-0	Conceptual Design Complete	CD-1	CD-2	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	3Q FY 2019[a]	3Q FY 2019[a]	3Q FY 2020[a]	N/A	4Q FY 2024[a]
FY 2020	07/17/2015	4/18/2017	4/18/2017	3Q FY 2019[a]	3Q FY 2019[a]	3Q FY 2019[a]	N/A	2Q 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

[a] This project is pre-CD-2 and schedule estimates are preliminary.

Fiscal Year	Performance Baseline Validation	CD-3
FY 2017	N/A	N/A
FY 2018	N/A	N/A
FY 2019	3Q FY 2019	N/A
FY 2020	4/18/2018	3Q FY 2019

CD-3 – Approve Start of Construction

Project Cost History

(dollars in thousands)

Fiscal Year	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]
FY 2020	7,000	78,000	85,000[b]	1,000	N/A	1,000	86,000[b]

2. 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.

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

[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.

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 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 will be conducted in accordance with the project management requirements in DOE Order 413.3B, and all appropriate project management requirements will be met.

Key Performance Parameters (KPPs)

Performance Measure	Threshold	Objective
Multistory Laboratory/Office Building	67,000 gross square feet	134,000 gross square feet

3. Financial Schedule

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs[a]
Total Estimated Cost (TEC)			
Design			
FY 2017	2,500	2,500	38
FY 2018	4,500	4,500	5,000
FY 2019	—	—	1,962
Total, Design	7,000	7,000	7,000
Construction			
FY 2018	15,500	15,500	—
FY 2019	20,000	20,000	10,000
FY 2020	10,000	10,000	20,000
Outyears	32,500	32,500	48,000
Total, Construction	78,000	78,000	78,000
TEC			
FY 2017	2,500	2,500	38
FY 2018	20,000	20,000	5,000
FY 2019	20,000	20,000	11,962
FY 2020	10,000	10,000	20,000
Outyears	32,500	32,500	48,000
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
Outyears	70	70	70

[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.
[c] Other Project Costs (OPC) are funded through laboratory overhead.
[d] Costs through 2017 reflect actual Costs; costs for FY 2018 and the outyears are estimates.

(dollars in thousands)

	Budget Authority (Appropriations)	Obligations	Costs[a]
Total, OPC except D&D	1,000	1,000	1,000
Total Project Cost (TPC)			
FY 2015	120	120	120
FY 2016	510	510	510
FY 2017	2,800	2,800	338
FY 2018	20,000	20,000	5,000
FY 2019	20,000	20,000	11,962
FY 2020	10,000	10,000	20,000
Outyears	32,570	32,570	48,070
Total, TPC[b]	**86,000**	**86,000**	**86,000**

4. 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
Total, TEC[a]	**85,000**	**85,000**	**N/A**
Contingency, TEC	*16,000*	*16,000*	*N/A*
Other Project Cost (OPC)[b]			
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
Contingency, OPC	*70*	*70*	*N/A*
Total Project Cost[b]	**86,000**	**86,000**	**N/A**
Total, Contingency	***16,070***	***16,070***	***N/A***

[a] This project has not received CD-2 approval; funding estimates are consistent with the approved cost ranges.
[b] Other Project Costs (OPC) are funded through laboratory overhead.

5. Schedule of Appropriation Requests

(dollars in thousands)

Request Year	Type	Prior Years	FY 2017	FY 2018	FY 2019	FY 2020	Outyears	Total
FY 2017	TEC	—	2,500	TBD	TBD	TBD	TBD	85,000[a]
	OPC[b]	500	—	TBD	TBD	TBD	TBD	2,000
	TPC	—	2,500	TBD	TBD	TBD	TBD	87,000[a]
FY 2018	TEC	—	2,500	1,500	TBD	TBD	TBD	85,000[a]
	OPC[b]	500	—	500	—	—	—	1,000
	TPC	500	2,500	2,000	TBD	TBD	TBD	86,000[a]
FY 2019	TEC	—	2,500	1,500	5,000	20,000	56,000	85,000[a]
	OPC[b]	630	300	—	—	—	70	1,000
	TPC	630	2,800	1,500	5,000	20,000	56,070	86,000[a]
FY 2020	TEC	—	2,500	20,000	20,000	10,000	32,500	85,000[a]
	OPC[b]	630	300	—	—	—	70	1,000
	TPC	630	2,800	20,000	20,000	10,000	32,570	86,000[a]

6. Related Operations and Maintenance Funding Requirements

Start of Operation or Beneficial Occupancy Expected (fiscal quarter or date)	2Q FY 2024
Expected Useful Life (number of years)	50
Expected Future Start of D&D of this capital asset (fiscal quarter)	4Q FY 2074

Related Funding Requirements
(dollars in thousands)

	Annual Costs		Life-Cycle Costs	
	Previous Total Estimate	Current Total Estimate	Previous Total Estimate	Current Total Estimate
Operations	508	508	25,428	25,428
Utilities	94	94	4,670	4,670
Maintenance and Repair	1,525	1,525	76,285	76,285
Total – Operations and Maintenance	2,127	2,127	106,383	106,383

[a] This project has not received CD-2 approval; funding estimates are consistent with the approved cost ranges.

[b] Other Project Costs (OPC) are funded through laboratory overhead.

7. 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*................	67,000–134,000
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

8. Acquisition Approach

The Management and Operating (M&O) contractor, Fermi Research Alliance, LLC will perform the acquisition for this project, 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.

Safeguards and Security

Overview
The Department of Energy's (DOE) 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 to protect 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 2020 Budget Request
The FY 2020 Request for S&S is $110,623,000. The FY 2020 Request supports sustained levels of operations in S&S program elements including Protective Forces, Security Systems, Information Security, Cyber Security, Personnel Security, Material Control and Accountability, and Program Management.

The FY 2020 Request ensures that the S&S program's highest priority is accomplished, which is to provide adequate security for the special nuclear material housed in Building 3019 at the Oak Ridge National Laboratory (ORNL). The Request also ensures the Cyber Security program can adequately detect, mitigate, and recover from cyber intrusions and attacks against DOE laboratories.

The 2018 revision of DOE's Design Basis Threat (DBT) addresses protection measures for a more encompassing range of threats and assets than just special nuclear material and classified matter. This revised DBT mandates additional risk assessments and security planning for the protection of chemicals and radioactive sources that could affect persons on-site, whereas, the previous protection standard only addressed quantities that could have an impact off-site. The DBT also calls for "Active Shooter" and "Insider Threat" mitigation.

Implementing the revised DBT is the near- and long-term basis for S&S program and risk mitigating funding decisions at SC laboratories. SC is on schedule to complete implementation planning by March 31, 2019, including Security Risk Assessments. Full compliance (based on the most complex laboratories milestones) is expected by September 30, 2022. The S&S program will implement the DBT in stages, starting with the highest priorities including the protection of personnel. The FY 2020 Request includes $4,513,000 to address highest priority items of the DBT.

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 DBT implementation through the 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.

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, includes 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

(dollars in thousands)

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Protective Forces	43,545	43,545	43,545	—
Security Systems	10,097	10,370	14,883	+4,513
Information Security	4,356	4,356	4,356	—
Cyber Security	30,619	33,346	33,346	—
Personnel Security	5,334	5,444	5,444	—
Material Control and Accountability	2,431	2,431	2,431	—
Program Management	6,618	6,618	6,618	—
Total, Safeguards and Security	**103,000**	**106,110**	**110,623**	**+4,513**

Safeguards and Security

Activities and Explanation of Changes

FY 2019 Enacted		FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Safeguards and Security	**$106,110,000**	**$110,623,000**	**+$4,513,000**
Protective Forces	$43,545,000	$43,545,000	—
The FY 2019 Enacted budget continues funding to maintain proper protection levels, equipment, and technical training needed to ensure effective performance at all SC laboratories.		The Request will support security officers assigned to protect and respond to S&S interests, along with their related equipment and training.	The FY 2020 Request provides sustained support for the Protective Forces activity.
Security Systems	$10,370,000	$14,883,000	+$4,513,000
The FY 2019 Enacted budget continues funding to maintain the security systems currently in place.		The Request will support physical protection of Departmental personnel, material, equipment, property, and facilities, and security infrastructure and systems. Funding also supports initial implementation of security modifications identified in the revised DBT.	Funding increases to begin implementing DBT mandated physical security modifications at SC laboratories. Automated access controls are the programs first priority to protect the workforce and mitigate active shooter and workplace violence threats.
Information Security	$4,356,000	$4,356,000	$—
The FY 2019 Enacted budget continues funding to maintain personnel, equipment, and systems necessary to ensure sensitive and classified information is safeguarded at SC laboratories.		The Request will support personnel, equipment, and systems necessary to ensure sensitive and classified information is safeguarded at SC laboratories.	FY 2020 funding provides sustained support for Information Security activities.
Cyber Security	$33,346,000	$33,346,000	$—
The FY 2019 Enacted budget continues funding to maintain the necessary level of protection of laboratory computers, networks, and data from unauthorized access.		The Request will support protection of laboratory computers, networks, and data from unauthorized access.	FY 2020 funding provides sustained support for Cybersecurity activities.

FY 2019 Enacted		FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Personnel Security	$5,444,000	$5,444,000	$—
The FY 2019 Enacted budget continues funding to maintain Personnel Security efforts at SC laboratories. Funding is requested to support SC Headquarters security investigations.		The Request will support Personnel Security efforts at SC laboratories.	FY 2020 funding provides sustained support for Personnel Security activities.
Materials Control and Accountability	$2,431,000	$2,431,000	$—
The FY 2019 Enacted budget continues funding to maintain protection of material at SC laboratories.		The Request will support functions ensuring Departmental materials are properly controlled and accounted for at all times.	FY 2020 funding provides sustained support for MC&A activities.
Program Management	$6,618,000	$6,618,000	$—
The FY 2019 Enacted budget continues funding to maintain oversight, administration, and planning for security programs at SC laboratories and supported security procedures and policy support for SC Research missions.		The Request will support oversight, administration, and planning for security programs at SC laboratories and will support security procedures and policy support for SC Research missions.	Program Management funding levels are sustained.

Estimates of Cost Recovered for Safeguards and Security Activities

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.

(dollars in thousands)

	FY 2018 Actual Costs	FY 2019 Planned Costs	FY 2020 Planned Costs
Ames National Laboratory	40	70	20
Argonne National Laboratory	1,100	1,000	1,000
Brookhaven National Laboratory	915	851	837
Lawrence Berkeley National Laboratory	1,007	749	1,044
Oak Ridge Institute for Science and Education	509	571	495
Oak Ridge National Laboratory	5,428	5,163	5,163
Pacific Northwest National Laboratory	5,000	5,500	5,500
Princeton Plasma Physics Laboratory	55	55	30
SLAC National Accelerator Laboratory	158	179	190
Total, Security Cost Recovered	**14,212**	**14,138**	**14,279**

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 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 50 states and the District of Columbia. The portfolio of 27 scientific user facilities serves over 32,000 users per year. SC also oversees ten of DOE’s 17 national laboratories.

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), and the 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.
- 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 funding allocations for all ten SC national laboratories through administration of laboratory Management and Operating (M&O) contracts and is responsible for over 3,000 financial assistance awards (grants and cooperative agreements) per year to university, non-profit, and small business-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 2020 Request
The FY 2020 Request of $183,000,000 will support a total level of approximately 797 FTEs. SC will utilize available human capital workforce reshaping tools to manage federal staff 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 2020 Request includes:

- Two-hundred and ninety-five (295) 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.
- The Request includes the transfer of the mission of the New Brunswick Laboratory (NBL) Program Office to National Nuclear Security Administration (NNSA) Defense Programs which better aligns the program office with the NNSA's mission.
- Two (2) FTEs in the DOE Office of Planning and Management Oversight to support the Office of the Under Secretary for Science.
- Twenty-four (24) FTEs in the Office of the Chief Human Capital Officer operating the Shared Service Center (SSC) and supporting HR Advisory Offices.
- Two (2) FTEs supporting the President's Council of Advisors on Science and Technology (PCAST).[b]
- Forty (40) OSTI federal staff to manage SC's public access program.
- Four-hundred and thirty-four (434) Integrated Service Center (ISC) and site office federal staff.

[a] OMB Memo M-17-22
[b] PCAST is required by Executive Order 13539, as amended by Executive Order 13596.

Science Program Direction
Funding

(dollars in thousands)

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Headquarters				
Salaries and Benefits	59,565	58,955	62,655	+3,700
Travel	1,820	2,383	1,944	-439
Support Services	16,761	17,171	16,563	-608
Other Related Expenses	5,379	5,407	5,136	-271
Working Capital Fund	8,250	8,150	8,250	+100
Total, Headquarters	**91,775**	**92,066**	**94,548**	**+2,482**
Office of Scientific and Technical Information				
Salaries and Benefits	6,216	6,109	5,920	-189
Travel	95	100	105	+5
Support Services	1,931	1,931	1,970	+39
Other Related Expenses	980	980	939	-41
Total, Office of Scientific and Technical Information	**9,222**	**9,120**	**8,934**	**-186**
Field Offices				
Salaries and Benefits	69,334	69,075	67,743	-1,332
Travel	1,030	1,717	1,425	-292
Support Services	4,972	4,335	3,945	-390
Other Related Expenses	6,667	6,687	6,405	-282
Total, Field Offices	**82,003**	**81,814**	**79,518**	**-2,296**
Total Program Direction				
Salaries and Benefits	135,115	134,139	136,318	+2,179
Travel	2,945	4,200	3,474	-726
Support Services	23,664	23,437	22,478	-959
Other Related Expenses	13,026	13,074	12,480	-594
Working Capital Fund	8,250	8,150	8,250	+100
Total, Program Direction	**183,000**	**183,000**	**183,000**	**—**
Federal FTEs	**825**	**810**	**797**	**-13**

Program Direction

Activities and Explanation of Changes

FY 2019 Enacted		FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Program Direction	**$183,000,000**	**$183,000,000**	**$—**
Salaries and Benefits	$134,139,000	$136,318,000	+$2,179,000
The FY 2019 Enacted Budget supports 810 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. The Enacted Budget supports costs associated with Federal employee benefits, including health insurance costs and retirement allocations in the Federal Employees Retirement System.		The FY 2020 Request will support 797 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 Request will support costs associated with Federal employee benefits, including health insurance costs and retirement allocations in the Federal Employees Retirement System.	The increase is based on projected payroll requirements in FY 2020 for the requested staffing level of 797 FTEs. The projections take into consideration grade/step levels for the current workforce, the status of current vacancies, and ongoing workforce planning efforts.
Travel	$4,200,000	$3,474,000	-$726,000
The FY 2019 Enacted Budget supports facility visits where the use of electronic telecommunications are 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 Enacted Budget also supports 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 FY 2020 Request will support facility visits where the use of electronic telecommunications are 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 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	The decrease is based on projected travel requirements for FY 2020 associated with facility visits, mandatory on-site inspections, and program/project reviews. No change in proposed travel costs for SC Advisory Committees.

FY 2019 Enacted	FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
the Department regarding the complex scientific and technical issues that arise in the planning, management, and implementation of SC programs.	Department regarding the complex scientific and technical issues that arise in the planning, management, and implementation of SC programs.	
The FY 2019 Enacted Budget supports the PCAST advisory committee travel.	The Request will support the PCAST advisory committee travel.	The FY 2020 Request includes increased travel for staff supporting the PCAST advisory committee.
Support Services $23,437,000	$22,478,000	-$959,000
The FY 2019 Enacted Budget supports 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 research and development (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 2020 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 decrease is based on projected contract requirements in FY 2020. The Request takes into consideration current contractor staffing levels and management decisions affecting future contract requirements.
The FY 2019 Enacted Budget supports essential information technology infrastructure; necessary upgrades to SC's financial management system; ongoing operations and maintenance of IT systems; and safety management support.	The FY 2020 Request will support essential information technology infrastructure; necessary upgrades to SC's financial management system; ongoing operations and maintenance of IT systems; and safety management support.	
The FY 2019 Enacted Budget funds federal staff training and education to maintain appropriate certification and update skills.	The FY 2020 Request will fund federal staff training and education to maintain appropriate certification and update skills.	

FY 2019 Enacted		FY 2020 Request	Explanation of Changes FY 2020 Request vs FY 2019 Enacted
Other Related Expenses	$13,074,000	$12,480,000	-$594,000
The FY 2019 Enacted Budget supports 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 includes miscellaneous purchases for supplies, materials, and subscriptions.		The FY 2020 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 decrease will align with projected requirements for FY 2020.
Working Capital Fund	$8,150,000	$8,250,000	+$100,000
The FY 2019 Enacted Budget supports the SC contribution to the Working Capital Fund (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 FY 2020 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 align with projected requirements for FY 2020.

Supporting Information
Funding

(dollars in thousands)

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Headquarters				
Science HQ				
Salaries and Benefits	56,000	55,365	58,695	+3,330
Travel	1,820	2,358	1,744	-614
Support Services	16,761	17,171	16,563	-608
Other Related Expenses	4,579	4,607	4,100	-507
Working Capital Fund	8,250	8,150	8,250	+100
Total, Science HQ	**87,410**	**87,651**	**89,352**	**+1,701**
Under Secretary for Science				
Salaries and Benefits	440	440	440	—
Other Related Expenses	400	400	400	—
Total, Under Secretary for Science	**840**	**840**	**840**	**—**
Human Capital Shared Service Center				
Salaries and Benefits	3,125	3,150	3,144	-6
Other Related Expenses	400	400	400	—
Total, Human Capital Shared Service Center	**3,525**	**3,550**	**3,544**	**-6**
President's Council of Advisors on Science and Technology				
Salaries and Benefits	—	—	376	+376
Travel	—	25	200	+175
Other Related Expenses	—	—	236	+236
Total, President's Council of Advisors on Science and Technology	**—**	**25**	**812**	**+787**

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
	(dollars in thousands)			
Total Headquarters				
Salaries and Benefits	59,565	58,955	62,655	+3,700
Travel	1,820	2,383	1,944	-439
Support Services	16,761	17,171	16,563	-608
Other Related Expenses	5,379	5,407	5,136	-271
Working Capital Fund	8,250	8,150	8,250	+100
Total, Headquarters	**91,775**	**92,066**	**94,548**	**+2,482**
Office of Scientific and Technical Information				
Salaries and Benefits	6,216	6,109	5,920	-189
Travel	95	100	105	+5
Support Services	1,931	1,931	1,970	+39
Other Related Expenses	980	980	939	-41
Total, Office of Scientific and Technical Information	**9,222**	**9,120**	**8,934**	**-186**
Field Offices				
Chicago Office				
Salaries and Benefits	20,824	21,098	20,305	-793
Travel	200	350	300	-50
Support Services	1,092	759	694	-65
Other Related Expenses	2,329	2,339	2,315	-24
Total, Chicago Office	**24,445**	**24,546**	**23,614**	**-932**
Oak Ridge Office				
Salaries and Benefits	18,769	17,940	17,640	-300
Travel	232	450	300	-150
Support Services	2,414	2,110	1,976	-134
Other Related Expenses	3,667	3,677	3,428	-249
Total, Oak Ridge Office	**25,082**	**24,177**	**23,344**	**-833**
Ames Site Office				
Salaries and Benefits	620	628	644	+16
Travel	23	28	30	+2
Support Services	2	2	2	—
Total, Ames Site Office	**645**	**658**	**676**	**+18**

	(dollars in thousands)			
	FY 2018 Enacted	**FY 2019 Enacted**	**FY 2020 Request**	**FY 2020 Request vs FY 2019 Enacted**
Argonne Site Office				
Salaries and Benefits	4,032	4,080	3,956	-124
Travel	80	120	95	-25
Support Services	195	195	199	+4
Other Related Expenses	20	20	20	—
Total, Argonne Site Office	**4,327**	**4,415**	**4,270**	**-145**
Berkeley Site Office				
Salaries and Benefits	3,186	3,222	3,330	+108
Travel	55	46	70	+24
Support Services	215	215	220	+5
Other Related Expenses	105	105	107	+2
Total, Berkeley Site Office	**3,561**	**3,588**	**3,727**	**+139**
Brookhaven Site Office				
Salaries and Benefits	3,938	3,982	3,864	-118
Travel	70	94	90	-4
Support Services	542	542	341	-201
Other Related Expenses	287	287	294	+7
Total, Brookhaven Site Office	**4,837**	**4,905**	**4,589**	**-316**
Fermi Site Office				
Salaries and Benefits	2,352	2,380	2,324	-56
Travel	75	131	105	-26
Support Services	42	42	33	-9
Other Related Expenses	28	28	28	—
Total, Fermi Site Office	**2,497**	**2,581**	**2,490**	**-91**
Oak Ridge National Laboratory Site Office				
Salaries and Benefits	5,145	5,180	4,896	-284
Travel	80	131	105	-26
Support Services	215	215	220	+5
Other Related Expenses	25	25	26	+1
Total, Oak Ridge National Laboratory Site Office	**5,465**	**5,551**	**5,247**	**-304**

(dollars in thousands)

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Pacific Northwest Site Office				
Salaries and Benefits	4,752	4,785	4,736	-49
Travel	100	209	160	-49
Support Services	34	34	35	+1
Other Related Expenses	56	56	56	—
Total, Pacific Northwest Site Office	**4,942**	**5,084**	**4,987**	**-97**
Princeton Site Office				
Salaries and Benefits	1,690	1,710	1,750	+40
Travel	35	78	70	-8
Support Services	15	15	15	—
Other Related Expenses	59	59	60	+1
Total, Princeton Site Office	**1,799**	**1,862**	**1,895**	**+33**
SLAC Site Office				
Salaries and Benefits	2,178	2,200	2,222	+22
Travel	40	38	50	+12
Support Services	198	198	202	+4
Other Related Expenses	40	40	40	—
Total, SLAC Site Office	**2,456**	**2,476**	**2,514**	**+38**
Thomas Jefferson Site Office				
Salaries and Benefits	1,848	1,870	2,076	+206
Travel	40	42	50	+8
Support Services	8	8	8	—
Other Related Expenses	51	51	31	-20
Total, Thomas Jefferson Site Office	**1,947**	**1,971**	**2,165**	**+194**
Total Field Offices				
Salaries and Benefits	69,334	69,075	67,743	-1,332
Travel	1,030	1,717	1,425	-292
Support Services	4,972	4,335	3,945	-390
Other Related Expenses	6,667	6,687	6,405	-282
Total, Field Offices	**82,003**	**81,814**	**79,518**	**-2,296**

(dollars in thousands)

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Total Program Direction				
Salaries and Benefits	135,115	134,139	136,318	+2,179
Travel	2,945	4,200	3,474	-726
Support Services	23,664	23,437	22,478	-959
Other Related Expenses	13,026	13,074	12,480	-594
Working Capital Fund	8,250	8,150	8,250	+100
Total, Program Direction	**183,000**	**183,000**	**183,000**	**—**
Federal FTEs	**825**	**810**	**797**	**-13**
Technical Support				
System review and reliability analyses	973	973	993	+20
Management Support				
Automated data processing	9,080	9,080	9,262	+182
Training and education	740	740	757	+17
Reports and analyses, management, and general administrative services	12,871	12,644	11,466	-1,178
Total, Management Support	**22,691**	**22,464**	**21,485**	**-979**
Total, Support Services	**23,664**	**23,437**	**22,478**	**-959**
Other Related Expenses				
Rent to GSA	637	637	624	-13
Rent to others	1,424	1,424	1,402	-22
Communications, utilities, and miscellaneous	2,653	2,653	2,676	+23
Other services	2,133	2,181	2,373	+192
Operation and maintenance of equipment	2	2	2	—
Operation and maintenance of facilities	1,512	1,512	1,267	-245
Supplies and materials	690	690	703	+13
Equipment	3,975	3,975	3,433	-542
Total, Other Related Expenses	**13,026**	**13,074**	**12,480**	**-594**
Working Capital Fund	**8,250**	**8,150**	**8,250**	**+100**

Public Access[a]

The Department of Energy's Public Access Plan, issued in July 2014 in response to policy memorandum issued by the White House Office of Science and Technology Policy (OSTP), outlines DOE's model and policy for increasing public access to scholarly publications and digital data resulting from DOE research funding. DOE's enabling authorization and subsequent legislation requires DOE to provide public access to its unclassified R&D results; the DOE Public Access Plan added peer-reviewed, final accepted manuscripts to the types of unclassified scientific and technical information already made publicly accessible as required by these longstanding statutes. For digital data resulting from sponsored research (as defined by OMB Circular A-110), the Plan requires the submission of data management plans with funding proposals to DOE and provides guidelines for preserving and provide access to digital research data as appropriate.

Implementation of the Plan has been carried out through DOE internal agency policy directive, with requirements specified in national labs management & operating contracts and annual performance plans, and in the terms and conditions of DOE financial assistance awards (grants and cooperative agreements). Under the DOE policy, DOE-funded researchers are required to submit metadata and final accepted manuscripts to DOE or to their institutional repositories, and DOE makes these research papers freely accessible to the public within 12 months of publication through the portal DOE PAGES (Public Access Gateway for Energy and Science). DOE's public access model also includes cooperation with the publishing community and with other federal agencies. Since implementation of the DOE policy, DOE is among the top agencies in implementing public access, with DOE PAGES providing free access to 62,000 scholarly publications resulting from DOE research funding. To promote discovery, DOE enables broad indexing of this content by commercial search engines, provides an application programming interface (API) to DOE PAGES, and includes this collection in the cross-agency search portal Science.gov.

[a] Responds to the reporting requirement specified by the FY 2018 House Energy and Water Development Appropriations Committee Report 115-230 to provide an update on the DOE Public Access Plan; https://www.energy.gov/downloads/doe-public-access-plan; https://www.osti.gov/public-access-policy; https://www.energy.gov/datamanagement/doe-policy-digital-research-data-management.

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)

	(dollars in thousands)			
	FY 2018 Planned Cost	FY 2018 Actual Cost	FY 2019 Planned Cost	FY 2020 Planned Cost
Brookhaven National Laboratory	5,908	5,723	4,272	4,919
Lawrence Berkeley National Laboratory	6,999	7,000	12,950	15,750
Notre Dame Radiation Laboratory	175	160	125	124
Oak Ridge National Laboratory	15,298	17,904	15,260	14,534
Oak Ridge Office	6,324	3,899	4,223	4,568
Office of Scientific and Technical Information	412	346	381	381
SLAC National Accelerator Laboratory	4,878	3,029	4,761	3,023
Thomas Jefferson National Accelerator Facility	75	187	232	170
Total, Direct-Funded Maintenance and Repair	**40,069**	**38,248**	**42,204**	**43,469**

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)

	(dollars in thousands)			
	FY 2018 Planned Cost	FY 2018 Actual Cost	FY 2019 Planned Cost	FY 2020 Planned Cost
Ames Laboratory	2,900	2,150	2,600	2,400
Argonne National Laboratory	59,500	54,132	70,950	52,050
Brookhaven National Laboratory	45,918	30,262	37,146	38,578
Fermi National Accelerator Laboratory	19,238	16,818	20,801	19,936
Lawrence Berkeley National Laboratory	24,352	24,538	29,318	24,112
Lawrence Livermore National Laboratory	2,984	2,102	3,044	2,144
Los Alamos National Laboratory	635	641	648	926
Oak Ridge Institute for Science and Education	490	664	499	468
Oak Ridge National Laboratory and Y-12	64,202	67,565	79,260	70,179
Pacific Northwest National Laboratory	8,137	5,329	8,635	6,888
Princeton Plasma Physics Laboratory	8,200	4,834	6,577	5,250
Sandia National Laboratories	3,058	3,088	3,119	5,512
SLAC National Accelerator Laboratory	10,835	12,619	15,809	8,919
Thomas Jefferson National Accelerator Facility	6,550	8,202	5,374	8,600
Total, Indirect-Funded Maintenance and Repair	**256,999**	**232,944**	**283,780**	**245,962**

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 2018 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 2018 to the amount planned for FY 2018, including Congressionally directed changes.

Science
Total Costs for Maintenance and Repair

	(dollars in thousands)	
	FY 2018 Planned Costs	**FY 2018 Actual Costs**
Ames Laboratory	2,900	2,150
Argonne National Laboratory	59,500	54,132
Brookhaven National Laboratory	51,826	35,985
Fermi National Accelerator Laboratory	19,238	16,818
Lawrence Berkeley National Laboratory	31,351	31,538
Lawrence Livermore National Laboratory	2,984	2,102
Los Alamos National Laboratory	635	641
Notre Dame Radiation Laboratory	175	160
Oak Ridge Institute for Science and Education	490	664
Oak Ridge National Laboratory and Y-12	79,500	85,469
Oak Ridge Office	6,324	3,899
Office of Scientific and Technical Information	412	346
Pacific Northwest National Laboratory	8,137	5,329
Princeton Plasma Physics Laboratory	8,200	4,834
Sandia National Laboratories	3,058	3,088
SLAC National Accelerator Laboratory	15,713	15,648
Thomas Jefferson National Accelerator Facility	6,625	8,389
Total, Maintenance and Repair	**297,068**	**271,192**

Science
Excess Facilities

Excess Facilities are facilities no longer required to support the Department's needs, present or future missions or functions, or the discharge of its responsibilities. The table below reports the funding to deactivate and dispose of excess infrastructure, including stabilization and risk reduction activities at high-risk excess facilities. These activities result in surveillance and maintenance cost avoidance and reduced risk to workers, the public, the environment, and programs. This includes reductions in costs related to maintenance of excess facilities (including high-risk excess facilities) necessary to minimize the risk posed by those facilities prior to disposition. Science has no reported direct funded excess facilities costs.

Costs for Indirect-Funded Excess Facilities

	(dollars in thousands)			
	FY 2018 Planned Cost	**FY 2018 Actual Cost**	**FY 2019 Planned Cost**	**FY 2020 Planned Cost**
Argonne National Laboratory	6,700	58	6,750	92
Brookhaven National Laboratory	40	1,161	893	875
Fermi National Accelerator Laboratory	150	207	243	150
Lawrence Berkeley National Laboratory	—	25	66	48
Oak Ridge National Laboratory	1,000	2,289	1,000	1,000
SLAC National Accelerator Laboratory	—	—	50	—
Total, Indirect-Funded Excess Facilities	**7,890**	**3,740**	**9,002**	**2,165**

Science
Research and Development

(dollars in thousands)

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Basic	4,842,854	4,978,915	4,471,870	-507,045
Applied	—	—	—	—
Subtotal, R&D	4,842,854	4,978,915	4,471,870	-507,045
Equipment	197,355	277,069	182,408	-94,661
Construction	1,160,494	1,261,065	821,194	-439,871
Total, R&D	**6,200,703**	**6,517,049**	**5,475,472**	**-1,041,577**

Science
Small Business Innovative Research/Small Business Technology Transfer (SBIR/STTR)

(dollars in thousands)

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Office of Science				
Advanced Scientific Computing Research				
SBIR	19,040	22,329	23,269	+940
STTR	2,678	3,140	3,272	+132
Basic Energy Sciences				
SBIR	53,652	52,617	51,393	-1,224
STTR	7,545	7,400	7,227	-173
Biological and Environmental Research				
SBIR	21,393	21,702	15,679	-6,023
STTR	3,007	3,052	2,204	-848
Fusion Energy Sciences				
SBIR	11,598	12,992	8,899	-4,093
STTR	1,631	1,827	1,252	-575
High Energy Physics				
SBIR	21,377	21,124	17,171	-3,953
STTR	3,006	2,971	2,415	-556
Nuclear Physics				
SBIR	16,875	17,500	16,336	-1,164
STTR	2,373	2,461	2,297	-164
Total, Office of Science SBIR	**143,935**	**148,264**	**132,747**	**-15,517**
Total, Office of Science STTR	**20,240**	**20,851**	**18,667**	**-2,184**
Other DOE[a]	TBD	TBD	TBD	TBD
Total, DOE SBIR	**143,935**	**148,264**	**132,747**	**-15,517**
Total, DOE STTR	**20,240**	**20,851**	**18,667**	**-2,184**

[a] The other DOE programs SBIR/STTR funding amounts are listed in the other DOE budget volumes.

Science
Safeguards and Security Crosscut

(dollars in thousands)

	FY 2018 Enacted	FY 2019 Enacted	FY 2020 Request	FY 2020 Request vs FY 2019 Enacted
Protective Forces	43,545	43,545	43,545	—
Security Systems	10,097	10,370	14,883	+4,513
Information Security	4,356	4,356	4,356	—
Cyber Security	30,619	33,346	33,346	—
Personnel Security	5,334	5,444	5,444	—
Material Control and Accountability	2,431	2,431	2,431	—
Program Management	6,618	6,618	6,618	—
Total, Safeguards and Security	**103,000**	**106,110**	**110,623**	**+4,513**

Department of Energy

FY 2020 Congressional Budget

Funding by Appropriation by Site

($K)

Science	FY 2018 Total Enacted	FY 2019 Enacted	FY 2020 Request
Ames Laboratory			
Basic Energy Sciences			
Basic Energy Sciences	15,790	17,620	17,581
Biological and Environmental Research			
Biological and Environmental Research	1,000	1,250	0
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	556	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	3,492	0	1,000
Safeguards and Security			
Safeguards and Security	1,229	1,231	1,231
Total, Ames Laboratory	**22,067**	**20,101**	**19,812**
Ames Site Office			
Program Direction			
Program Direction	645	658	676
Total, Ames Site Office	**645**	**658**	**676**
Argonne National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	122,782	153,798	159,318
Basic Energy Sciences			
Basic Energy Sciences	295,783	360,799	371,817
Biological and Environmental Research			
Biological and Environmental Research	32,349	31,442	19,445
High Energy Physics			
High Energy Physics	14,979	15,695	10,157
Nuclear Physics			
Nuclear Physics	32,818	33,384	29,293
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	1,328	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	54,105	53,393	44,850
Safeguards and Security			
Safeguards and Security	9,166	9,996	10,019
Total, Argonne National Laboratory	**563,310**	**658,507**	**644,899**
Argonne Site Office			
Program Direction			
Program Direction	4,327	4,415	4,270
Total, Argonne Site Office	**4,327**	**4,415**	**4,270**

Department of Energy

FY 2020 Congressional Budget

Funding by Appropriation by Site

($K)

Science	FY 2018 Total Enacted	FY 2019 Enacted	FY 2020 Request
Berkeley Site Office			
Program Direction			
Program Direction	3,561	3,588	3,727
Total, Berkeley Site Office	**3,561**	**3,588**	**3,727**
Brookhaven National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	1,116	1,590	728
Basic Energy Sciences			
Basic Energy Sciences	170,216	169,571	162,261
Biological and Environmental Research			
Biological and Environmental Research	14,842	12,107	9,001
High Energy Physics			
High Energy Physics	64,652	82,255	77,542
Nuclear Physics			
Nuclear Physics	206,394	209,914	201,989
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	2,266	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	43,500	49,200	18,400
Safeguards and Security			
Safeguards and Security	12,413	13,933	14,013
Total, Brookhaven National Laboratory	**515,399**	**538,570**	**483,934**
Brookhaven Site Office			
Program Direction			
Program Direction	4,837	4,905	4,589
Total, Brookhaven Site Office	**4,837**	**4,905**	**4,589**

Department of Energy

FY 2020 Congressional Budget

Funding by Appropriation by Site

($K)

Science	FY 2018 Total Enacted	FY 2019 Enacted	FY 2020 Request
Chicago Operations Office			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	20,550	16,885	30,533
Basic Energy Sciences			
Basic Energy Sciences	260,829	339,965	285,591
Biological and Environmental Research			
Biological and Environmental Research	165,637	123,181	93,051
Fusion Energy Sciences			
Fusion Energy Sciences	177,355	140,519	85,446
High Energy Physics			
High Energy Physics	116,220	110,234	67,793
Nuclear Physics			
Nuclear Physics	186,037	153,940	119,753
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	1,713	1,713	1,550
Safeguards and Security			
Safeguards and Security	50	50	50
Program Direction			
Program Direction	24,445	24,546	23,614
Total, Chicago Operations Office	**952,836**	**911,033**	**707,381**
Fermi National Accelerator Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	341	174	174
Basic Energy Sciences			
Basic Energy Sciences	354	135	135
High Energy Physics			
High Energy Physics	456,274	519,303	407,903
Nuclear Physics			
Nuclear Physics	210	0	0
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	250	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	20,000	20,000	10,000
Safeguards and Security			
Safeguards and Security	5,341	7,037	7,877
Total, Fermi National Accelerator Laboratory	**482,770**	**546,649**	**426,089**
Fermi Site Office			
Program Direction			
Program Direction	2,497	2,581	2,490
Total, Fermi Site Office	**2,497**	**2,581**	**2,490**

Department of Energy

FY 2020 Congressional Budget

Funding by Appropriation by Site

($K)

Science	FY 2018 Total Enacted	FY 2019 Enacted	FY 2020 Request
Idaho National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	70	70	70
Basic Energy Sciences			
Basic Energy Sciences	900	4,592	4,103
Fusion Energy Sciences			
Fusion Energy Sciences	2,700	5,510	2,500
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	406	0	0
Total, Idaho National Laboratory	**4,076**	**10,172**	**6,673**
Lawrence Berkeley National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	190,635	213,107	179,276
Basic Energy Sciences			
Basic Energy Sciences	174,716	225,806	174,244
Biological and Environmental Research			
Biological and Environmental Research	154,819	148,595	121,568
Fusion Energy Sciences			
Fusion Energy Sciences	0	895	1,115
High Energy Physics			
High Energy Physics	78,190	82,427	53,678
Nuclear Physics			
Nuclear Physics	27,821	26,121	19,759
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	1,111	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	54,850	5,000	11,000
Safeguards and Security			
Safeguards and Security	7,240	7,155	7,175
Total, Lawrence Berkeley National Laboratory	**689,382**	**709,106**	**567,815**

Department of Energy

FY 2020 Congressional Budget

Funding by Appropriation by Site

($K)

Science	**FY 2018 Total Enacted**	**FY 2019 Enacted**	**FY 2020 Request**
Lawrence Livermore National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	6,675	5,531	2,097
Basic Energy Sciences			
Basic Energy Sciences	926	1,804	1,772
Biological and Environmental Research			
Biological and Environmental Research	28,821	21,928	20,633
Fusion Energy Sciences			
Fusion Energy Sciences	9,218	8,819	6,786
High Energy Physics			
High Energy Physics	3,940	2,315	1,000
Nuclear Physics			
Nuclear Physics	893	1,728	1,650
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	482	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	50	0	0
Total, Lawrence Livermore National Laboratory	**51,005**	**42,125**	**33,938**
Los Alamos National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	3,003	3,626	2,135
Basic Energy Sciences			
Basic Energy Sciences	18,121	23,337	22,358
Biological and Environmental Research			
Biological and Environmental Research	30,098	25,424	17,525
Fusion Energy Sciences			
Fusion Energy Sciences	3,607	3,087	3,610
High Energy Physics			
High Energy Physics	1,930	2,640	1,260
Nuclear Physics			
Nuclear Physics	9,111	9,360	8,791
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	520	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	350	0	0
Total, Los Alamos National Laboratory	**66,740**	**67,474**	**55,679**

Department of Energy
FY 2020 Congressional Budget
Funding by Appropriation by Site
($K)

Science	FY 2018 Total Enacted	FY 2019 Enacted	FY 2020 Request
National Renewable Energy Laboratory			
Basic Energy Sciences			
Basic Energy Sciences	7,741	12,600	12,620
Biological and Environmental Research			
Biological and Environmental Research	924	108	80
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	1,156	0	0
Total, National Renewable Energy Laboratory	**9,821**	**12,708**	**12,700**
Nevada Operations Office			
Basic Energy Sciences			
Basic Energy Sciences	482	0	0
Total, Nevada Operations Office	**482**	**0**	**0**
Oak Ridge Institute for Science & Education			
Basic Energy Sciences			
Basic Energy Sciences	600	0	0
Biological and Environmental Research			
Biological and Environmental Research	3,874	1,478	1,023
Fusion Energy Sciences			
Fusion Energy Sciences	300	750	1,000
High Energy Physics			
High Energy Physics	1,523	0	0
Nuclear Physics			
Nuclear Physics	697	697	636
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	9,322	0	0
Safeguards and Security			
Safeguards and Security	1,929	1,892	1,894
Total, Oak Ridge Institute for Science & Education	**18,245**	**4,817**	**4,553**

Department of Energy

FY 2020 Congressional Budget

Funding by Appropriation by Site

($K)

Science	FY 2018 Total Enacted	FY 2019 Enacted	FY 2020 Request
Oak Ridge National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	378,431	446,543	405,466
Basic Energy Sciences			
Basic Energy Sciences	370,246	410,799	322,274
Biological and Environmental Research			
Biological and Environmental Research	81,772	84,620	57,312
Fusion Energy Sciences			
Fusion Energy Sciences	146,127	162,283	134,658
High Energy Physics			
High Energy Physics	500	920	370
Nuclear Physics			
Nuclear Physics	10,421	18,206	23,476
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	30,800	51,000	45,000
Safeguards and Security			
Safeguards and Security	12,215	12,864	29,973
Total, Oak Ridge National Laboratory	**1,030,512**	**1,187,235**	**1,018,529**
Oak Ridge National Laboratory Site Office			
Program Direction			
Program Direction	5,465	5,551	5,247
Total, Oak Ridge National Laboratory Site Office	**5,465**	**5,551**	**5,247**
Oak Ridge Office			
Basic Energy Sciences			
Basic Energy Sciences	995	0	0
Biological and Environmental Research			
Biological and Environmental Research	995	0	0
Nuclear Physics			
Nuclear Physics	24	50	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	9,182	6,434	8,800
Safeguards and Security			
Safeguards and Security	22,074	23,472	4,558
Program Direction			
Program Direction	25,082	24,177	23,344
Total, Oak Ridge Office	**58,352**	**54,133**	**36,702**

Department of Energy
FY 2020 Congressional Budget
Funding by Appropriation by Site
($K)

Science	**FY 2018 Total Enacted**	**FY 2019 Enacted**	**FY 2020 Request**
Office of Scientific & Technical Information			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	148	155	155
Basic Energy Sciences			
Basic Energy Sciences	221	0	0
Biological and Environmental Research			
Biological and Environmental Research	188	154	148
Fusion Energy Sciences			
Fusion Energy Sciences	148	0	0
High Energy Physics			
High Energy Physics	32	0	0
Nuclear Physics			
Nuclear Physics	171	285	129
Safeguards and Security			
Safeguards and Security	783	759	759
Program Direction			
Program Direction	9,222	9,120	8,934
Total, Office of Scientific & Technical Information	**10,913**	**10,473**	**10,125**
Pacific Northwest National Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	2,881	5,597	2,460
Basic Energy Sciences			
Basic Energy Sciences	21,069	33,216	33,205
Biological and Environmental Research			
Biological and Environmental Research	113,735	117,434	75,930
Fusion Energy Sciences			
Fusion Energy Sciences	1,413	250	1,413
High Energy Physics			
High Energy Physics	2,725	1,460	775
Nuclear Physics			
Nuclear Physics	500	500	0
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	1,020	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	20,000	24,000	9,000
Safeguards and Security			
Safeguards and Security	12,654	12,459	12,759
Total, Pacific Northwest National Laboratory	**175,997**	**194,916**	**135,542**

Department of Energy

FY 2020 Congressional Budget

Funding by Appropriation by Site

($K)

Science	FY 2018 Total Enacted	FY 2019 Enacted	FY 2020 Request
Pacific Northwest Site Office			
Program Direction			
Program Direction	4,942	5,084	4,987
Total, Pacific Northwest Site Office	**4,942**	**5,084**	**4,987**
Princeton Plasma Physics Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	385	385	335
Fusion Energy Sciences			
Fusion Energy Sciences	104,483	107,770	67,207
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	398	0	0
Safeguards and Security			
Safeguards and Security	2,684	3,354	3,358
Total, Princeton Plasma Physics Laboratory	**107,950**	**111,509**	**70,900**
Princeton Site Office			
Program Direction			
Program Direction	1,799	1,862	1,895
Total, Princeton Site Office	**1,799**	**1,862**	**1,895**
Sandia National Laboratories			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	9,579	17,331	11,786
Basic Energy Sciences			
Basic Energy Sciences	24,903	28,219	27,743
Biological and Environmental Research			
Biological and Environmental Research	10,407	10,002	9,200
Fusion Energy Sciences			
Fusion Energy Sciences	3,139	1,265	1,419
High Energy Physics			
High Energy Physics	0	100	0
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	120	0	0
Total, Sandia National Laboratories	**48,148**	**56,917**	**50,148**

Department of Energy

FY 2020 Congressional Budget

Funding by Appropriation by Site

($K)

Science	**FY 2018 Total Enacted**	**FY 2019 Enacted**	**FY 2020 Request**
Savannah River National Laboratory			
Basic Energy Sciences			
Basic Energy Sciences	0	420	410
Biological and Environmental Research			
Biological and Environmental Research	50	0	0
Fusion Energy Sciences			
Fusion Energy Sciences	50	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	50	0	0
Total, Savannah River National Laboratory	**150**	**420**	**410**
SLAC National Accelerator Laboratory			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	528	1,366	720
Basic Energy Sciences			
Basic Energy Sciences	415,038	389,853	235,574
Biological and Environmental Research			
Biological and Environmental Research	5,949	4,463	3,300
Fusion Energy Sciences			
Fusion Energy Sciences	5,550	2,340	6,200
High Energy Physics			
High Energy Physics	68,126	64,007	48,692
Nuclear Physics			
Nuclear Physics	1,047	1,015	774
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	415	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	8,800	9,400	3,000
Safeguards and Security			
Safeguards and Security	4,251	4,304	4,328
Total, SLAC National Accelerator Laboratory	**509,704**	**476,748**	**302,588**
Stanford Site Office			
Program Direction			
Program Direction	2,456	2,476	2,514
Total, Stanford Site Office	**2,456**	**2,476**	**2,514**

Department of Energy

FY 2020 Congressional Budget

Funding by Appropriation by Site

($K)

Science	**FY 2018 Total Enacted**	**FY 2019 Enacted**	**FY 2020 Request**
Thomas Jefferson National Accelerator Facility			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	273	387	382
High Energy Physics			
High Energy Physics	25	350	1,227
Nuclear Physics			
Nuclear Physics	124,332	129,017	125,964
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	150	0	0
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	9,900	0	2,000
Safeguards and Security			
Safeguards and Security	2,717	3,021	3,037
Total, Thomas Jefferson National Accelerator Facility	**137,397**	**132,775**	**132,610**
Thomas Jefferson Site Office			
Program Direction			
Program Direction	1,947	1,971	2,165
Total, Thomas Jefferson Site Office	**1,947**	**1,971**	**2,165**
Washington Headquarters			
Advanced Scientific Computing Research			
Advanced Scientific Computing Research	72,603	68,955	125,253
Basic Energy Sciences			
Basic Energy Sciences	311,070	147,264	186,597
Biological and Environmental Research			
Biological and Environmental Research	27,540	122,814	66,218
Fusion Energy Sciences			
Fusion Energy Sciences	78,021	130,512	91,396
High Energy Physics			
High Energy Physics	98,884	98,294	97,641
Nuclear Physics			
Nuclear Physics	83,524	105,783	92,640
Workforce Development for Teachers and Scientists			
Workforce Development for Teachers and Scientists	0	22,500	19,500
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	0	11,500	9,000
Safeguards and Security			
Safeguards and Security	8,254	4,583	9,592
Program Direction			
Program Direction	91,775	92,066	94,548
Total, Washington Headquarters	**771,671**	**804,271**	**792,385**

Department of Energy

FY 2020 Congressional Budget

Funding by Appropriation by Site

($K)

Science	FY 2018 Total Enacted	FY 2019 Enacted	FY 2020 Request
Y-12 National Security Complex			
Science Laboratories Infrastructure			
Science Laboratories Infrastructure	500	1,250	0
Total, Y-12 National Security Complex	**500**	**1,250**	**0**
Total, Science	**6,259,903**	**6,585,000**	**5,545,972**

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 a contract covered by the Federal Acquisition Regulation;

(C) issue a letter of intent to make an allocation, award, or Agreement in excess of the limits in subparagraph (A) or (B); or

(D) 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 "Conference" column in the "Department of Energy" table included under the heading "Title III—Department of Energy" in the joint 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, and obtain the prior approval of, 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.
(h) 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. 302. 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**]***2020* until the enactment of the Intelligence Authorization Act for fiscal year **[**2019**]***2020*.

SEC. 303. 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. 304. 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. 305. The Secretary of Energy may not transfer more than $274,833,000 from the amounts made available under this title to the working capital fund established under section 653 of the Department of Energy Organization Act (42 U.S.C. 7263): *Provided*, That the Secretary may transfer additional amounts to the working capital fund after the Secretary provides notification in advance of any such transfer to the Committees on Appropriations of both Houses of Congress: *Provided further*, That any such notification shall identify the sources of funds by program, project, or activity: *Provided further*, That the Secretary shall notify the Committees on Appropriations of both Houses of Congress before adding or removing any activities from the fund.**]**

SEC. **[**306**]***305*. (a) None of the funds made available in this or any prior Act under the heading "Defense Nuclear Nonproliferation" may be made available to enter into new contracts with, or new agreements for Federal assistance to, the Russian Federation. (b) The Secretary of Energy may waive the prohibition in subsection (a) if the Secretary determines that such activity is in the national security interests of the United States. This waiver authority may not be delegated. (c) A waiver under subsection (b) shall not be effective until 15 days after the date on which the Secretary submits to the Committees on Appropriations of both Houses of Congress, in classified form if necessary, a report on the justification for the waiver.

[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**]***306*. Notwithstanding section 161 of the Energy Policy and Conservation Act (42 U.S.C. 6241), upon a determination by the President in this fiscal year that a regional supply shortage of refined petroleum product of significant scope and duration exists, that a severe increase in the price of refined petroleum product will likely result from such shortage, and that a draw down and sale of refined petroleum product would assist directly and significantly in reducing the adverse impact of such shortage, the Secretary of Energy may draw down and sell refined petroleum product from the Strategic Petroleum Reserve. Proceeds from a sale under this section shall be deposited into the SPR Petroleum Account established in section 167 of the Energy Policy and Conservation Act (42 U.S.C. 6247), and such amounts shall be available for obligation, without fiscal year limitation, consistent with that section.

SEC. 307. Section 310 of the Omnibus Appropriations Act, 2009 (Public Law 111–8; 50 U.S.C. 2743a note) and section 306 of the Consolidated Appropriations Act, 2012 (Public Law 112–74; 50 U.S.C. 2743a) are repealed.

SEC. 308. 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. 309. (*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. 310. Notwithstanding provisions of title 5, United States Code, the Southeastern Power Administration shall pay power system dispatchers at basic pay and premium pay rates that are based on those prevailing for similar occupations in the electric power industry. Pay may not be paid, by reason of this section, at a rate in excess of the rate of basic pay for level V of the Executive Schedule.

SEC. 311. Section 3131 of the National Defense Authorization Act for Fiscal Year 2000 (Public Law 106–65; 10 U.S.C. 2701 note) is amended by striking "or the defense activities of the Department of Energy".

(Energy and Water Development and Related Agencies Appropriations Act, 2019.)

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. (a) None of the funds made available in title III of this Act may be transferred to any department, agency, or instrumentality of the United States Government, except pursuant to a transfer made by or transfer authority provided in this Act or any other appropriations Act for any fiscal year, transfer authority referenced in the joint explanatory statement accompanying this Act, or any authority whereby a department, agency, or instrumentality of the United States Government may provide goods or services to another department, agency, or instrumentality. (b) None of the funds made available for any department, agency, or instrumentality of the United States Government may be transferred to accounts funded in title III of this Act, except pursuant to a transfer made by or transfer authority provided in this Act or any other appropriations Act for any fiscal year, transfer authority referenced in the joint explanatory statement accompanying this Act, or any authority whereby a department, agency, or instrumentality of the United States Government may provide goods or services to another department, agency, or instrumentality. (c) The head of any relevant department or agency funded in this Act utilizing any transfer authority shall submit to the Committees on Appropriations of both Houses of Congress a semiannual report detailing the transfer authorities, except for any authority whereby a department, agency, or instrumentality of the United States Government may provide goods or services to another department, agency, or instrumentality, used in the previous 6 months and in the year-to-date. This report shall include the amounts transferred and the purposes for which they were transferred, and shall not replace or modify existing notification requirements for each authority.

SEC. 503. 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).

SEC. 504. (a) None of the funds made available in this Act may be used to maintain or establish a computer network unless such network blocks the viewing, downloading, and exchanging of pornography. (b) Nothing in subsection (a) shall limit the use of funds necessary for any Federal, State, tribal, or local law enforcement agency or any other entity carrying out criminal investigations, prosecution, or adjudication activities.

SEC. 505. Section 611 of the Energy and Water Development Appropriations Act, 2000 (P.L. 106–60; 10 U.S.C. 2701 note) is amended as follows: (*a*) *In subsection (a), by striking "the Army, acting through the Chief of Engineers" and inserting "Energy".* (*b*) *In subsection (a)(6), by striking "by the Secretary of the Army, acting through the Chief of Engineers" and striking ", which may be transferred upon completion of remediation to the administrative jurisdiction of the Secretary of Energy".* (*c*) *In subsection (a), by adding after paragraph (6) the following undesignated matter: "Upon completion of remediation of a site acquired by the Secretary of the Army prior to fiscal year 2020, the Secretary of the Army may transfer administrative jurisdiction of such site to the Secretary of Energy.".* (*d*) *In subsection (b), by striking "the Army, acting through the Chief of Engineers," and inserting "Energy".* (*e*) *In subsection (c), by striking "amounts made available to carry out that program and shall be available until expended for costs of response actions for any eligible site" and inserting "'Other Defense Activities' appropriation account or successor appropriation account and shall be available until expended for costs of response actions for any eligible Formerly Utilized Sites Remedial Action Program Site".* (*f*) *By redesignating subsection (f) as subsection (g).* (*g*) *By inserting after subsection (e) the following new subsection: "(f) The Secretary of Energy, in carrying out subsection (a), shall enter into an agreement with the Secretary of the Army to carry out the functions and activities described in subsections (a)(1) through (a)(6).".*

[SEC. 505. For an additional amount for "Department of the Interior—Bureau of Reclamation—Water and Related Resources", $21,400,000, to remain available until expended, for transfer to Reclamation's Upper Colorado River Basin Fund to carry out environmental stewardship and endangered species recovery efforts pursuant to the Grand

Canyon Protection Act of 1992 (Public Law 102–575), Public Law 106–392, the Colorado River Basin Project Act (43 U.S.C. 1551(b)), and the Act of April 11, 1956 (commonly known as the "Colorado River Storage Project Act") (43 U.S.C. 620n). This division may be cited as the "Energy and Water Development and Related Agencies Appropriations Act, 2019".**]**
(Energy and Water Development and Related Agencies Appropriations Act, 2019.)